ORAL STRENGTH COMPARISONS ACROSS AGE AND SEX IN HEALTHY VOLUNTEERS

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Proper functioning of the oral musculature is crucial in the oral phases of swallowing and also significantly affects the pharyngeal phase of swallowing. The lips help extract incoming food from utensils, or seal around straws or cups to introduce liquid into the oral cavity. Once inside, they seal the oral cavity to avoid loss of the bolus anteriorly. The cheeks are tensed to ensure that the bolus remains in the medial portion of the oral cavity and does not become pocketed in the lateral sulci. The tongue has the most extensive role in oral swallowing; it requires movements in multiple directions to allow for adequate bolus preparation, manipulation, and transport (Groher & Crary, 2010).

Due to the normal aging process, muscles weaken through a process known as sarcopenia (Visser, 2009). This process reduces the number of muscle fibers in muscle groups which, in turn, results in a loss of muscle strength. If muscle strength is diminished to a great degree, swallowing physiology could be altered (Stierwalt & Youmans, 2007). The physical alterations in swallowing could lead to dysphagia if there is no compensation by the person. Additionally, the reduction in strength could result in a reduced resilience to weakness caused by neurologic disease or insult. Significantly lower tongue strength scores have been found between persons with oral dysphagia due to a variety of diagnoses compared to healthy age and sex matched peers (Stierwalt & Youmans, 2007).

A breakdown in oral musculature can lead to various forms of dysphagia that can negatively impact a patient's physical health, and quality of life. Breakdowns could include, but are not limited to, inadequate bolus containment, breakdown / preparation, transport, clearance, and/or control, and can lead to an inability to tolerate some or all consistencies effectively and/or safely (Groher and Crary, 2010). This intolerance, if unknown or ignored, may lead to mild to profound health problems with potential negative effects on the person's nutrition, hydration, respiratory status, and could potentially be deadly (Groher & Crary, 2010). Additionally, changing, limiting, or completely withholding oral feeding or drinking can lead to a mild to profound reduction in the quality of a patient's life because of a potential loss of socialization, self-esteem, finances, and/or independence. (Ekberg, Hamdy, Woisard, Wuttge-Hannig, & Ortega, 2002).

With the increasing use of instrumented strength measuring devices, oral musculature strength across individuals can be quantified objectively. Previously, clinicians relied on subjective, experienced-based estimations of strength, such as resistance testing with a tongue blade. Now that devices such as the Iowa Oral Performance Instrument (IOPI; IOPI Northwest, 2005) are available and being employed, sufficient research needs to be completed to fully understand the measurements. Once sufficient understanding of the normal range of oral strength across age and sex is established, better evaluations can be performed for earlier and more precise identification of weakness that could cause or exacerbate dysphagia. This early detection could be used to prevent some of the complications associated with dysphagia.

To date, several studies have been completed on anterior tongue strength and, to a lesser extent, posterior tongue strength for healthy, adult individuals using the IOPI. (Clark & Solomon, 2012; Crow & Ship, 1996; Gingrich, Steirwalt, Hageman, & LaPointe, 2012; Kays, Hind, Gangnon, & Robbins, 2010; Neil & Palmer, 2011; Palmer, Jaffe, McCulloch, Finnegan,, Van Daele, & Luschei, 2008; Robbins, Levine, Wood, Roecker, & Luschei, 1995; Robin, Goel, Somodi, & Luschei, 1992; Solomon, Drager, & Luschei, 2002; Solomon & Munson, 2004; Solomon, Robin, Mitchinson, Van Daele, & Luschei, 2010; Vitrano, 2010; Youmans & Stierwalt, 2006; Youmans, Youmans, & Stierwalt, 2008). However, to this author's knowledge, only one investigation has measured oral strength in the tongue in multiple positions, the lips, and the cheeks (Clark & Solomon, 2012). Therefore, insufficient data have been obtained regarding most oral strength measurements to date. Systematic replication of this study will contribute to the establishment of normal ranges of functioning across individuals of varying ages and sex.

