Research Article

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Suggested Citation

Solomon, N. P., & Clark, H. M. (2020). The effect of an anti-slip surface on objective measures of tongue strength in healthy adults. *International Journal of Orofacial Myology and Myofunctional Therapy*, 46(1), 13-21.

DOI: <https://doi.org/10.52010/ijom.2020.46.1.2>

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THE EFFECT OF AN ANTI-SLIP SURFACE ON OBJECTIVE MEASURES OF TONGUE STRENGTH IN HEALTHY ADULTS

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ABSTRACT

Purpose: Instrumental assessments of tongue strength have provided clinicians with the ability to obtain quantitative measures to document lingual weakness. A technical challenge with a common instrument is that the surface of the of the bulb-shaped sensor is smooth and can be slippery when contacted by the tongue. This study evaluated whether adding a textured layer to the bulb leads to enhanced strength measures in neurologically normal adults. **Methods:** Maximum-effort maneuvers for anterior and posterior tongue elevation, right and left tongue lateralization, and tongue protrusion were available from 62 healthy adults using the Iowa Oral Performance Instrument (IOPI). The IOPI tongue bulb was either bare or covered with a single layer of gauze. The maximum pressure ($P_{\max}$) exerted on the bulb from three trials was used as the outcome variable for each task. **Results:** In addition to significant main effects for both bulb-cover and task, there was a significant interaction between the use of gauze and the direction of the tongue-strength maneuver. $P_{\max}$ was significantly greater when a gauze-covered bulb was used for tongue lateralization and protrusion but not for tongue elevation maneuvers. **Conclusion:** Using a single-layer of gauze on the smooth tongue-bulb helped reduce slippage of the tongue and resulted in greater $P_{\max}$ values when evaluating tongue strength in the lateral and protrusive directions, but not for tongue elevation. Efforts to develop a more permanent solution to texturizing the bulb's surface are needed.

Keywords: tongue strength, objective orofacial assessment, reliability

INTRODUCTION

Assessing tongue strength is a standard component of an assessment for orofacial myofunctional issues in people of all ages, and is easily quantifiable because of simple clinical instrumentation. The most common tool is the Iowa Oral Performance Instrument® (IOPI), which provides a numeric display of the peak pressure generated by pressing the tongue against an air-filled bulb (Adams et al., 2013). According to standard protocol with the IOPI, strength is recorded as the highest pressure generated across three brief maximum-effort trials.

Previously, we published normative data for seven different measures of orofacial strength and examined age differences for young, middle-age, and older women and men (Clark &

Solomon, 2012). Five tasks targeted lingual strength: elevation of the anterior and posterior portions of the tongue dorsum, tongue lateralization to each side, and midline tongue protrusion. Overall, these assessments revealed tongue strength for neurologically normal adults that averaged 58 kilopascal (kPa) with somewhat lower values for posterior tongue elevation and tongue lateralization and higher values for tongue protrusion. Some measures of tongue strength decreased significantly with age, but there were no statistically significant differences between the sexes. The study also included assessments of facial muscle strength, including midline interlabial compression and buccodental compression on each side, with results averaging about 30 kPa. Unlike lingual strength measures, facial strength did not differ significantly with age but was significantly greater for men than women.

A development that made measurement of tongue lateralization and protrusion as well as buccodental compression possible was an adaptor manufactured for several years. It was described and used in several previous reports (Clark et al., 2009; Clark & Solomon, 2012; Solomon et al., 2008). Although it is not currently available, the measurements are still relevant and are worth considering in the event that such an adaptor is made again in the future. In particular, assessment of tongue lateralization would be appropriate if neuromuscular asymmetry is suspected. Unilateral tongue weakness can occur in cases of unilateral CN XII damage and unilateral central nervous system (CNS) damage. Previously, Solomon et al. (2008) examined the association between subjective ratings and objective measures of tongue lateralization strength in 44 adults referred for motor speech assessment. Correlations between subjective ratings and objective measures were moderately strong (.64 and .72 for right and left lateralization, respectively).

In that study, the authors noted that the tongue tended to slip during lateralization, protrusion, and posterior elevation maneuvers (Solomon et al., 2008). Therefore, the bulb was wrapped in a single layer of gauze. In our subsequent paper on normative data for orofacial strength that drew from multiple studies (Clark & Solomon, 2012), gauze was often but not always used during data collection. This study directly compared tongue-strength maneuvers performed with and without gauze.

The purpose of this study was to determine if tongue strength, according to $P_{\max}$ values, differed when the IOPI bulb had a textured surface, accomplished with a single layer of loosely woven gauze, from when it was bare. Tasks included five tongue-strength maneuvers. In addition, results were compared across two sessions in a subset of participants to consider whether the use of a textured tongue bulb improved session-to-session reliability. Hypotheses included greater tongue-strength measures and more consistent results across

two sessions when the bulb was covered with gauze.

