Research Article

Quantitative evaluation of tongue protrusion force

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QUANTITATIVE EVALUATION OF TONGUE PROTRUSION FORCE

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ABSTRACT

The tongue plays an important role in the functions of speech, mastication, swallowing, and breathing. The tongue helps in the maintenance of proper dental alignment and arch stability. Adequate strength is essential for the tongue to perform these tasks. Recently the Biomechanical Engineering Group from Universidade Federal de Minas Gerais, Brazil, developed a device to improve tongue strength evaluation. The purpose of this study is to describe and compare the main results obtained in tongue protrusion force measurements in different age groups using this new device. Fifteen healthy subjects were given a qualitative evaluation and determined to have normal tongue strength. They were separated by age in three groups: children, adults and elderly. They were then given a quantitative evaluation. Maximum and average forces were analyzed. The time taken to reach maximum force was also assessed. Higher values of maximum and average tongue force were obtained in the adult group, followed by the elderly group and the group of children. Older subjects had greater tongue force when compared to children. However, there were statistically significant differences in the average force and in the maximum force only between children and adults. Time taken to reach maximal isometric force was longer in the elderly group and shorter in the group of children than in the group of adults although no statistically significant difference was found between groups.

KEYWORDS: tongue, muscle strength, instrumentation

INTRODUCTION

The tongue plays an important role in the functions of speech (Dworkin, Aronson & Mulder, 1980), mastication, and in the oral and pharyngeal stages of swallowing (Stierwalt & Youmans, 2007). The tongue also aids in maintaining upper airway patency during sleep (Bu Sha, Strobel & England, 2002) helping in the maintenance of proper dental alignment and arch stability (Posen, 1972). Adequate strength is essential for the tongue to perform these tasks.

During the normal aging process, children's tongue strength increases with age, reaching its peak in late adolescence. In this late adolescence phase, tongue strength is very similar to adults (Potter, Kent & Lazarus, 2009; Potter & Short, 2009). After 60 years of age, there is a deficit in strength, and changes in skeletal muscles occur. During this period, loss of skeletal muscle mass occurs due to muscle atrophy caused by motor neuron loss (Berger & Doherty, 2010). Tongue

musculature also suffers from these age related changes (Crow & Ship, 1996).

Some studies have demonstrated a decrease in tongue strength in the elderly (Crow & Ship, 1996; Mortimore, Fiddes, Stephens & Douglas, 1999; Mortimore, Bennett & Douglas, 2000; Hayashi, Tsuga, Hosokawa, Yoshida, Sato & Akagawa, 2002). In contrast, other studies have not found differences between children and adults (Lambrechts, Baets, Fieuws & Willems, 2010), or between adults and elderly (Dworkin et al., 1980; Hartman, Dworkin & Keith, 1980; Stierwalt & Youmans, 2007). Protrusion tongue force was also measured by Mortimore et al. (1999) and Bu Sha, England, Parisi & Strobel (2000) in healthy adults. They found maximum tongue forces of 30 N and 28 N respectively. In the elderly, tongue protrusion force was measured by Dworkin et al. (1980) and Hartman et al. (1980) but the values for age groups were not presented. No study was found that measured tongue protrusion force in children.

The evaluation of tongue strength is a usual and important task in clinical Speech-Language Pathology practice. However, such assessment is usually carried out in a subjective way, and is influenced by the experience of the professional. This makes diagnosis and follow up harder to accomplish. The Biomechanical Engineering Group from Universidade Federal de Minas Gerais, Brazil, developed a measurement system to evaluate tongue protrusion force as an interdisciplinary project (Barroso, Costa, Saffar, Las Casas, Motta, Perilo, Batista & Brito, 2009). The purpose of this study is to describe and compare the main results obtained by the system in different age groups.

METHODS

Subjects

This study was conducted with the approval of the Ethics Committee of the University (authorizations 135/04 and 540/07). Fifteen healthy subjects were selected who had no speech or swallowing disorders and normal tongue strength as diagnosed by qualitative evaluation. Subjects were grouped by age in three groups: 5 children (range: 8-12 years; 4 female, 1 male), 5 adults (range: 19-53 years; 3 female, 2 male) and 5 elderly (range: 73-87 years; 1 female, 4 male).

