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Title: Pressure profile similarities between tongue resistance training tasks and liquid swallows

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A portion of these data, namely the pressure data on water and nectar-thick juice swallows, has been reported in a related manuscript in the *Journal of Speech-Language, Hearing Research*, 53(2), 273-283.

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Pressure profile similarities between tongue resistance training tasks and liquid swallows

Abstract

Tongue-pressure resistance training is known to increase tongue strength in seniors and individuals with stroke-related dysphagia. However, evidence of associated functional improvements in swallowing is equivocal. We investigated similarities in pressure waveform profiles between swallowing and several of tongue-palate pressure tasks to identify tasks that may be best-suited for inclusion in tongue-pressure resistance training protocols for patients who are unable to safely perform real bolus swallows in treatment. Tongue-palate pressures were recorded in twenty healthy, young adults. Participants performed water and nectar-thick juice swallows, effortful and non-effortful saliva swallows, and “half-maximum” tongue-palate partial-pressure tasks emphasizing either anterior or posterior tongue-palate contact at different speeds. Pressure slopes (amplitude change over time) during the pressure application (rise) and withdrawal (release) phases were analyzed. A subset of four tasks with the greatest similarity in slope characteristics to those seen in bolus swallows was identified: anterior half-maximum tongue-presses; posterior maximum tongue-presses; posterior half-maximum slow tongue-presses; and effortful saliva swallows. We propose that future research should explore the degree to which swallowing improvements are obtained from treatment protocols that emphasize these tasks.
Introduction

Tongue pressure resistance training has recently emerged as a treatment approach with potential to yield positive outcomes in adults with swallowing impairment involving tongue weakness. Both healthy seniors and individuals with stroke-related dysphagia have been found to experience significant gains in measures of maximum isometric tongue strength following an 8-week course of resistance exercise in which treatment focused on achieving strength targets in the range of 60-80% of maximum isometric pressure capacity\(^1,2\). However, evidence that these improvements generalize to swallowing remains equivocal. In a small sample of 10 stroke patients, Robbins and colleagues\(^2\) reported faster oral transit times and improvements in penetration-aspiration scores on thin liquid swallowing tasks at post-treatment videofluoroscopy, but changes in other impairments, such as pharyngeal residue remained elusive.

Within the speech-language pathology literature, interest in exercise-based approaches to speech and swallowing rehabilitation has been growing\(^1-8\). Proponents of an exercise-based approach advise that the basic tenants of exercise-based physical rehabilitation must be applied to speech and swallowing goals, to afford the best chance of successful outcomes\(^4,8\). Treatment should employ tasks that are highly specific to the task for which functional outcomes are desired (i.e., swallowing). Secondly, exercises must be practiced with sufficient intensity to induce fatigue. Finally, exercise must be practiced with sufficient frequency for sufficient duration to be likely to induce muscle changes. The previous studies by Robbins and colleagues\(^1,2\) adhere to the latter two of these principles; tongue strength changes are targeted by including 60 task repetitions daily, in the 60-80% range of maximum capacity, on non-consecutive days over an 8-week period. Furthermore, the Robbins protocol addresses the possibility that
resistance exercises should selectively target different regions of the tongue by dividing the exercise tasks equally into anterior-emphasis and posterior-emphasis tongue-palate press tasks. For the anterior-emphasis tasks, patients are instructed to place a pressure bulb in the front of the mouth and squeeze the bulb using the front of the tongue. For the posterior-emphasis tasks, the pressure bulb is positioned further back in the mouth, and patients are instructed to squeeze the bulb using the back of the tongue. However, the Robbins exercise protocol focuses exclusively on strength and does not include actual swallowing tasks, or other possible tongue-press tasks, such as those emphasizing precision, endurance or speed. The fact that swallowing pressures are known to fall well short of those pressures registered in maximum isometric tasks calls the into question the emphasis on strength goals and outcomes in this approach.