The purpose of the current study was to measure most of the variables from the Clark and Solomon study with a large sample of participants; although, the study did have some methodological differences from their investigation. The population in questioned was obtained from the greater New York City area and was extremely heterogeneous in terms of participant background. Lip strength, cheek strength (bilaterally), anterior, protruding, and lateral tongue strength (bilaterally) were measured and analyzed across sex and age groups. The research questions included the following: how do the oral strength measures compare to previous studies?; how do the oral strength measures relate to each other?; do the oral strength measures change with age; and, how do the oral strength measures compare between the sexes?

Method

The following is a quantitative, between-subjects, descriptive research investigation. All research was approved by Long Island University's Institutional Review Board for Research involving human subjects.

Participants

One-hundred-and-thirty-two participants contributed to the study. All participant recruitment was accomplished via word of mouth and printed advertisements. Participants were divided into three age groups: younger (20 - 39), middle (40 - 59), and older (60+). Each group contained 44 participants: 22 men and 22 women. Table 1 contains mean ages and standard deviations for each group and subgroup. Participants filled out a questionnaire regarding their health, physical status, and demographics, and participated in an oral mechanism examination by an experienced Speech-Language Pathologist. All volunteers were reportedly in good health. Furthermore, volunteers were excluded from the study if they had a known prior history of neurologic disease, insult, or injury, head and neck cancer, oral surgery (other than routine dental procedures such as wisdom teeth extraction), or any history of respiratory, speech, or swallowing impairments. Additionally, the oral mechanism examination demonstrated oral anatomy and physiology within normal limits as determined by the examiner. Prior to obtaining the final participant pool, five participants were excluded for the following reasons: history of pharyngeal cancer, history of brain trauma, history of seizures, frontal lisp, and missing data. In sum, prior to participating, a participant was recruited, determined to fit into an under filled age and sex group, gave informed consent, and was screened for excluding variables or structural abnormalities. Recruitment continued until all groups were filled and equal.

Instrumentation

The Iowa Oral Performance Instrument (IOPI Northwest, 2005) was used to elicit all measurements. The IOPI is a small, handheld device that allows the examiner to record peak measurements of exertion on an air-filled bulb. The soft, air-filled bulb was connected to the device via thin plastic tubing. A reading of the peak level of force is displayed on an LCD display, measured in kiloPascals (kPa). Calibration of the IOPI was tested and confirmed to be acceptable weekly as per the manufacturer's instructions (IOPI Northwest, 2005).

Table 1: Description of the Participants

Group		Number of Subjects	Mean Age (SD)
Younger	Male	22	29.13 (5.40)
	Female	22	28.50 (5.09)
	Total	44	28.82 (5.20)
Middle	Male	22	50.50 (5.90)
	Female	22	49.95 (4.23)
	Total	44	50.23 (5.08)
Older	Male	22	67.64 (7.66)
	Female	22	69.00 (8.13)
	Total	44	68.32 (7.83)
Total	Male	66	49.12 (17.23)
	Female	66	49.09 (17.07)
	Total	132	49.12 (17.32)

Procedures

All participants were tested in the same quiet, well-lit room. They were all seated upright in a straight-backed chair. Informed consent was established and the questionnaire and the oral mechanism examination were completed.

Prior to each measurement task, participants were trained as to the placement of the air-filled bulb in their oral cavities for each specific task. Participants were instructed and reinstructed until bulb placement was reliably accurate. Once participants demonstrated appropriate placement, data were taken. Measurements were taken at each of the following locations, with the following instructions.

Mean maximum isometric pressure of the anterior tongue pressing superiorly (TS) was measured with the air-filled bulb on top of the anterior tongue. The entire blue bulb was inserted into the oral cavity on the superior tongue just posterior to the central incisors. The participant was then instructed to press superiorly with his/her tongue, squeezing the bulb between the anterior tongue and hard palate with maximal force.

Mean maximum isometric pressure of the tongue protruding forward (TP) was measured with the air-filled bulb anterior to the anterior tongue tip. The entire blue bulb was inserted into the oral cavity immediately behind the central incisors with the teeth closed around the plastic tubing. The participant was then instructed to press anteriorly with his/her tongue, squeezing the bulb between the tongue tip and the central incisors with maximal force.