Qualitative evaluation

Qualitative evaluation of tongue strength was obtained by having the participant press his/her tongue against a tongue blade, and against the examiner's finger for approximately 10 seconds with resistance provided by the examiner. This method was used to assess the force of both protrusion and lateralization. The examiners rated tongue strength as normal, slightly weak, moderately weak, or

severely weak (Clark, Henson, Barber, Stierwalt & Sherrill, 2003). Only those individuals who had obtained normal classification for tongue strength in the qualitative evaluation were submitted to the next stage - the quantitative evaluation.

Quantitative evaluation - equipment and procedure

The system used in this study was described by Motta, Perim, Perilo, Las Casas, Costa, Magalhães & Saffar (2004), Perilo, Motta, Las Casas, Saffar & Costa (2007) and Barroso et al. (2009). The authors of the current study labeled the device FORLING. It is composed of a piston/cylinder set, attached to a double protector mouth piece (like the one used by boxers), and coupled hydraulically to a pressure sensor. The values are transmitted by the digital acquisition system to a personal computer, as shown in Figure 1.

Before the test, the oral silicone double protector was disinfected using alcohol 70% and covered with a transparent non toxic PVC film (Doctor Film) so as to assure hygiene. For each trial the oral double protector was inserted and fitted in the mouth of the subject, who was given 15 seconds for accommodation.

After this period, the subject was instructed to push the cylinder head by protruding the tongue as hard as possible, holding it for 10 seconds (the same amount of time trial that was used for the qualitative evaluation). This procedure was repeated three times, with one minute intervals. Verbal reinforcement was provided at each repetition.

Figure 1. Diagram of the system (Motta et al., 2004)

The exerted tongue force was converted into a pressure measurement, Pascals, by the piston/cylinder assembly. After the acquisition of this data, the conversion of pressure to exerted force in newtons was calculated using the computer program MatLab®. Using this computer program the entire force time history was recorded for the duration of the application of tongue force. Figure 2. presents the graphic representation of this force in newtons as the vertical axis, while the amount of time in seconds is represented on the horizontal axis. Barroso et al. (2009) calculated the maximum uncertainty of the measurement system and found that it is about 0.18%.

Data analysis

Maximum and average forces were calculated for each individual and for each trial performed. Average force for each trial was defined as the average of the force signal throughout the 10 second period of sustained contraction. Average force for each individual was the average of force obtained in the three

trials. Maximum force for each trial refers to the peak force of the considered time interval. The maximum force of each subject was calculated by the average of the maximum force obtained in the three trials, because it better reflects the actual maximum performance of the individual. Average values for each age group were then calculated. Time taken to reach maximum force was also recorded during each trial, and the average value for each subject and for each age group was calculated. The coefficient of variation for each subject and for each group was calculated to verify the homogeneity of the results. Analysis of variance was used to determine if there was a difference in average force, maximum force, or time to reach maximum force between the age groups. The Tukey test was used for multiple comparisons. The Friedman test was used to verify if there were statistically significant differences between average forces obtained by the three trials. A p-value < 0.05 was considered statistically significant for all statistical procedures.

Figure 2. An example of the Force Time Series.

RESULTS

Average forces, maximum forces, time taken to reach maximum force, standard deviations and coefficients of variation for each subject are shown in Table 1. The three columns after the subjects are related to average force (value, standard deviation and coefficient of variation), the next three to maximum force and the last three columns are related to the time spent to reach maximum force.

Average forces, maximum forces, time taken to reach maximum force, standard deviations and coefficients of variation for each age group are shown in Table 2. The greatest values of maximum and average tongue force were obtained in the adult group followed by the elderly and children. Time taken to reach maximal isometric force was longer in the elderly group and shorter in children than in adults.