In our laboratory, we have been studying patterns of tongue-pressure application in swallowing and exploring tongue-pressure resistance training as a method for effective swallow rehabilitation. Our primary goal is to restore functional swallowing with thin liquids. We have been particularly interested in the possible contribution of motor skill to tongue pressure application, inspired by evidence from other rehabilitation literature that skill training (involving the repeated practice of goal-oriented tasks) can lead to faster and more sustainable changes in motor function than strength training alone. Skilled movements are defined as those movement tasks that require the modification and organization of muscle synergies into effective movement sequences. Our interest in this concept led us to develop a tongue resistance training protocol that involves repeated practice of sub-maximal partial pressure generation tasks, with an emphasis on pressure precision. The lack of clear evidence of generalization from improved pressure outcomes to improved swallowing outcomes in these cases, prompted us to investigate pressure profiles more closely and to explore the role of timing (and temporal modulation) as...
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a factor in tongue-pressure behavior in swallowing. Systematic variations in the temporal
aspects of tongue-pressure onset and withdrawal between water and nectar-thick juice swallows
have recently been described in healthy young adults\textsuperscript{13}. The rise and release phases of tongue-
apalate pressure behavior may logically be considered to have primary salience for propulsion of a
bolus through the mouth towards the pharynx in swallowing\textsuperscript{14-16}. This observation supports the
speculation that treatment tasks that most closely match the slope characteristics (i.e., amplitude
changes over time) of both tongue-pressure application and release in healthy swallowing may
be optimal tasks to include in a program of swallowing rehabilitation. Although true task-
specificity for swallowing would require actual swallows, the idea that some non-swallowing
tongue-press tasks might closely mirror critical aspects of the tongue-pressure motor pattern seen
in swallowing is important, given that many patients who aspirate may be unable to safely
include bolus swallows in their swallowing rehabilitation regime.

The goal of the current study was to explore similarities in tongue-pressure profile
between liquid swallowing tasks and various tongue-press tasks in healthy adults, based on 3
specific criteria: a) whether pressures are registered in the same locations on the palate; b) the
rate of amplitude change at the anterior palate during the pressure onset phase (rise slope); and c)
the rate of amplitude change at the posterior palate during the pressure release phase (release
slope) (see Figure 1). For the current study, we studied partial-pressure amplitude targets in the
range of 50\% of each participant’s maximum isometric pressure capacity (henceforth called
“half-maximum tongue-press” tasks). The choice of this target range was motivated by previous
evidence showing that habitual swallowing pressures typically fall in or below this half-
maximum range\textsuperscript{9}. 


Discrete liquid swallowing tasks were performed with two stimuli: water (DSW) and nectar-thick apple juice (DSANEC). Comparator tasks included both anterior-emphasis tasks, for which the front of the tongue is pressed up against the front of the palate (the alveolar ridge, just behind the upper incisors), and posterior-emphasis tasks, for which the back of the oral tongue is pressed up against the back of the palate (targeting the anatomical region around the transition from the hard to soft palate). Task instructions for the following comparator tasks are detailed in Table 1: anterior emphasis half-maximum tongue-press tasks (AHMAX); posterior-emphasis maximum effort tongue-press tasks (PMAX); posterior emphasis half-maximum tongue-press tasks (PHMAX); non-effortful saliva swallows (NESS)\textsuperscript{13,15}, and effortful saliva swallows (ESS)\textsuperscript{13,15}. The half-maximum tongue-press tasks were conducted at habitual (AHMAX; PHMAX), fast (AHMAXFAST; PHMAXFAST) and slow (AHMAXSLOW; PHMAXSLOW) rates.