Mean maximum isometric pressure of the tongue moving laterally (TL) to the right and to the left were measured with the air-filled bulb between the lingual and dental surfaces. The blue bulb was inserted lateral to the tongue until the most-posteriorly-inserted portion was against the second molar. The participant was then instructed to press laterally with his/her tongue, squeezing the bulb between the lateral tongue and the teeth with maximal force.

Mean maximum isometric pressure of the cheek muscles (C) on the right and left were measured with the air-filled bulb between the dental and buccal surfaces. The blue bulb was inserted into the buccal cavity until the most-posteriorly-inserted portion was against the second molar. The participant was then instructed to squeeze his/her cheek muscles with maximal force.

During each trail, the examiner encouraged the participants to expend maximal effort for approximately two seconds. Following the participants maximal effort, he/she was asked to rest for thirty seconds while the peak value was recorded from the IOPI for that trial. Three trials were performed for the tongue pressing superiorly, tongue protrusion, and lip tasks. The mean of the three trials was calculated for each participant for each variable. Six trials were performed for the tongue lateralization and cheeks tasks: three per side (right and left). The mean of the three trials performed for the right and the mean of the three trial for the left were calculated for these variables.

Reliability

A second examiner, blinded to the first examiners measurements, also recorded the values measured for 10% of the sampled variables. Reliability was established at 100%. Test-retest reliability for measuring anterior tongue strength with the IOPI was previously establish during a prior investigation (Youmans & Stierwalt, 2006).

Data Analyses

Descriptive statistics were calculated for all variables. Pearson product-moment correlations were performed to examine the relation between the dependent variables. Lateral tongue strength on the right and left were compared, as were the right and left cheek strength scores to determine if they were statistically equal and could be collapsed. A paired *t*-test was used to determine whether or not they differed significantly. A two-way multivariate analysis of variance (MANOVA) was computed to determine the main effects of age group and sex on the TS,TP,TL,C, and L variables, as well as their interactions. All computations were made via SPSS version 13.0 statistical software package. Alpha was set at 0.05.

Results

Descriptive statistics were computed for each dependent variable. These data are presented in Table 2 for each age and sex category. Table 3 illustrates the correlations between the variables. Statistically significant correlations were found between all of the strength measurements (TS, TP, TL, C, L).

Table 2: Descriptive Statistics for the Dependent Variables by Age and Sex

Variable	Age Group	Sex	Mean (SD)
TS	Younger	Male	65.92 (17.69)
		Female	58.74 (10.62)
	Middle	Male	60.11 (13.67)
		Female	57.41 (18.77)
	Older	Male	58.61 (11.84)
		Female	48.50 (20.52)
TP	Younger	Male	57.53 (19.89)
		Female	55.74 (13.97)
	Middle	Male	52.83 (12.53)
		Female	50.70 (19.96)
	Older	Male	50.15 (15.34)
		Female	44.38 (17.09)
TL	Younger	Male	50.03 (18.12)
		Female	43.59 (22.89)
	Middle	Male	46.89 (14.80)
		Female	39.03 (21.92)
	Older	Male	43.17 (16.66)
		Female	36.37 (16.82)
C	Younger	Male	29.97 (5.12)
		Female	19.08 (6.19)
	Middle	Male	28.95 (7.94)
		Female	25.39 (8.14)
	Older	Male	27.56 (7.63)
		Female	20.90 (8.82)
L	Younger	Male	32.77 (13.23)
		Female	29.21 (12.14)
	Middle	Male	34.52 (10.66)
		Female	27.78 (10.59)
	Older	Male	32.29 (9.16)
		Female	31.27 (16.65)

TS = anterior tongue strength measured pushing superiorly; TP = tongue strength during protrusion; TL = tongue strength during lateralization; C = cheek strength; L = lip strength

Table 3
Correlations (r) between the Dependent Variables

	TS	TP	TL	C	L
TP	0.48 (<0.001)				
TL	0.46 (<0.001)	0.38 (<0.001)			
C	0.37 (<0.001)	0.33 (<0.001)	0.45 (<0.001)		
L	0.32 (<0.001)	0.27 (<0.001)	0.17 (0.04)	0.35 (<0.001)	

p-value in parentheses. TS = anterior tongue strength measured pushing superiorly; TP = tongue strength during protrusion; TL = tongue strength during lateralization; C = cheek strength; L = lip strength