METHODS

Participants

Sixty-six of the 171 adults with normal speech and swallowing who were included in the study by Clark and Solomon (2012) took part in the bulb-condition experiment at the same time as the original data collection. Of these, 62 (53 men, 9 women; age $M = 45.0$ yr, $SD = 21.9$ yr, $\min = 18$, $\max = 89$) had complete data sets for five tongue-strength tasks measured both with and without gauze draped over the IOPI tongue bulb. They were recruited from two research sites for several related experiments as detailed by Clark and Solomon (2012). Each participant demonstrated grossly normal orofacial structure and function for completing the assessment tasks; this required sufficient anterior and lateral dentition and dental alignment to hold the bulb-holder adaptor.

Instrumentation

The IOPI (IOPI Medical LLC, Carnation, WA), coupled with individual, disposable tongue bulbs, was used for all measurements. The instrument consists of a hand-held or table-top box containing pressure-sensing circuitry including a peak-hold function. Results are displayed digitally (in kPa) or by a row of 9 LED lights. The IOPI's tongue bulb is made of flexible polyvinyl chloride (PVC) material that forms an air-filled bulb (internal volume = 2.8 ml). It attaches to the main component via thin flexible tubing. An optional bulb-holder adapter (Clark et al., 2009; Clark & Solomon, 2012; Solomon et al., 2008) was used for tongue lateralization and protrusion tasks, as illustrated in Figure 1. The adapter, shown in the bottom row of Figure 2, consisted of a plastic stick with a solid oblong plate set perpendicular to the stick at one end. Silicone-rubber pads under the plate served as bite cushions to secure the position of the adapter in the mouth. The bulb was adhered to the plate with double-sided surgical-grade tape.

Figure 1. Tongue bulb holder during tongue lateralization (left) and protrusion (right) maneuvers

Procedures

Tongue strength was assessed with five tasks: anterior and posterior tongue elevation, tongue lateralization to the right and left, and tongue protrusion. The bulb was either bare (Figure 2, left column) or covered loosely with a single layer of 2" x 2" gauze on the side facing the tongue (Figure 2, right column). The order of the bare and gauze-covered bulb conditions was randomized.

The examiner instructed the participants to press the tongue against the bulb as hard as

possible and then to relax. Trials lasted approximately 1—3 seconds. The examiner provided enthusiastic verbal encouragement for each trial. These tasks have been described in detail previously (Clark & Solomon, 2012; Solomon et al., 2008). The maximum value from three maximum-effort trials for each task was used to indicate strength.

For test-retest reliability, 12 young men (age $M = 22.1$ yr) from the larger group of 62 participants returned for a second testing session at least one week later ($M = 16.8$ days, range = 8—37).

Figure 2. Bulb without (top row) and with the adapter (bottom row), and the bulb covered with a single layer of gauze (right column)

Statistical Analysis

To examine the effect of using a layer of gauze on the bulb for tongue-strength assessments, a repeated-measures analysis of variance (RM-ANOVA) was conducted with bulb-cover condition and tongue-strength maneuvers as within-subjects factors. Significance level was set *a priori* to $\alpha = .05$. To determine contributors to significant interactions, follow-up RM-ANOVAs were conducted for each maneuver separately with gauze condition as the within-subjects factor. To account for the five separate tests, $\alpha = .01$ for these comparisons. Test-retest reliability was also tested with RM-ANOVA, with session, cover, and tasks as within-subjects factors. None of the research questions involved group comparisons, so no between-subjects factors were included in the models.

For each analysis, $P_{\max}$ was the dependent variable. The Greenhouse-Geisser correction was applied for tests that failed the Mauchley Test for sphericity.

RESULTS

$P_{\max}$ values averaged across all participants for each task with a bare bulb and a gauze-covered bulb are plotted in Figure 3. $P_{\max}$ values were significantly greater in the gauze condition than in the bare-bulb condition when collapsed across task (Table 1, top). There was also a significant main effect for task, with the lowest $P_{\max}$ measured for posterior tongue elevation and the highest values for tongue protrusion. The interaction between the bulb condition and task was statistically significant.

Figure 3. Maximum pressure ($P_{\max}$) generated (best of three trials) by the tongue against an air-filled bulb averaged across 62 normal adults. The bulb was bare (grey bars) or loosely covered in a single layer of gauze (black bars). Error bars = +1 SD.

To determine which tasks contributed to the significant interaction, univariate tests were examined (Table 1, bottom). Significant differences between the bulb-cover conditions were found for both directions of tongue lateralization and tongue protrusion. Strength testing for tongue lateralization and protrusion conducted with a gauze-covered bulb yielded 12% greater $P_{\max}$ than with a bare bulb. There was a tendency for $P_{\max}$ to be greater in the

gauze condition for posterior tongue elevation as well.

