Original articles

Characterization of tongue strength via objective measures

Caracterização da força da língua por meio de medidas objetivas

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Conflict of interest: non-existent

ABSTRACT

Purpose: to analyze axial tongue strength and related parameters by using the Forling.

Methods: data regarding 92 participants, including men and women with a mean age of 23.3 ± 7.7 years, were analyzed.

Results: the mean value of the mean tongue strength was 13.0 N, and the maximum strength value was 18.3 N. The mean and maximum tongue strengths showed positive correlation and highly significant association (p < 0.001). The energy accumulated by the tongue was 131.1 N/s. The mean time required for the maximum tongue strength to be reached was 3.8 s, and the decrease in time (p < 0.001) from the first to the third measurements indicates an effect of training.

Conclusion: the instrument proved to be capable of measuring parameters that are important to the speech-language pathologist, indicating that it can be a promising complementary tool for clinical evaluation.

Keywords: Tongue; Muscle Strength; Speech, Language and Hearing Sciences

RESUMO

Objetivo: analisar a força axial da língua e parâmetros relacionados por meio do FORLING.

Método: foram analisados os dados de 92 participantes, entre homens e mulheres, com média de 23,3±7,7 anos.

Resultados: no parâmetro força média da língua, identificaram-se valores médios de 13,0 N, já para a força máxima observou-se valor médio de 18,3 N. A força média e a máxima da língua apresentaram correlação positiva e associação altamente significante (p<0,001). A energia acumulada pela língua indicou valores de 131,1 N/s. O tempo médio gasto para que se alcance a força máxima da língua foi de 3,8 segundos, indicando um efeito do treinamento ao se comparar a 1ª à 3ª medida, com redução dos valores (p<0,001).

Conclusão: o instrumento demonstrou ser capaz de mensurar parâmetros importantes para o fonoaudiólogo, indicando ser uma promissora ferramenta complementar à avaliação clínica fonoaudiológica.

Descritores: Língua; Força Muscular; Fonoaudiologia

INTRODUCTION

In view of the various human physical and muscular characteristics, particularly in Brazil due to an admixture of races, the forces exerted by distinct muscle groups need to be better understood. Among these muscles, the tongue is considered a primary muscle because it is fundamental in the processes of nutrition and human communication [1], as well as in the stability of occlusion [2].

Various instruments have been developed to determine tongue strength, either axial, cranial, or lateral, with the aim of obtaining objective measurements. The Iowa Oral Performance Instrument (IOPI) has been, without doubt, one of the most used methods in research on lingual pressure/strength [3]. Although it has a straight forward handling and excellent portability, the use of the IOPI presents limitations in Brazil because it has not been certified by the National Agency for Sanitary Surveillance and is thus difficult to import.

Faced with these issues, the Biomechanical Engineering Group of the Federal University of Minas Gerais developed the Forling, a low-cost evaluation device that determines the axial strength of the tongue, that is, the protrusion strength [4-8].

The protrusion of the tongue against resistance involves the action of the intrinsic lingual muscles, in addition to the genioglossus muscle [9], which are often altered in patients with myofunctional orofacial and cervical impairments. Therefore, this is a topic of interest for the field of Speech-Language Pathology. Lingual protrusion force has also been shown to be predictive of airway patency during sleep in patients with obstructive sleep apnea [10].

Until the present date, studies conducted by using the Forling have basically considered as parameters maximum and mean strengths because these are the most described in the literature. However, because the equipment permits other analyses, it is important to explore these other applications by using a larger sample and to investigate the variability of all possible parameters.

Thus, the aim of this study was to analyze axial tongue strength and related parameters by using the Forling.

METHODS

This cross-sectional descriptive study was conducted at the Faculty of Medicine of the Federal University of Minas Gerais, using data from medical records. All participants assigned the informed consent.

The study was approved by the Research Ethics Committee of the Federal University of Minas Gerais, under protocol no. 496/09, and by the Federal University of São Paulo, under protocol no. 1981/09.

We selected the medical records of individuals aged between 14 and 60 years from the database of the Biomechanical Engineering Group because maximum lingual strength does not vary significantly within this age group [11-13]. Thus, we analyzed the data from the medical records of 92 individuals, of whom 29 (32.6%) were men and 63 (67.4%) were women, with ages between 14 and 53 years (mean±SD, 23.3±7.7 years).