The paired *t*-test conducted to determine whether a difference existed for right-sided (M = 43.14) versus left-sided (M = 43.14) tongue lateralization strength showed that differences were not statistically significant (t (131) = -0.08, p = 0.94). Likewise, the paired *t*-test comparing right-sided (M = 24.94) and left-sided (M = 25.67) cheek strength demonstrated that the sides were statistically the same (t (131) = -1.55, p = 0.12). The results for both variables were then collapsed and a single tongue lateralization strength variable (TL) and cheek strength (C) variable were used for further analyses.

Multivariate and univariate tests were conducted prior to pairwise comparisons to avoid family-wise error. Pillai's Trace calculations were used for the omnibus tests when conducting the MANOVA. Statistically significant results were found for the age group variable (F (10,246) = 1.88, p = 0.04) and for the sex variable (F (5,122) = 6.14, $p < 0.0001$). A statistically significant interaction did not exist between age and sex variables.

Univariate tests for age were significant for the TS (F (2, 126) = 3.37, p = 0.04) and TP (F (2, 126) = 3.47, p = 0.03) variables. Significance was not established for the remaining variables (TL, L, C). Univariate tests for sex were significant for the TS (F (1, 126) = 5.76, p = 0.02), TL (F (1, 126) = 4.64, p = 0.03), and C (F (1, 126) = 29.71, $p < 0.0001$) variables. Significance was not established for the remaining variables (TP, L).

Pairwise comparisons were then conducted. The TS variable for age demonstrated a statistically significant difference between the youngest (M = 62.33) and oldest groups (M = 53.55, p = 0.03); the middle group did not differ significantly from the other two groups (M = 58.76). These results are depicted in Figure 1. Likewise, the TP variable for age showed a statistically significant difference between the youngest (M = 56.64) and oldest groups (M = 47.27, p = 0.03); the middle group did not differ significantly from the other two groups (M = 51.77). These results are illustrated in Figure 2. The TS variable for sex exhibited a statistically significant difference between the men (M = 61.55) and women (M =

54.88, $p = 0.02$). These results are pictured in Figure 3. The TL variable for sex demonstrated a statistically significant difference between the men ($M = 46.70$) and women ($M = 39.66$, $p = 0.03$). These results can be viewed in Figure 4. Finally, the C variable for sex resulted in a statistically significance between the men ($M = 28.83$) and women ($M = 21.79$, $p < 0.0001$). These results are shown in Figure 5.

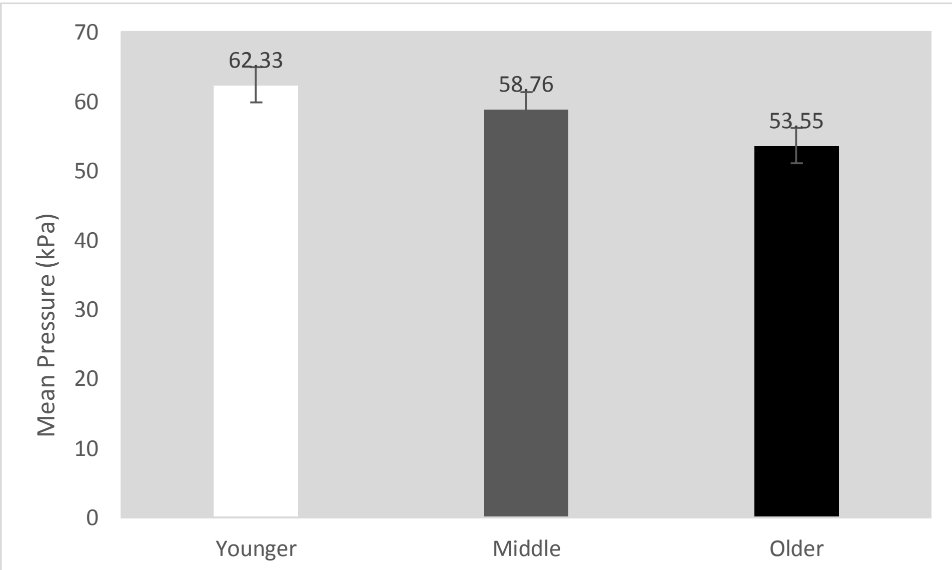

Figure 1: Maximal Anterior Tongue Strength Exerted Superiorly (TS) by Age Group
Means and standard error values of maximal anterior tongue strength pushing in a superior direction across the three age groups. Statistically significant differences were found between the younger and older groups.