For the subset of participants who returned for a second session, no significant differences occurred between sessions (Tables 2 and 3). The main effect for bulb-cover was significant for the lateralization and protrusion tasks. There were no significant interactions between session and cover for any task.

Table 1. RM-ANOVA results for overall model (N = 62) with bulb condition and task as within-subjects variables, and follow-up RM-ANOVA univariate tests with bulb condition as the within-subjects variable.

Within-Subjects Conditions	F	df	P	η^2
bulb	39.851	1, 61	< .0001*	.395
task	27.155	2, 158.2	< .0001*	.308
bulb x task	4.986	3, 204.9	.0016*	.076
* $p < .05$				
Task	F	df	P	d
anterior	1.608	1, 61	.2096	.161
posterior	6.797	1, 61	.0115	.326
right	21.979	1, 61	< .0001*	.592
left	21.375	1, 61	< .0001*	.580
protrude	22.097	1, 61	< .0001*	.593
* $p < .001$				

Table 2. Means (and SD) for test-retest reliability. $P_{\max}$ data (in kPa) for five tongue-strength tasks across two separate sessions by 12 participants.

Task	Session 1		Session 2	
	Bare	Gauze	Bare	Gauze
Anterior	59.6 (14.8)	58.5 (11.4)	57.8 (12.9)	58.6 (10.8)
posterior	52.2 (13.0)	56.3 (11.6)	55.3 (13.4)	54.8 (14.3)
Right	51.1 (12.8)	58.9 (15.5)	55.1 (11.4)	63.8 (15.1)
Left	52.8 (14.1)	62.8 (18.0)	58.4 (12.7)	67.3 (16.7)
Protrude	66.3 (15.6)	76.3 (12.9)	69.8 (13.0)	78.4 (12.5)

Table 3. Test-retest reliability conducted over two sessions with 12 participants. RM-ANOVA results with session and bulb-cover condition as within-subjects variables. Univariate results are listed for each tongue-strength task.

Task	Session		Cover		Session x Cover	
	F(1,11)	p	F(1,11)	p	F(1,11)	P
Anterior	0.454	.544	0.004	.952	0.373	.554
Posterior	0.148	.708	1.325	.274	2.242	.162
Right	3.875	.075	23.974	< .001*	0.035	.855
Left	6.228	.030	15.615	.002*	0.062	.808
Protrude	1.576	.235	11.951	.005*	0.163	.694

* $p < .01$

DISCUSSION

The results supported our hypothesis that $P_{\max}$ results are greater when the IOPI bulb was covered with gauze than when it was bare. Follow-up tasks revealed that this difference could be attributed to the lateralization and protrusion tasks, less so for the posterior-tongue elevation task, and not to the anterior-tongue elevation task. This research question was motivated by our own experience (Solomon et al., 2008), but it should be noted that previous authors have also commented on problems with tongue slippage (Adams et al., 2013; Hewitt et al., 2008; Yoshikawa et al., 2011). Interestingly, these studies involved only the tongue-elevation tasks, not the tasks for which our data revealed significant differences in $P_{\max}$. Yoshikawa et al. (2011) reported that the slippage was most problematic when attempting to place the bulb on the tongue in a precise anterior-posterior position so that they could use the IOPI bulb to validate a novel sensor. Hewitt et al. (2008) used the IOPI in a study of tongue-elevation strengthening exercises, and included an anecdotal report from one healthy adult who had difficulty doing the exercises because the bulb “slides around too much” (p. 21).

Recent efforts to address the issue of tongue slippage were presented by VanRavenhorst-Bell et al. (2019). They developed two types of anti-slip patches adhered to the IOPI bulb and evaluated $P_{\max}$ for anterior or posterior tongue elevation by 40 normal adults. There was no difference in $P_{\max}$ in either position with or without the patches. A self-report questionnaire revealed that participants preferred the bare bulb for comfort but preferred one of the anti-slip

patches on the bulb for retention of bulb placement and bulb stability. Similarly, participants in the present study often reported a perception of better and more stable contact between the tongue and bulb when gauze was used. VanRavenhorst-Bell et al. (2019) concluded that use of an anti-slip patch may improve the reliability of testing without affecting normative $P_{\max}$ values.

The present results do not support the hypothesis that results would be more consistent between two sessions when the tongue bulb was covered with gauze. As with the larger group, $P_{\max}$ values were greater for the lateralization and protrusion tasks when gauze was used, but there was no significant interaction between session and cover when 20% of the participants were retested during a separate session. In addition, informal comparison of variability across participants, as indicated by SD (Table 2), indicated no systematic differences across sessions or by varying the condition of the IOPI bulb. It is important to recall that these data reflect the maximum $P_{\max}$ value from three trials. It is possible that gauze might have yielded more stability between the three test trials for each maneuver. In practice, unacceptable differences between trials (>10%) are viewed as invalid and the task should be repeated until three comparable trials are obtained.