Methods

Participants

Twenty healthy adults (10 male, 10 female), under the age of 40, provided written consent for participation in the study. Participants attended an intake session in which an oral mechanism examination and a swallow screening were performed to rule out clinical signs of swallowing difficulty. Participants with known histories of swallowing difficulties, stroke, brain injury, neurodegenerative disease, or head and neck cancer were excluded. The study was approved by the Toronto Rehabilitation Institute Research Ethics Board. Data were collected using the orolingual manometry module of the KayPentax Digital Swallow Workstation (KayPentax, Lincoln Park, NJ). A soft plastic strip containing 3 silicon air bulbs (diameter: 13 mm; inter-bulb spacing: 8 mm) was adhered to each participant’s palate in
midline using a small amount of a cyanoacrylate dental adhesive (Iso-Dent, Ellman International Inc., Oceanside, NY). The strip was positioned such that the anterior bulb was located immediately behind the front teeth. Pressures from the anterior, medial and posterior palatal bulbs were registered on a monitor in a window with a 500 mm Hg maximum, and sampled at 250 Hz. For a few participants, it became obvious that maximum pressures exceeded 500 mm Hg, in which case the equipment was adjusted to allow a maximum of 750 mm Hg. Equipment was calibrated at the beginning of each recording session as per manufacturer’s instructions. Prior to attaching the tongue-bulb array, task-training was provided. Participants were taught to perform maximum emphasis anterior and posterior emphasis tongue presses and immediate feedback regarding pressure values was provided using the Iowa Oral Performance Instrument (IOPI). Participants were then instructed in the performance of half-maximum tongue-press tasks, again using the IOPI for biofeedback. The experiment then proceeded using the KayPentax equipment to register tongue-palate pressures. Participants were instructed to perform the different experimental tasks in randomized order, with 5 repetitions per task, to enable the calculation of representative task mean data values for each participant. Previous literature regarding intra-participant variability in swallowing suggests that at least 3 repetitions of a given swallowing task are required to obtain representative tongue-pressure measures. Instructions were displayed in front of the participant on a computer monitor, so that mandatory quiet rest periods could be interspersed between tasks. For the saliva swallow tasks, one swallow was cued every 30 seconds, for a total signal recording time of 2 minutes, 30 seconds per task. This ensured a rest period between swallows to allow for saliva replenishment. The bolus swallow and tongue-press tasks were performed at a natural pace, unless the task instructions specifically indicated that the participant was to perform rapid or slow half-
maximum tongue-presses. For the bolus swallow tasks, participants were provided with a cup containing approximately 150 ml of water or nectar-thick apple-juice (Resource™, Nestlé Nutrition, Highland Park, MI) and cued to take 5 comfortably-sized sips of liquid in a row from the cup, performing one discrete swallow per sip, and then removing the cup from their lips before the next swallow. Precise sip-volume measurement techniques cannot easily be employed during the collection of natural reiterated discrete swallowing data. However, based on previous studies using these same tasks, it can be assumed that sip size in this study fell between 5 and 10 ml per swallow, and likely varied less than 2 ml from swallow to swallow within a participant.

Data Processing

The first step in data processing was to index important events in the pressure waveforms. This task was completed by two trained research associates who aligned a cursor in the KayPentax manometry software with the onset, peaks and offsets of pressure events in each pressure waveform. For each event, the timepoint (in milliseconds) and pressure amplitude (in mm Hg) was recorded in a spreadsheet for subsequent analysis. Ten percent of the data were indexed in duplicate for the purposes of calculating inter-rater agreement, which was excellent (Intra-class correlation = 1.00). Due to a technical problem with the pressure measurement equipment, data for one male participant could not be included in the analysis. Pressure amplitude differences in mm Hg (henceforth called range), durations (in milliseconds) and slopes (range divided by duration, in mm Hg per second) were calculated for the anterior pressure bulb rise-phase (pressure onset to pressure peak at the anterior bulb) and posterior pressure bulb release-phase (pressure peak to pressure offset at the posterior bulb) of each pressure event. Prior to further analysis, all range data were normalized relative to a standardized value of 600 mm Hg.
assigned to the peak maximum anterior isometric pressure rise-range value registered at the anterior pressure bulb for each participant:

\[
\text{Normalized pressure range} = \frac{\text{Pressure range}}{\text{Maximum Isometric Pressure range}} \times 600
\]

Normative values for maximum isometric pressures at the anterior palate have previously been reported to fall at approximately 600 mm Hg for healthy young adults\(^9\).