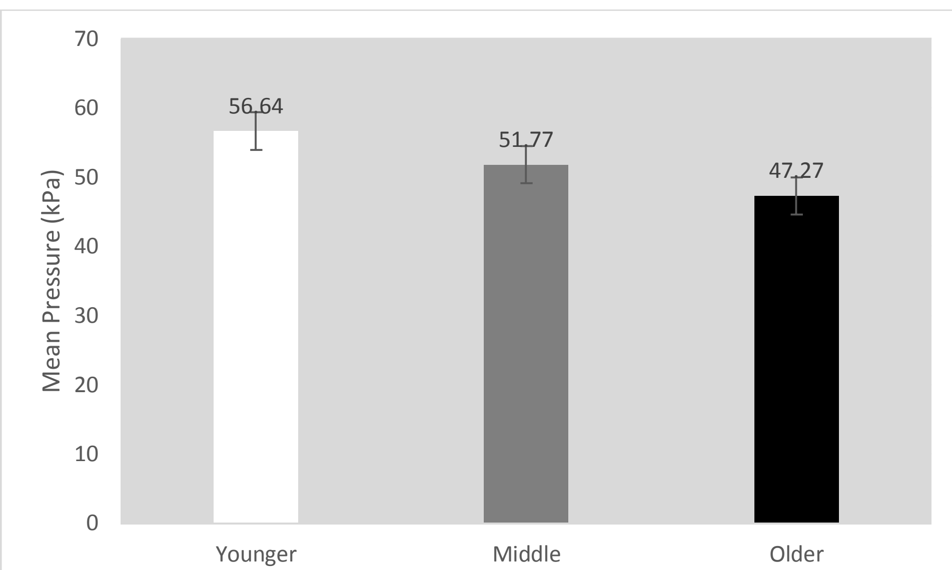

Figure 2: Maximal Anterior Tongue Strength during Protrusion (TP) by Age Group

Means and standard error values of maximal tongue strength pushing in an anterior direction (protruding) across the three age groups. Statistically significant differences were found between the younger and older groups.

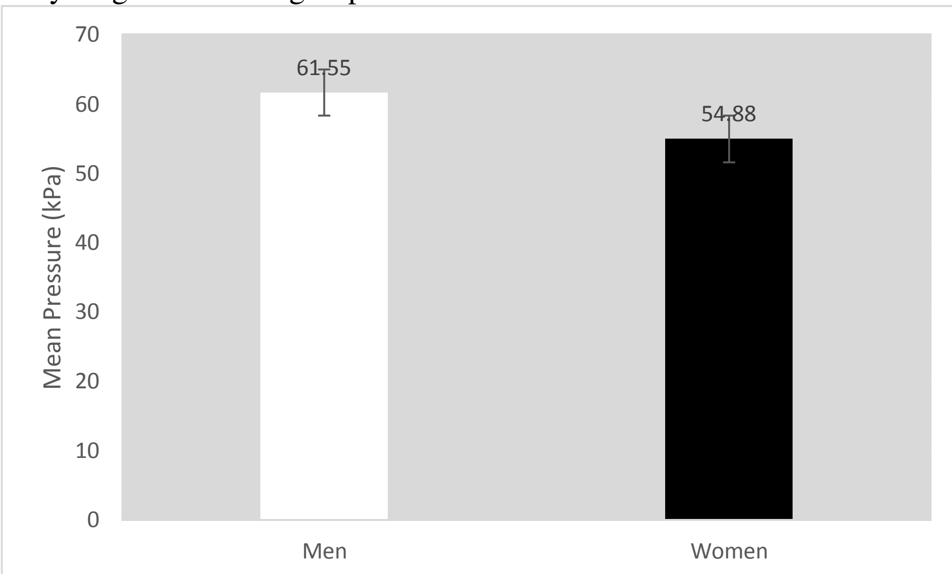

Figure 3: Maximal Anterior Tongue Strength Exerted Superiorly (TS) by Sex
Means and standard error values of maximal anterior tongue strength pushing in a superior direction between the sexes. Statistically significant differences were found between the groups.