Assessments were performed by using the Forling [4-8]. The device is composed of a piston-cylinder assembly (covered externally by a Teflon structure) coupled to a rod that triggers the system and a silicone double oral protector, similar to that used by boxers, to accommodate the dental arches. The use of this arch fixation device permits greater stability during the assessment and prevents the creation of parasite forces in the measuring system.

The triggering rod, which is characterized as the element of transduction of the force of the tongue to the piston-cylinder assembly, has an anatomical shape with a concave surface for accommodating the tongue and to prevent the creation of negative pressures, that is, non-axial forces.

The piston-cylinder assembly comprises a glass hypodermic syringe (BD Yale ™, New Jersey) with a nominal capacity of 5 mL, filled with water up to a volume of 1 mL; and the cross-sectional area of the piston is 1.15×10^{-4} m². The fact that water is incompressible permits the length of the ejected part of the piston to be practically constant, which minimizes the effect of the tongue distension level on the generated force.

With the aid of a flexible tube filled with water, the piston-cylinder assembly is coupled to the pressure transducer (Warme, model WTP-4010, series 670/06) with a nominal range of 700 kPa. The transducer is the sensor element responsible for the transformation of the pressure exerted by the tongue on the assembly into electric tension.

The instrument fixation system, which is made of steel, was developed to facilitate the handling of the equipment during the assessments, such as height adjustment for each participant, and to minimize the

oscillations resulting from using the instrument in positions other than the horizontal position.

Data are then sent to a data acquisition board (Ontrak, model ADU100) with tension and power adjusted to 10 V. The function of the board is to scan data that are sent analogically by the pressure transducer. Subsequently, data are sent to a computer via a USB port.

In the computer, a software developed in the MATLAB platform, converts electric tension data (millivolts) regarding pressure into force (Newtons), generates the curves (by recording the force x time pairs), and stores the generated data. The measured pressure is converted into force by using the equation $F = P \times S$, where F is the force measured in newtons, P is the pressure measured in pascal, and S is the cross-sectional area of the piston-cylinder assembly expressed in meter squared.

The strength values were recorded at a rate of 10 samples per second. The uncertainty associated with the system was previously calculated, and a value of approximately 0.18% of the value of the generated force was obtained [5].

Before the subjects were assessed, the nozzle was completely covered with a nontoxic transparent PVC film (Doctor Film), for a simple and quick sanitization with 70% alcohol.

The subjects were seated, with their backs well supported, their feet flat on the ground, and their hands resting on the base of the equipment. After the correct fitting of the oral protector in the dental arches, the subjects waited for approximately 20 s (accommodation period). After this time, the subjects were asked to push the triggering rod of the plunger with the tongue after hearing the acoustic signal (a signal generated automatically by the system) as strongly as they could and to keep pushing until they heard the second acoustic signal, which was programed to be triggered 10 s later. Only in this training situation were the subjects allowed to see the graph generated in real time. This procedure was performed three more times, at 1 min intervals between measurements and with verbal positive reinforcement in each measurement. The first measurement (training) was disregarded.

The following parameters were investigated in the medical records: the 3 measures of mean axial strength, which is equivalent to the mean of the strengths that the subject applied in each test; the 3 measures of maximum axial strength, which correspond to the highest value of force applied at any point of the 3 measurements; and the time required for the subject to reach the maximum strength in each of the 3 assessments. The energy accumulated by the tongue (force x time) was calculated based on these data and represents the area under the curve of the graph of each measurement.

The database was created based on R statistical program routines. The descriptive results were presented in measures of central and dispersion tendency.

The Wilcoxon test was used to compare between the mean and maximum axial tongue strength values. The Spearman coefficient was used to analyze the correlation between these strengths because the data did not show normal distribution. In both cases, the level of significance was set at 5%.

The Friedman test was used to compare the time required to reach the maximum tongue strength between the 3 measurements because the data did not show normal distribution; the results were considered significant at $p \leq 0.05$. To identify the difference between each measurement, multiple comparisons were performed by using the Bonferroni method. This method, that is, a correction of the level of significance, consists in comparing all pairs of means by using individual tests (in this case the Wilcoxon test) and considering a level of significance lower than the overall level of significance. An overall level of significance (α) is fixed, and for each comparison, a level of significance (α^*) is used ($\alpha^* = \alpha/k$, where k is the number of comparisons). Because each comparison includes 3 measurements, the results were considered significant at $p = 0.017$, that is, 0.05/3.

The energy accumulated by the tongue was defined as the area under the curve of the graph time (seconds) versus tongue strength (Newtons) for every assessed moment. To calculate this area, the trapeze rule was used. In the case of this function, the number of subintervals was the same as the number of observations for each subject.