**Analysis**

The analysis for this study was conducted in a stepwise fashion. First, chi-square statistics were used to compare the frequency with which activation of both the anterior and posterior pressure bulbs occurred in the different tasks included in the study. Descriptive statistics for rise slope and release slope were then examined, and Forest Plots showing 95% confidence interval overlap across tasks were prepared (Figures 2 and 3). To further examine task differences statistically, two mixed model analysis of variance models (rise slope; release slope) were run using the mixed procedure in SPSS 16.0 (SPSS, Inc., 2007). Both models controlled for the within-subjects nature of the eleven tasks by including random effects for participant and the participant X task interaction, with a variance components covariance structure and restricted maximum likelihood estimation. Furthermore, rather than using the mean response of the five replicate trials for each swallowing task as the experimental unit, which ignores variability among replications, we captured the variation among the trials directly by modelling the variance-covariance matrix of the residuals on each task for each participant. The best-fitting covariance structure for the residuals across trials was a diagonal structure, which
estimated a unique variance for each trial, but had no additional correlation among these residuals. Autoregressive and compound symmetry covariance structures were tested, but neither resulted in improved fit of the model, so the simpler diagonal structure was retained (-2RLL = 7607.58). Sex was included as a fixed, between-subjects factor to both models, but there were no significant main effects in either one (rise slope: $F(1, 14.4) = 0.112, p = 0.743$; release slope $F(1, 16.47) = 0.354, p = 0.56$). Consequently, the sex factor was dropped from the model. Post-hoc tests compared each of the nine pressure tasks to each of the two bolus swallowing tasks (DSW and DSANEC), using Sidak adjustments to control for Type I error. The nine pressure tasks were not compared to each other, since these comparisons were not of interest.

Results

The water, and nectar-thick apple juice swallowing tasks typically elicited activation of both the anterior and posterior pressure bulbs. The saliva swallow tasks presented with this same activation pattern at least 94% of the time. By contrast, the anterior half-maximum tongue-press tasks were significantly less likely to display activation of both bulbs ($\chi^2, df = 10, = 424.43, p = 0.000$) and involved isolated activation of the anterior bulb at least 84% of the time. The posterior maximum tongue-press task most commonly elicited co-activation of both bulbs (77% of the time), with the remaining cases involving isolated posterior bulb activity. The posterior half-maximum tongue-press tasks involved co-activation of both bulbs between 50% and 56% of the time, and isolated posterior activation 35-47% of the time.

The activation pattern comparison suggested that anterior-emphasis half-maximum tongue-press tasks were dissimilar from swallowing tasks in their tongue-pressure profiles. This was further confirmed in the descriptive statistics (Table 2) and the Forest Plot comparisons of rise and release-slope confidence interval overlaps. These suggested that the AHMAX and
PMAXTP tasks had similar rise-slopes to the water and nectar-thick swallows (Figure 2), while the ESS and PHMAXSLOW tasks overlapped with the water and nectar-thick juice swallows for release-slope (Figure 3).

In the mixed model ANOVAs, a significant main effect of task was found in the rise slope data, $F(10, 129.18) = 12.74, p < 0.001)$. The AHMAXFAST task had a significantly greater rise slope than both discrete water ($p < .001$) and nectar-thick apple juice ($p < .001$) swallowing tasks. None of the other tasks showed significant differences in pairwise comparisons to the water and nectar-thick juice swallows.

A significant main effect of task was also found in the release slope data, $F(7, 82.52) = 16.78, p = 0.000)$. The smaller value for the error degrees of freedom in this analysis reflects exclusion of the anterior-emphasis half-maximum tongue-press tasks from the model, based on the fact that these involved no activation of the posterior pressure bulb. Posthoc pairwise comparisons identified significant differences between discrete water swallows and the PHMAX ($p < 0.007$), PHMAXFAST ($p < 0.000$) and PMAXTP ($p < 0.000$) tasks. Significant pairwise differences from the nectar-thick juice swallows were also found for the PHMAXFAST ($p < 0.000$) and PMAXTP ($p < 0.011$) tasks.

In summary, all tasks other than the AHMAXFAST task were found to have statistical similarity (or non-difference) from water and nectar-thick juice swallows with respect to rise slope. Of these, inspection of confidence interval overlaps suggests that the AHMAX and PMAXTP tasks have rise slope values that fall closest to those seen in liquid swallowing tasks.

With respect to release slope, clear differences were noted between liquid swallowing tasks and the AHMAX (regular rate, slow and fast), PHMAX, PHMAXFAST and PMAXTP tasks. This leaves the non-effortful and effortful saliva swallow tasks and the posterior half-maximum slow
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1 task, which demonstrated statistical non-difference from the liquid swallowing tasks. Of these, confidence interval overlaps were strongest for the effortful saliva swallows and PHMAXSLOW task.