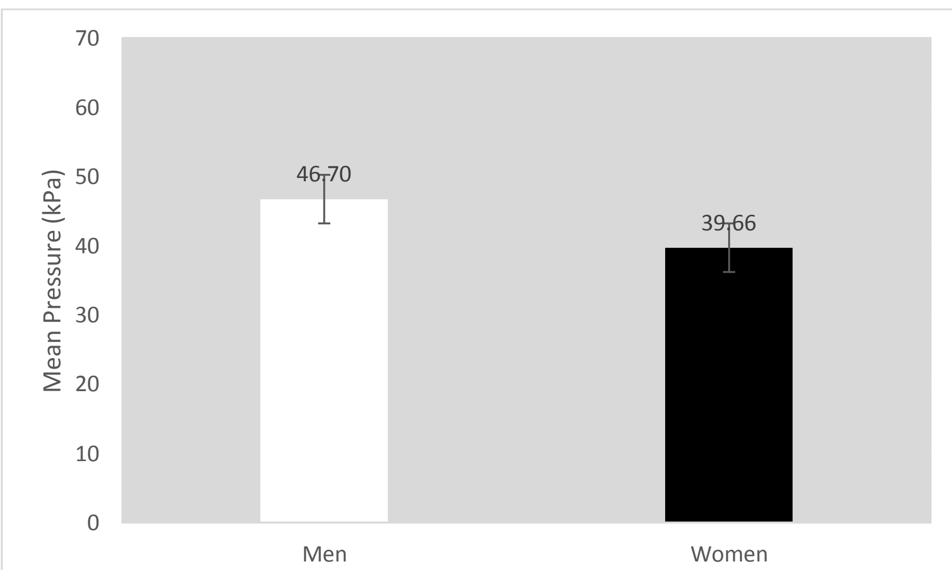

Figure 4: Maximal Anterior Tongue Lateralization Strength (TL) by Sex
Means and standard error values of maximal tongue strength pushing laterally between the sexes. Statistically significant differences were found between the groups.

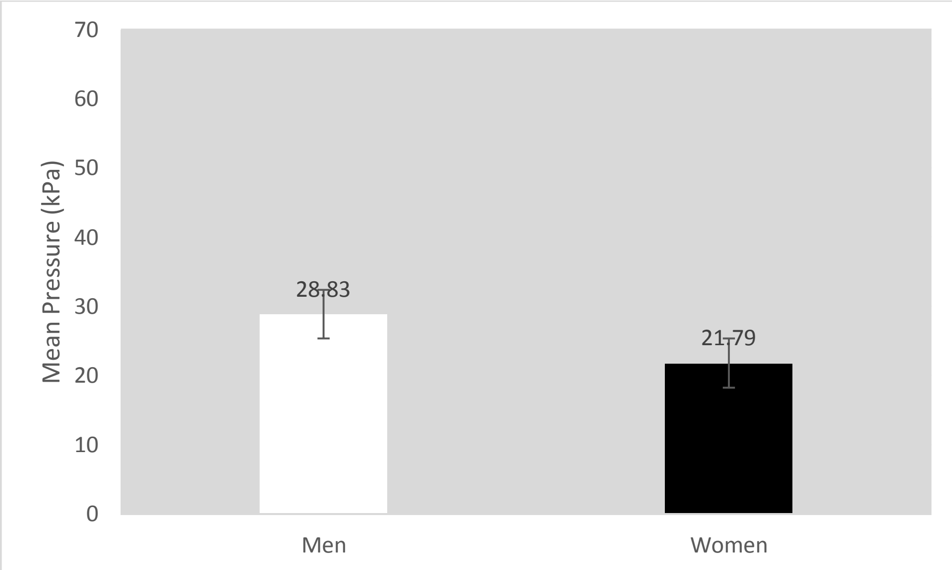

Figure 5: Maximal Cheek Strength (C) by Sex
Means and standard error values of maximal cheek strength between the sexes. Statistically significant differences were found between the groups.