RESULTS

The analysis of the mean and maximum axial tongue strengths (Table 1) showed that the latter was higher than the former for all the measurements and for the overall mean, as expected. According to the coefficients of variation, the maximum strength values tended to be slightly more homogeneous in each of the three measurements and in the overall mean. In addition, we observed (Figure 1) that the mean and maximum

tongue strengths showed a highly positive correlation in all the assessments, as well as a significant difference.

Moreover, the energy accumulated by the tongue (Table 2) did not vary between the three assessments.

However, the time required to reach the maximum tongue strength varied between the three measurements (Table 3), with the value for the first being higher than that for the third.

Table 1. Mean and maximum axial tongue strengths in newtons

Measurement/ tongue strength	Mean	Standart deviation	Minimum	Maximum	Q1	Median	Q3	CV	p Value[1]
First									
mean	12.7	4.6	4.4	29.1	9.3	11.9	14.9	36.6	<0.001
Maximum	18.0	5.6	6.3	32.4	13.6	17.4	21.1	31.3	
Second									
mean	13.2	4.5	4.3	33.8	10.2	12.4	15.7	34.2	<0.001
Maximum	18.4	5.9	6.6	39.7	14.4	17.0	21.0	32.2	
Third									
mean	13.3	4.6	5.3	31.2	10.1	12.8	15.7	34.3	<0.001
Maximum	18.6	5.9	7.1	34.6	14.7	18.2	21.4	31.8	
Mean									
Mean	13.0	4.3	4.6	31.4	10.2	12.4	14.9	32.9	<0.001
Maximum	18.3	5.4	6.9	35.6	14.6	17.9	21.3	29.7	

Q1, first quartile; Q3, third quartile; CV, coefficient of variation.
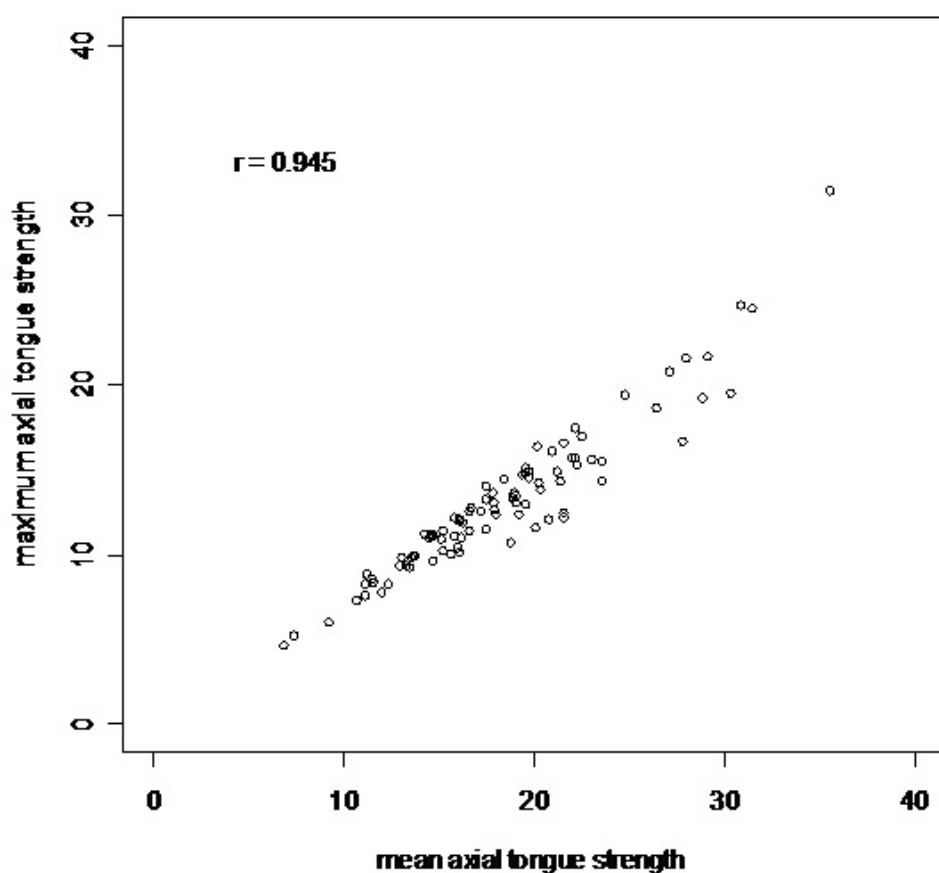[1]Wilcoxon test.