Discussion

The primary goal of this study was to identify those tongue resistance training tasks that most closely resemble bolus swallows in their pressure slope rise and release characteristics, so that these tasks might become a focus in future swallowing treatment studies. We have demonstrated that in healthy young adults, the rise slope characteristics of anterior emphasis half-maximum tongue-press tasks (AHMAX) and posterior-emphasis maximum effort tongue-press tasks (PMAXTP) are most similar to those seen in water and nectar-thick juice swallows. Similarly, the slope characteristics of pressure release in saliva swallowing tasks (non-effortful and effortful) and slow posterior-emphasis half-maximum tongue-press tasks (PHMAXSLOW) are similar to those seen in liquid swallowing tasks. As an outcome of this study, we propose that future research should explore the potential of treatment protocols emphasizing these tasks, (i.e., with slope profiles that are not significantly different from those seen in healthy swallowing), to yield improvements that generalize to functional swallowing. It must, of course, be recognized that the absence of significant differences in an ANOVA test cannot be interpreted to imply equivalence across the tasks that were compared in this study. The current findings, therefore, represent preliminary evidence that requires further substantiation.

It is of interest to note that the pressure ranges registered during discrete water and discrete nectar-thick swallowing tasks in this experiment fell well short of maximum isometric
pressure values (normalized to a value of 600 mm Hg) consistent with previous studies\textsuperscript{9}. This phenomenon appears to have occurred to a greater degree in our research participants than previously described in the literature. The healthy young adults in this study registered swallowing pressure amplitudes in the range of only 10\% -15\% of maximum isometric values, i.e. pressures of 50-100 mm Hg or 6-12 KPa), normalized using a standardized maximum isometric pressure value of 600 mm Hg. Previous studies have observed a higher range of swallowing pressures approaching 50\% of maximum values\textsuperscript{9}. One possible explanation for this apparent discrepancy is the fact that the current study did not involve radiation exposure, thereby allowing greater (and perhaps more representative) sampling of behavior across repeated task performances. However, this finding also suggests that the ideal magnitude of partial-pressure targets requires further study. Our study explored pressure profiles for half-maximum tongue-press tasks. It remains unknown whether tongue-press tasks targeting values in the 10-25\% maximum range, or those targeting values in the >50\% maximum range may have slope profiles that differ from swallow pressure slope profiles to an even smaller extent. At this point it is clearly premature to speculate on the ideal magnitude of partial pressure task targets.

A second observation of importance in this study, as shown in Table 2, is that half-maximum tongue-press tasks with anterior emphasis typically result in pressure patterns with little or no activity registered at the medial and posterior palate bulb locations. Posterior-emphasis half-maximum tasks failed to involve anterior bulb activation in a substantial number of our participants. This suggests that these tasks elicit pressure patterns that are questionably similar to those seen in normal swallowing tasks and further supports our concern that they may not have sufficient similarity in slope characteristics to bolus swallows for inclusion in tongue-resistance training protocols for swallow-rehabilitation.
Non-effortful saliva swallows yielded quite different pressure patterns than bolus swallows in this study. Specifically, both the rise and release phases of pressure were prolonged in the NESS task; consequently, the slopes of pressure rise and release at the anterior and posterior pressure bulbs, respectively, were found to be significantly less steep than those observed in bolus swallows. This finding suggests that there may be a particular salience to the parameter of pressure slope for swallowing function in the presence of a bolus, and that it may not be adequate to focus exclusively on pressure range as a therapeutic target.

Inspection of the descriptive statistics in Table 2 shows that pressure slopes were steeper in the rise phase for discrete water swallows than for discrete nectar-thick juice swallows, while the reverse phenomenon (steeper release) was observed with the nectar-thick stimuli. This difference, which was in the order of 20-120 mm Hg/sec, requires further investigation because it may reflect an important modulatory factor in swallowing related to the precision of slope application and release across stimuli of differing viscosity. Furthermore, this suggests that pressure withdrawal by the posterior tongue may be a particularly important component in swallowing function. Pressure withdrawal has not, to our knowledge, been targeted in tongue resistance training protocols to date.