Discussion
This investigation attempted to extend the known findings regarding tongue strength in multiple directions, lip strength, and cheek compression strength. Age and sex differences were also investigated.

The lack of differences between the left and right tongue lateralization and cheek strength was expected. This result supports Clark and Solomon's (2012) findings. These data suggest that individuals are designed reasonably symmetrically in terms of oral muscle strength.

Measurements of adults' anterior tongue strength is by far the most well documented variable (Clark & Solomon, 2012; Crow & Ship, 1996; Gingrich et al., 2012; Kays et al., 2010; Neel & Palmer, 2011; Palmer et al., 2008; Robbins et al., 1995; Robin et al., 1992; Solomon et al., 2002; Solomon & Munson, 2004; Solomon et al., 1996; Vitrano, 2010; Youmans & Stierwalt, 2006; Youmans et al., 2008). Taken as a whole, our results fall into similar ranges to those other investigations with the caveat that all of the investigations differ somewhat (Adams, Mathisen, Bains, Lazarus, & Callister, 2013). Posterior tongue strength was not investigated here due to complaints of discomfort from some of the participants during pilot work.

The other variables were only measured as part of the Clark and Solomon investigation (2012). The participants in this study performed higher on the TS (with the exception of the middle group) and L tasks. The remaining variables studied in this investigation (TP, TL, C) were lower than what were observed in that investigation for all age groups. In both studies, the TS variable was measured using the same method. Measurement of the TP, TL, C, and L variables were measured differently. In the previous study, the researchers used a bulb holder to position the tongue bulb for the TP, TL and C measurements. Pilot trials for the current study yielded complaints of discomfort from some of the participants when using the bulb holder; therefore, the examiner relied on training to ensure proper placement with the hope that increased participant comfort would yield strength scores more representative of their abilities. Similarly, in the previous investigation, lip compression scores were obtained with the air-filled bulb between tongue depressors. That was not included in this investigation; however, both investigations returned similar measurements. The age groups in the previous investigation differed as well. The participants in their younger group were younger than in this investigation and middle group participants were older, but the older groups were similar in age. It is not clear whether methodological differences or sample differences were responsible for the differences between the studies. Certainly there is a range of normal functioning. Further replication is necessary to further establish normal oral strength ranges and variability.

All of the dependent variables were significantly and positively correlated suggesting that the individual participants generally tended to perform similarly across tasks in terms of strength. That is, if a person has a higher score on one task, he will likely have a higher score on another task. A person who demonstrates weakness on one task will likely demonstrate similar weakness on the next task. Therefore, one strength measure might give the examiner some indication of the general state of the oral musculature. However, because the correlations were not perfect, the value of measuring the entire oral musculature remains if one has the opportunity.

All scores trended downward age with the notable exception of the lip strength scores. Also, cheek compression scores in the younger female group produced the lowest results. As with several previous findings, anterior tongue strength was significantly higher in the younger group than the older group (Nicosia, Hind, Roecker, Carnes, Doyle, Dengel, & Robbins, 2000; Robbins et al., 1995; Stierwalt & Youmans, 2007; Youmans & Stierwalt, 2006; Youmans et al., 2008). This was further confirmed by a meta-analysis by Adams et al. (2013). However, not all investigations returned significant results between these groups (Clark & Solomon, 2012).

Younger participants were significantly stronger than older participants in terms of tongue protrusion as well. This result, as well as the lack of significance between age groups for lip or cheek strength mirrored the results of Clark and Solomon (2012). However, whereas they found significant differences for tongue lateralization between younger and older age groups, I did not. These results suggest that the tongue is the most susceptible to the effects of sarcopenia due to age compared to the lip or cheek muscles; although it appears variable across persons.