Figure 1. Correlation between the mean and maximum axial tongue strengths

Table 2. Energy accumulated by the tongue and time required to reach the maximum tongue strength

Measurement	Mean	Standart deviation	Minimum	Maximum	Q1	Median	Q3	CV
Accumulated energy								
First	127.2	46.7	43.9	291.9	93.3	118.9	150.1	36.7
Second	132.4	452	42.9	338.3	102.7	123.6	156.6	34.1
Third	133.7	46.2	53.2	312.4	102.1	128.9	157.6	34.6
Mean	1311	43.3	46.7	314.2	102.9	124.9	149.6	33.0
Time to reach the maximum strength								
First	4.5	2.9	0.5	9.9	1.8	4.0	7.1	64.4
Second	3.7	2.6	0.3	10.1	1.3	3.1	5.4	70.3
Third	3.1	2.3	0.4	10.0	1.2	2.3	5.1	74.2
Mean	3.8	2.0	0.6	8.4	2.1	3.7	5.2	52.6

Q1, first quartile; Q3, third quartile; CV, coefficient of variation.

Table 3. Comparison of the time required to reach the maximum tongue strength (in seconds) between the first, second, and third measurements

Time/mean	Median	Interquartile distance	p Value[1]	Comparison of measurements	p Value[2]
First	4.0	5.3		First x second	0.018
Second	3.1	4.1	<0.001	First x third	<0.001
Third	2.3	3.9		Second x third	0.025

[1]Friedman test. [2]Wilcoxon test.

DISCUSSION

The assessment of tongue strength depends on the degree of protrusion [14,15], on the distance between the mandible and the maxilla, and on the size of the area of the tongue that is in contact with the sensor. Failure to reproduce these parameters causes a significant variation in the results [14]. The device used in the present study was carefully built to eliminate these biases.

Moreover, other factors can affect the assessment of lingual strength, thus possibly invalidating the results, such as the instructions given to the patient, external motivation, number of tests, feedback, or positive reinforcement and the relationship between the position of the tongue and that of the mandible [16,17]. In the present study, the instructions for performing the assessments were accompanied by a demonstration of how to operate the equipment and by a visual feedback of the test, in a situation called training. In addition, throughout the procedure, the subjects received positive feedback during the execution of the task [11,17]. Previous studies also provided an acoustic signal [14,18]. Regarding the effect of the mandibular position, Solomon and Munson [16] observed in their study that tongue strength decreased as a result of an increase

in the height of the oral protectors. Therefore, we believe that an instrument designed to provide reliable data must be capable of controlling the degree of mouth opening and, most of all, of reproducing it. Our instrument was able to do just this in the present study because a double oral protector (teether) was used.

Although mean strength values are not described in the literature, to our knowledge, the only study that used this parameter and conducted by researchers other than the Group of Biomechanical Engineering of the UFMG [14] reported a value of 13.0 N, which is in line with our findings even if the methods used were different. In recently published studies by using the Forling, we found a mean force value of 8.0 N in a study with elderly subjects (n = 10) [5]; 16.0 N in a study with adults [6], which is close to that obtained in the present study, although the sample in that study was formed by only 5 participants; and 13.3 N [7], which is very close to our result but was obtained in a sample of elderly subjects (n = 11).

The results of studies that have assessed maximum axial tongue strength in newtons were distinct from those described in the present study (18.3 N). Some were higher than ours, for example, 32 N [19], 26±8 N for

men and 20±7 N for women [20], 30±6 N [21], 28±2 N [15], and some were lower, for example, 14.1 N [14], 16±8 N for men and 11±4 N for women [22]. However, it should be noted that although the same unit of measurement was used, the use of different samples and assessment methods tends to produce divergent results, hence the variability of results between the studies. It is ideal to use the same instrument when comparing results; otherwise, several other factors need to be taken into consideration. The maximum strength values obtained in more recent studies using the Forling were the following: 11.2 N [5], 22.8 N [6], and 18.9 (sample of elderly) [7]. The differences in subject age and the small size of the samples used in the above-mentioned research studies may explain the observed disparities. The study that used FORLING with 105 young adults found the value of 18±8 N [8].