Clearly, a major issue with respect to the interpretation of this study is the fact that these pressure phenomena were measured in healthy adults. It remains unknown whether people with swallowing impairment involving tongue weakness will demonstrate similarities in pressure profiles across tasks in the same manner. A broader sampling of healthy adults across the age span will also be needed in order to establish normative ranges for adults of different ages with respect to pressure slope parameters. These considerations precluded the direct application of these findings to patient populations. Nonetheless, we speculate that if patients with dysphagia...
are found to have deviant pressure slopes, a meaningful goal of swallowing intervention would be to attempt to establish more normative pressure slope patterns. The findings of the present study serve to inform such future efforts, and suggest that an emphasis on tasks with slope characteristics similar to those seen in healthy swallowing may be an appropriate place to start.

Conclusion

In conclusion, this study has identified a subset of tongue-pressure resistance training tasks, which display pressure slope characteristics similar to those typically seen in water and nectar-thick liquid swallows. Saliva swallows were also found to yield pressure release slope profiles that closely resemble those typically seen in water and nectar-thick liquid swallows. We conclude that protocols for tongue-resistance training in individuals with dysphagia should incorporate these tasks to a substantial extent, if a goal of treatment is to include tasks that are similar to swallowing.
Acknowledgments:
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References


Figure 1. Screen capture of anterior and posterior pressure bulb waveforms during an anterior tongue press task. Onsets, offsets and peak pressures are denoted in each waveform by dashed vertical lines. The portion of the anterior bulb waveform from pressure onset until peak pressure is the rise phase. The portion of the posterior bulb waveform following the peak, until return to signal baseline, is the release phase. Pressure slope for these phases was calculated as the change in signal amplitude (in mm Hg) divided by the phase duration (seconds).
Forest plot showing the overlap in means and 95% confidence intervals for tongue pressure rise slope, measured at the anterior palate, during 11 different tasks: DSW (discrete water swallows); DSANEC (discrete nectar-thick apple juice swallows); NESS (non-effortful saliva swallows); ESS (effortful saliva swallows); AHMAXSLOW (anterior emphasis half-maximum tongue palate presses performed at a slow rate); AHMAX (anterior emphasis half-maximum tongue palate presses); AHMAXFAST (anterior emphasis half-maximum tongue palate presses performed at a fast rate); PHMAXSLOW (posterior emphasis half-maximum tongue palate presses performed at a slow rate); PHMAX (posterior emphasis half-maximum tongue palate presses); PHMAXFAST (posterior emphasis half-maximum tongue palate presses performed at a fast rate); and PMAXTP (posterior emphasis maximum isometric tongue palate presses). The dashed lines outline the interval capturing rise slope values for discrete water and nectar-thick juice swallows. Tasks with means and confidence interval boundaries falling outside these lines differ from these bolus swallowing tasks in rise slope.
Figure 3.

Forest plot showing the overlap in means and 95% confidence intervals for tongue pressure release slope, measured at the posterior palate, during 8 different tasks: DSW (discrete water swallows); DSANEC (discrete nectar-thick apple juice swallows); NESS (non-effortful saliva swallows); ESS (effortful saliva swallows); PHMAXSLOW (posterior emphasis half-maximum tongue palate presses performed at a slow rate); PHMAX (posterior emphasis half-maximum tongue palate presses); PHMAXFAST (posterior emphasis half-maximum tongue palate presses performed at a fast rate); and PMAXTP (posterior emphasis maximum isometric tongue palate presses). The dashed lines outline the interval capturing release slope values for discrete water and nectar-thick juice swallows. Tasks with means and confidence interval boundaries falling outside these lines differ from these bolus swallowing tasks in release slope.
Table 1. Experimental instructions