Table 1. Force Time By Group

Subjects	Favg (N)	SD	CV	Fmax (N)	SD	CV	Time (s)	SD	CV
Child 1	5.8	1.50	0.26	10.9	0.83	0.08	1.1	0.17	0.16
Child 2	8.1	1.15	0.02	10.1	0.65	0.06	3.1	1.68	0.54
Child 3	10.2	0.46	0.04	14.1	0.38	0.03	4.3	1.36	0.31
Child 4	6.8	0.81	0.12	9.7	0.06	0.01	1.5	0.89	0.59
Child 5	5.8	1.66	0.29	7.0	1.93	0.27	3.8	2.70	0.71
Adult 1	14.5	0.40	0.03	20.6	1.88	0.09	5.1	1.04	0.20
Adult 2	18.7	1.83	0.10	28.7	2.58	0.09	1.3	0.17	0.13
Adult 3	11.1	1.56	0.14	17.1	3.45	0.20	5.4	4.41	0.82
Adult 4	15.1	1.15	0.08	19.7	1.80	0.09	5.3	3.85	0.73
Adult 5	20.3	2.88	0.14	28.0	3.75	0.13	1.7	0.10	0.06
Elderly 1	21.5	2.85	0.13	29.6	1.91	0.06	6.2	2.55	0.41
Elderly 2	7.8	0.56	0.07	11.8	1.40	0.12	3.9	1.73	0.44
Elderly 3	5.1	1.11	0.22	10.3	2.90	0.28	4.4	2.05	0.47
Elderly 4	15.6	2.54	0.16	22.7	3.38	0.15	4.7	1.99	0.42
Elderly 5	4.5	0.50	0.11	6.4	0.74	0.11	9.5	0.15	0.02

Favg – average force in newtons, SD – standard deviation, CV – coefficient of variation, Fmax – maximum force in newtons, time – time in seconds taken to reach maximum force.

Table 2. Average force, maximum force, time taken to reach maximum force, standard deviation and coefficient of variation in different age groups

Group	Favg (N)	SD	CV	Fmax (N)	SD	CV	Time to peak (s)	SD	CV
Children	7.34	1.86	0.25	10.36	2.55	0.25	2.76	1.37	0.54
Adults	15.96	3.63	0.23	22.84	5.21	0.23	3.76	2.22	0.59
Elderly	10.91	4.44	0.52	16.17	6.03	0.47	5.75	2.27	0.40

Favg – average force, Fmax – maximum force, time to peak – time taken to reach maximum force, SD – standard deviation, CV – coefficient of variation.

The scatter plot with error bars of average force, maximum force and time to reach maximum force, in each age group is shown in Figure 3. for Children, Figure 4. for Adults, and Figure 5. for Elderly. Figure 6. show the scatter plot with error bars of average force, maximum force and time to reach maximum force, for the three age groups with an analysis of variance. The differences between the groups for maximum and average forces were considered significant. When groups were compared in pairs, there were statistically significant differences in average force ($p = 0.040$) and in maximum force ($p =$

0.016) only between children and adults. No statistically significant difference was found in average force comparisons between children and elderly ($p = 0.499$) nor between adults and elderly ($p = 0.269$). Neither was a statistically significant difference found in maximum force comparing children and elderly ($p = 0.365$), nor between adults and elderly ($p = 0.274$). There was no statistically significant difference between the groups for the length of time to reach maximum force. Table 3. shows the comparison of average and maximum forces for the three trials. There was no significant difference in the trials for either parameter.

Figure 3. Average force, maximum force and time taken to reach maximum force for each child.

Figure 4. Average force, maximum force and time taken to reach maximum force for each adult.

Figure 5. Average force, maximum force and time taken to reach maximum force for each elderly subject.

Figure 6. Average force, maximum force and time taken to reach maximum force in different age groups with analysis of variance. *p-value < 0.05.

Table 3. Average force and maximum force on the three trials for each group and statistic for comparison of the average values of the three trials.

Subjects	Trial 1		Trial 2		Trial 3		P-value ¹
	Average	SD	Average	SD	Average	SD	
Average Force (N)							
Children	6.9	2.2	8.0	1.2	7.0	2.4	0.247
Adult	16.7	4.1	16.4	4.1	14.7	3.3	0.35
Elderly	11.1	8.4	10.2	5.9	11.3	8.2	0.549
Maximum Force (N)							
Children	10.1	3.5	10.5	2.1	10.3	2.6	0.951
Adult	24.1	3.8	23.4	7.1	21.0	5.5	0.247
Elderly	15.3	10.6	16.4	9.0	16.8	9.9	0.549

SD – Standard deviation, ¹ Friedman test.

DISCUSSION

There are few published studies on tongue strength among healthy children. Consequently, values of musculature strength during the grown phase still remains vague.

It is known that, at the stage of the preprimary dentition, the tongue fills the oral cavity and that suction is its main function. With the expansion of the jaws, enlargement of the oral cavity and eruption of teeth, the swallowing pattern changes and the orofacial muscle function becomes stronger due to mastication (Ruan, Chen, Gu, Lu, Su & Guo, 2005). Tongue strength increases rapidly through ages 3–8 years and then continues to develop at a slower rate with age, until its peak in late adolescence. At the age of 16, tongue strength is very similar to adults (Potter & Short, 2009).