The matrix of correlation between the mean and maximum axial tongue strengths showed a highly positive association with a high statistical significance. Therefore, we were able to observe that a single parameter was sufficient to assess the axial force by using the Forling. For clinical practice, mean strength seems to be the most important parameter because it translates the ability of the musculature to sustain contractions and can be an evaluation tool for the speech-language pathologist. One of the strategies used in clinical practice is instructing the patient to push a wooden spatula with the tongue to assess muscle tone [23]. On the contrary, maximum isometric contraction is not required for any function of the stomatognathic system. However, considering that the strengths are correlated, it is possible to opt for the use of the maximum strength because it is the easiest to calculate and has a slightly lower coefficient of variation. The numerous studies conducted with the IOPI usually used the maximum tongue pressure as reference, including assessment of the efficacy of the therapeutic interventions [24-30].

Focusing more specifically on speech-language therapy, we can suppose that the myofunctional orofacial training of the maximum strength can increase mean tongue strength and vice versa, without the need to use various distinct exercises. Moreover, we suppose that the determination of axial tongue strength allows for making inferences regarding lingual strength in other directions. A study that investigated anterior, right lateral, and left lateral directions showed that subjects who exhibited higher values of tongue force in one direction also reached high values in all the other

directions and those who exhibited low tongue strength values in one direction also showed low values in all the directions [18]. Regarding dysphagia, strong evidence was found that endurance training improves tongue strength [31] and strength training through isometric exercises improves performance in the swallowing [32,33].

The parameter "energy accumulated by the tongue" has only been described in one compiled study [18]; in this case, it was calculated manually and the value obtained was 131.1 N/s. A manual calculation was also performed in the study with Forling [7] (108 N/s). We chose to study this parameter because although two subjects may exhibit the same mean and maximum axial tongue strength values, the areas under the curve of the graph may differ. The area under the graph, called endurance, provides more complete and accurate information about tongue strength than does the maximum strength peak because a tongue that is strong and able to sustain muscular contraction will generate a high and stable curve, whereas a tongue that is weak and has difficulties in sustaining contraction will result in a low and irregular curve [18].

Therefore, the determination of the energy required for the tongue to push the plunger is related to the subject's ability to maintain a certain level of strength over time. When we consider two individuals who attain the same value of maximum strength, the one that is able to maintain that strength (or close) will be able to transfer a higher level of energy, which is calculated as the area above the graph. A high value of maximum strength followed by a rapid decrease indicates that the peak of strength was episodic and will not contribute much to the performance of the stomatognathic system functions, which are submaximal.

This can also be assessed by comparing the mean and maximum strengths. The similarity between these values indicates that no significant decrease in strength occurred after the peak was reached. From a clinical perspective, the inability to maintain strength for a reasonable time indicates impaired lingual tone, which requires the intervention of a speech-language pathologist.

However, when we analyzed our data, we observed a behavior very similar to that of the axial tongue strength. Thus, the type of analysis for the parameter "energy accumulated by the tongue" used in the present study did not add relevant information. More studies using different analysis methods are needed to better understand this parameter.

Another parameter that is not described in the studies is the time required to reach maximum tongue strength. We opted to analyze it because it allows observing the effect of training on the tongue's muscular response. In the literature, we found only two studies that investigated this factor. Dworkin and Aronson [18] concluded that normal individuals usually exhibit a maximum peak of strength in the first second, which does not occur with dysarthric individuals. In the study by Hewitt et al. [34], the maximum time required to reach the peak was ≤1 s for most of the participants, a result that differs from our finding (3.8 s), where a longer time was needed to reach maximum force, probably because the methods used were different. The study that used the Forling and analyzed this parameter showed the same result of 3.8 s [6].

The time required to reach the maximum tongue strength decreased according to the measurements performed, with the first being higher than the third. We can thus conclude that the repetition of the task makes the musculature reach its maximum force peak quicker. Indirectly, this parameter can evaluate the speed of tongue response to task training. However, we emphasize that this parameter showed a high coefficient of variation in all measurements performed. Therefore, even if this parameter has not been described in other studies, we think it needs to be further investigated and understood.

The instrument that was used is in the process of improvement, which includes simplification of the mechanism, portability, and increase in sampling rate (higher than the current 10 Hz). According to Hewitt et al. [34], the ideal rate for the signal acquisition of the isometric lingual pressure would be 62.5 Hz, with acceptable values as low as 50 Hz. We think that given that the basic operation characteristics of the instrument are maintained, the data presented herein are applicable to the portable version of the Forling.

The results of this study showed that the Forling can be applied in the clinical practice of Speech-Language Pathology and has the potential of becoming an important research tool, particularly for the study of diagnosis efficacy and orofacial myofunctional therapy.

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