<table>
<thead>
<tr>
<th>Task</th>
<th>Instruction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum isometric pressure, anterior emphasis (AMAXTP)</td>
<td>Press the front of your tongue up to the front of your palate (touching the bony ridge just behind your upper teeth) as hard as you can. We will be calling this the “front position”.</td>
</tr>
<tr>
<td>Discrete water swallow (DSW)</td>
<td>Take and swallow one sip of water, then remove the cup from your lips.</td>
</tr>
<tr>
<td>Discrete nectar-thick apple juice swallow (DSANEC)</td>
<td>Take and swallow one sip of this thick apple-juice, then remove the cup from your lips.</td>
</tr>
<tr>
<td>Non-effortful saliva swallow (NESS)</td>
<td>Swallow your saliva as you usually do.</td>
</tr>
<tr>
<td>Effortful saliva swallow (ESS)</td>
<td>Do a “hard” saliva swallow. Imagine that you are swallowing a whole grape.</td>
</tr>
<tr>
<td>Half-maximum anterior emphasis tongue-press (AHMAX)</td>
<td>In the front position you were able to hit a _____ kPa on your maximum effort tongue-press. Now I want you to aim for half of that value. So, try to hit a _____ kPa in the front position.</td>
</tr>
<tr>
<td>AHMAXSLOW</td>
<td>Your half maximum target value in the front position is _____ kPa. We now want you to complete this task slowly. We want you to gradually reach ____kPa. Try to make the numbers move up one at a time.</td>
</tr>
<tr>
<td>AHMAXFAST</td>
<td>Your half maximum target value in the front position is ____kPa. We now want you to complete this task fast. We want you to hit that same target of ____ kPa again but this time in a quick, fluid movement.</td>
</tr>
<tr>
<td>Maximum isometric pressure, posterior emphasis (PMAXTP)</td>
<td>Now you are going to perform a maximum effort press in the back position. Move the bulb about an inch further back from the front position. Then push straight up with the body of your tongue and squeeze the air out of the bulb against the roof of your mouth. Squeeze as hard as you can.</td>
</tr>
<tr>
<td>Half-maximum posterior emphasis tongue-press (PHMAX)</td>
<td>In the back position you were able to hit a _____ kPa on your maximum effort tongue-press. Now I want you to aim for half of that value. So, try to hit a _____ kPa in the back position.</td>
</tr>
<tr>
<td>PHMAXSLOW</td>
<td>Your half maximum target value in the back position is ____ kPa. We now want you to complete this task slowly. We want you to gradually reach ____ kPa. Try to make the numbers move up one at a time.</td>
</tr>
<tr>
<td>PHMAXFAST</td>
<td>Your half maximum target value in the back position is ____ kPa. We now want you to complete this task fast. We want you to hit that same target of ____ kPa again but this time in a quick, fluid movement.</td>
</tr>
</tbody>
</table>
Table 2.

<table>
<thead>
<tr>
<th>Task</th>
<th>Phase</th>
<th>Range (mm Hg⁺)</th>
<th>Duration (ms)</th>
<th>Slope (mm Hg/s)</th>
</tr>
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<tbody>
<tr>
<td></td>
<td></td>
<td>Mean</td>
<td>Std. Deviation</td>
<td>Mean</td>
</tr>
<tr>
<td>Discrete Water Swallows (DSW)</td>
<td>Rise</td>
<td>61.80</td>
<td>83.82</td>
<td>220.18</td>
</tr>
<tr>
<td></td>
<td>Release</td>
<td>65.39</td>
<td>64.68</td>
<td>274.53</td>
</tr>
<tr>
<td>Nectar-thick Apple Juice Swallows (DSANEC)</td>
<td>Rise</td>
<td>74.00</td>
<td>86.82</td>
<td>276.94</td>
</tr>
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<td></td>
<td>Release</td>
<td>77.77</td>
<td>58.40</td>
<td>257.51</td>
</tr>
<tr>
<td>Non-effortful Saliva Swallows (NESS)</td>
<td>Rise</td>
<td>108.82</td>
<td>119.87</td>
<td>569.86</td>
</tr>
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<td></td>
<td>Release</td>
<td>75.74</td>
<td>103.05</td>
<td>422.24</td>
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<tr>
<td>Effortful Saliva Swallows (ESS)</td>
<td>Rise</td>
<td>264.12</td>
<td>313.65</td>
<td>622.16</td>
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<tr>
<td></td>
<td>Release</td>
<td>145.27</td>
<td>143.26</td>
<td>483.99</td>
</tr>
<tr>
<td>Anterior Half Maximum Tongue Press (AHMAX)</td>
<td>Rise</td>
<td>302.98</td>
<td>125.84</td>
<td>987.66</td>
</tr>
<tr>
<td></td>
<td>Release</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Anterior Half Maximum Fast Tongue Press</td>
<td>Rise</td>
<td>345.80</td>
<td>144.42</td>
<td>443.84</td>
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*normalized vs. maximum anterior palate isometric pressure of 600 mm Hg