The population of children for this study was between 8 and 12 years of age. It was expected that they would have lower tongue strength values than adults, due to their stage of developmental maturation in muscle morphology and the central nervous system (Potter et al., 2009; Potter & Short, 2009). As expected, statistically significant differences were found in maximum and average tongue force between children and adults. The group of adults had higher tongue force than the group of children.

Posen (1972) measured maximum tongue protrusion force in a population aged between 8 and 12. The measures ranged between 600 g to 2350 g and the average value was 1534.83 g (approximately 15 N). In the present study, the children group obtained lower values (approximately 10 N). This difference may be due to differences in the instrument used to measure tongue force.

Potter et al. (2009) also measured tongue strength in children between 8 and 12. The average force value obtained was 53.47 kPa. In the present study, pressure was calculated by the division of force by area. An average tongue pressure for children was obtained which was approximately 63.83 kPa. This value is higher than that obtained in Potter's study. This difference may be explained by the difference in the direction of the measured force as Potter et al. (2009) measured tongue force in a cranial direction toward the palate.

Maximum force values obtained in the present study from adults and older individuals were also higher than those described in literature by Robbins, Levine, Wood, Roecker & Luschei, (1995); Crow & Ship, (1996); Stierwalt & Youmans, (2007). This difference in the values is possibly explained by the difference in the direction of tongue displacement during the measurement. Each tongue displacement involves different muscles, extrinsic and/or intrinsic. The weakness of a specific muscle can affect one direction more than the others, results can be different for each direction (Weijnen, Kuks, Van Der Bilt, Van Der Glas, Wassenberg & Bosman, 2000). Studies with protrusive tongue force (Mortimore et al., 1999; Bu Sha et al., 2000) also reported higher results than the present study. This may possibly have happened because the devices used for measurement were different, and this study was conducted with Brazilians who may have different facial characteristics than other populations.

When comparing the elderly group with the adult group a decrease in tongue strength was observed, although this decrease was not statistically significant. This decline, resulting from sarcopenia, produces a decrease in the size and number of muscle fibers, reduction in fiber density, in functional motor units, increase in non-contractile tissue and changes in central mechanisms. This age related change appears to have no clinical significance in normal aging, but in association with other pathologies, it could potentially cause a problem (Nicosia, Hind, Roecker, Carnes, Doyle, Dengel & Robbins, 2000).

The hypothesis raised by Motta and co-workers (2004) is that, knowing the capability of an individual to exert protrusion force with the tongue, it is possible to infer his/her capacity to accomplish other tasks. That presumably happens because the muscles responsible for tongue protrusion, including the genioglossus, verticalis and transversus (Pittman & Bailey, 2008) actively take part in swallowing, mastication, speech and other tasks.

Tongue pressure in cranial direction, elevated up toward the palate was recorded in a study by Robbins et al. (1995) during a maximal isometric task and during saliva swallows in young and older people. They found that, while isometric maximum pressure declined

with age, swallowing pressure did not. They linked this finding to the fact that for healthy individuals, regardless of age, swallowing pressures are sub-maximal with regard to those generated isometrically. Swallowing does not demand ~~tongue~~ maximum tongue force, leading to the conclusion that healthy elderly subjects manage to achieve the necessary pressures to successfully swallow.

Nicosia et al. (2000) found that, as tongue pressure is reduced in the elderly population, the available "pressure reserve", or difference between isometric and swallowing pressures, is also reduced. This reduction may leave aged individuals more vulnerable to suffer from dysphagia, as they have to work harder to achieve the necessary pressure to accomplish these functions.

Another important factor observed in results of the present study was ~~is~~ that in the older population, coefficients of variation related to maximum and average force, were greater than in the other groups (see figure 6), demonstrating that this population is less homogeneous than the groups of either children or adults, even though all participants were classified as having normal tongue strength during qualitative evaluation. This heterogeneity is presumably related to the biological variability of the subjects, especially older subjects, as they may have less muscular control than adults and children (Sosnoff & Voudrie, 2009). It is important to note that qualitative evaluation is accomplished according to the judgment of the examiner, who may have subconsciously had lower expectations for the elderly group and so clinically rated them as 'normal'. This is a limitation of the study. That is why the quantitative evaluation is an important complement to the clinical evaluation, This makes the diagnosis of tongue force more reliable, especially in the subjects with slight strength deficits, which are difficult to identify by clinical evaluation alone.