Males produced consistently higher strength scores on average for all measures compared to age-matched females. Three of the comparisons reached statistical significance. Males were significantly stronger in terms of anterior tongue strength than females. Previous studies have yielded inconsistent findings with respect to the difference between the sexes on measures of TS; however, the meta-analysis conducted by Adams et al. (2013) revealed significantly stronger TS scores for males compared to females, thus supporting the present findings.

Tongue lateralization was significantly different between the sexes with males being stronger. This result did not support the result from the Clark and Solomon study (2012). The lack of significant differences regarding tongue protrusion was supported by that study. Additionally, whereas this investigation did not yield sex-related differences in lip strength, theirs did. Finally, in terms of cheek strength, both investigations yielded significantly higher strength measurements for men compared to women. All of the aforementioned measurements, whether they reached a level of significance or not, demonstrated stronger average male scores than female scores in both investigations. Therefore, if these findings are accurate, it would be fair to say that men are generally stronger than women in terms of their oral musculature; however, the difference is not always great and there appears to be a good deal of variability.

The effect of differences between groups based on age or sex remains unclear. Whether the differences observed make functional, clinical differences to swallowing physiology has not been adequately studied thus far, especially in the measures other than anterior tongue strength. Youmans et al. (2008) studied anterior tongue strength during swallowing and found that when older males swallowed they used less strength than younger males, therefore, not tapping into their strength reserve greatly. Conversely, older females used more strength than younger females, thus leaving them with less of a strength reserve due to a maximum strength decline with age. Therefore, age-related differences in strength were potentially more serious for women than men. These data need to be replicated and other oral strength measures should be included to determine if these data are reliable and whether they hold true for other measurements of oral strength. The result of decreased strength could decrease the strength reserve if swallowing pressure needs remained unchanged, or seriously it if the pressure needs increased; decreased strength could also change how the individual swallows.

Although, dysphagia is not a product of normal aging in healthy individuals (Humber & Robbins, 2008; Kendall & Leonard, 2001), the risk of dysphagia increases due to an increased risk of dysphagia causing conditions with age. As mentioned, significantly lower anterior tongue strength scores have been found for persons with oral dysphagia compared to healthy peers (Stierwalt & Youmans, 2007). Strength differences in tongue protrusion and lateralization have also been observed in persons with oral phase dysphagia (Clark, Henson, Barber, & Sherill, 2007). Therefore, although it is not yet well understood, tongue strength decreases appear to be related to oral dysphagia. Again, these data need to be replicated and supported prior to trusting them fully. Additionally, other parts of the oral musculature should be assessed during swallowing.

Certainly, a threshold of oral strength required for normal swallowing versus dysphagia has not been established. Nor have precise physiological outcomes of a change in strength for one or more of our oral structures in terms of swallowing. The degree of variability among humans greatly impedes the process of establishing this. We all differ to some or a great degree in terms of our anatomical make-up, our physiologic differences in terms of swallowing, and so on. The best we can expect is a gross idea of how persons of different sexes and ages function when they are healthy and when they have varying degrees and types of dysphagia. To accomplish even this, a significant amount of study remains to be accomplished. More replication with large numbers of participants will give us a better understanding of this extremely complicated phenomenon. However, the task is potentially worth the effort given the clinical benefit from doing so.

Conclusion

The ultimate goal of this research is to have an improved evaluation method for detecting weakness in the oral musculature that might cause or exacerbate dysphagia. To that end, more direct and systematic replications are needed prior to establishing normative ranges of normal, oral strength measures across age and sex groups. This will take a significant amount of study given the variability of humans and their swallowing physiology. This is clear when comparing the results of the current study with past studies; however, once enough data are collected, oral strength and the variables that affect it, and its impact on swallowing will be better understood.

If the data from the current study are indeed accurate, some preliminary findings are as follows: muscle function appears to be symmetrical and of similar strength within persons throughout the oral musculature that were tested. Oral muscle strength is highly variable between people. As a general rule (although there are some exceptions and not all measurements reach a level of statistical significance), men and younger people are stronger than women and older people. Finally, of all the oral musculature tested in this study, the tongue appears to be the most susceptible to sarcopenia.

Footnote

The author declares no conflict of interest.

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