Although changes in $P_{\max}$ across sessions was not an objective of this study, it is interesting to note that the values did not increase significantly from Session 1 to Session 2 in the subset of participants included for reliability. Previous

research has reported increases in tongue-elevation $P_{\max}$ over two (Adams et al., 2014) or even three (O'Day et al., 2005; Weathers, 2000, as reported in O'Day et al.) sessions. These studies involved normal children (Weathers, 2000), normal young and middle-aged adults (Adams et al., 2014, O'Day et al., 2005), and older adults with Parkinson disease (O'Day et al., 2005). The reason for the lack of a difference in the present data is unclear but it could be due to the inclusion of additional tasks (lateralization and protrusion) such that the variability across tasks obscured the small difference for the elevation tasks in the statistical model. It is also possible that results might have changed over a greater number of sessions as participants would adapt to the task. Adams et al. (2015) examined reliability across four sessions in elderly adults and, although $P_{\max}$ values increased across the four sessions, changes were variable, small, and nonsignificant. Adams et al. (2014, 2015) concluded that the variability across time in their studies was within an acceptable degree of variability ($<10\%$ of $P_{\max}$). They also emphasize that familiarization with the method helped reduce variability.

Overall, the results from this study indicate that adding a textured surface to the IOPI bulb is unlikely to affect standard tongue-strength assessment, which currently involves only tongue elevation tasks. However, patients with suspected asymmetry in tongue strength might require a right-left comparison. Dworkin et al. (1980) compared tongue strength in 125 normal adults using strain-gauge transducers and found no difference when comparing right and left lateralization maneuvers. In our previous study, we also reported no significant right-to-left differences (Clark & Solomon, 2012). Tongue lateralization differed by 2.2% (1.2 kPa) between the sides when averaged across normal participants. In the present data subset, this difference was greater (4.0%, 2.2 kPa bare bulb; 4.2%, 2.6 kPa with gauze). More important for clinical interpretation, however, is the absolute difference between the sides. That is to say, the direction of the right-to-left and left-to-right differences cancel out when averaging results, but the absolute difference between the sides indicates when asymmetry exists in either direction. In the current data set, the median absolute difference between the two sides was 7.0 kPa (12.9%) with the bare bulb and 6.5 kPa (10.5%) with the textured bulb. This serves as a

reminder to clinicians that modest asymmetry for tongue-lateralization strength should be expected and is not necessarily a sign of impairment.

There are several potential limitations of this study. Participants did not receive thorough assessments for orofacial structure and function. This concern is mitigated for the most part because of the within-subjects design. A methodological concern is the possibility that the presence of the gauze could affect $P_{\max}$ results. The results provide evidence that this is not a concern since there was no significant difference between bulb-cover conditions for the tongue-elevation tasks. In addition, it is possible that the gauze did not entirely prevent slippage; this could not be confirmed with our current methods. Examining all three trials collected for each strength assessment would have been instructive for determining whether the gauze condition improved reliability across trials. A design limitation is that the study sample was predominately male, which was a practical result of the originating studies that included the bulb-cover manipulation. Fortunately, the male-female imbalance does not affect the present findings because there are no sex-differences for tongue-strength measures, and because the analyses involve within-subjects comparisons. In addition, the sample size for the test-retest reliability portion of the study was small; results of those analyses should be interpreted with caution. Finally, a practical limitation for future research and clinical applications is that the tongue-bulb holder is not currently being manufactured.

CONCLUSION

In conclusion, this study provided the first known empirical evidence that adding a slip-resistant texture to the IOPI bulb may help improve tongue-strength assessments in conditions that may be affected by slippage of the tongue on the bulb, especially during tongue lateralization and tongue protrusion. The typical tongue-strength task, anterior elevation, was not affected significantly by loosely wrapping the tongue bulb in gauze. Nonetheless, because previous literature has mentioned slippage problems with the bulb even during certain elevation tasks, it may be prudent to use a textured bulb in general.

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DISCLAIMER AND ACKNOWLEDGMENTS

The views expressed in this article are those of the authors and do not reflect the official policy of the Department of Army/Navy/Air Force, Department of Defense, or U.S. Government. The identification of specific products or scientific instrumentation is considered an integral part of the scientific endeavor and does not constitute endorsement or implied endorsement on the part of the author, DoD, or any component agency. We gratefully acknowledge Fletcher Hietpas, Matthew Makashay, and Caitlin Webb who contributed to data collection. This article is dedicated to Dr. Erich S. Luschei in appreciation for his mentorship, guidance, and unwavering support throughout our careers.

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