The coefficient of variation for each subject was calculated to verify the homogeneity of the results for average force and maximum force. Values of coefficient of variation up to 0.3% were considered as homogeneous. Table 1. shows that maximum force and average force were homogeneous for all subjects.

With respect to whether maximum or average force provides a better operational definition of

tongue strength, studies have shown that both measures indicated results similar to the qualitative evaluation of tongue strength. In this study we verified that maximum force was more homogeneous than average force for most of the subjects (57%). From a practical standpoint, using maximum force may be more efficient in a clinical setting because no calculation is required (Clark et al., 2003).

Three trials were done for each participant. The maximum force of each trial refers to the peak force of the considered time interval, while the maximum force of each subject was calculated by the average of the maximum force obtained in the three trials. The average force of each trial was the average of the force signal throughout the 10 second period of sustained contraction while average force of the subject is the average of the 3 trials. There was no consistent pattern in which trials produced the maximum tongue strength or average tongue strength (see Table 3.), although most of the subjects produced the highest values on their first attempt. Forty percent of the subjects reached the highest value of maximum force on the first trial, 33.3 % on the second trial, and 26.7% on the third trial. In relation to average force, 46.7 % of the subjects reached the highest value on the first trial, 33.3% on the second, and 20% on the third. The tendency of the subjects to produce the highest values on the first trials is probably related to tongue fatigue in second, and, especially, on third trial.

Lambert, Dyck (1978) apud by Dworkin et al. (1980) observed tongue force in subjects with degenerative diseases, and found that normal individuals produce maximum force in the first seconds of contraction whereas subjects with decreased tongue strength need at least seven seconds to reach peak force values. In thee current study, the sample was composed of healthy individuals and only one, from the elderly group, needed more than 7 seconds to reach maximum force. Although the time taken to reach maximum isometric force was longer among the elderly than for adults and children, there was no statistically significant difference between groups. Thus, it is important to consider requesting a shorter length of time for muscle contraction when evaluating tongue maximum force in healthy individuals. This could avoid the confounding variable of muscular fatigue. In this research, it was observed that although not statistically significant, there was a decrease of the force

values measured during the second and third assessments for most participating subjects.

The elderly presented more homogeneous results than adults or children for the parameter of time taken to reach maximum force. This may have happened because, unlike the latter two, the elderly maximum force was not reached on the first peak. Among older people, voluntary muscle responses become progressively slower due to an increased latency evoked primarily by changes of excitability in the central nervous system (Price & Darvell, 1981). Children reached peak forces faster than adults. A possible explanation would be that adults strictly try to adhere to maintaining a consistent force, being able to produce longer peaks of force than the initial one while children lose interest for the task, producing their maximum force only in the beginning of the test.

Endurance can be 'operationally defined' as the length of time for which an individual can maintain 50% of his maximum strength. It appears to be also important to characterize and differentiate tongue strength in different age groups. Additional research is needed to determine this parameter for each age group.

The Forling instrument used in this quantitative evaluation is able to reproduce qualitative evaluation results because the movements involved in both qualitative and quantitative strength measurements are the same (Barroso et al., 2009). Previous studies with the same instrument also indicated that both types of

evaluations produced concurring results (Perilo et al., 2007). It proved to be a reliable tool to measure tongue strength in all age groups. The double protector mouthpiece is soft and easily adaptable to several sizes of teeth and different dentition without discomfort to the patient. Another advantage is that the mechanism is simple to operate and to understand.

CONCLUSIONS

Adults had both higher average tongue force and maximum tongue force than that obtained in the elderly or children. There were statistically significant differences in average force and in maximum force only between children and adults. Time taken to reach maximal isometric force was longer in the elderly group and shorter among children when compared to adults, although no statistically significant difference was found between groups. The results of this study agree with other studies from literature and reaffirms that tongue force increases with age until reaching a peak at the adult stage, then declines with age.

The use of the Forling tool in research and in clinical orofacial myology practice can help speech-language pathologists with the quantification of tongue force. This would allow pre- and post-treatment assessment which would provide measurable gain, without a large amount of time required for the calculation.

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