# NEGATIVE PRESSURE AND MUSCLE ACTIVITY DURING DISCRETE SIPS FROM HIGH RESISTANCE STRAWS

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## ABSTRACT

The purpose of the current investigation was to explore how intra-oral negative pressure and submental muscle activity vary across sips from straws varying in internal diameter and across conditions of low versus high effort. Healthy adults took discrete sips from four straws varying in internal diameter. Sips were performed under normal and high effort conditions. Submental surface electromyography (sEMG) and negative intra-oral pressure were recorded during sips. Significant main effects of straw condition were observed for negative intra-oral pressure. A non-significant trend for increased muscle activity associated with smaller straw diameter was also observed. Significant main effects of effort condition were observed for both submental sEMG and negative intra-oral pressure. The findings are interpreted as supporting the clinical hypothesis that high resistance drinking straws varying in diameter may offer systematic overload to the oral musculature. The findings also support encouraging maximum effort to achieve even further overload.

**KEY WORDS:** Resistance straws, straw drinking, muscle activity, suction, negative pressure

## INTRODUCTION

### Negative Pressure and Muscle Activity during Discrete Sips from High Resistance Straws

Straw drinking requires creating negative air pressure to cause liquid to flow through a tube against gravity. Subjectively, straws with narrow diameters require the user to suck with greater effort, presumably because greater negative pressures are need to overcome the higher resistance offered by the smaller straws. This observation has led clinical innovators to propose the use of straws offering systematically increasing resistance as a means of strengthening the oral musculature (Rosenfeldt-Johnson, 2001; Smead, 2010). Although a number of aspects of physiology associated with straw drinking have been described in the literature, no studies have explored the effects of systematic variations in straw diameter. The current study examined intra-oral negative pressure and submental muscle activity associated with discrete sips from straws varying in internal diameter.

Within the context of deglutition, negative intra-oral pressure is achieved by retracting and depressing the tongue while maintaining an anterior and lingua-velar seal, thereby increasing volume of the oral cavity (Rushmer & Hendron, 1951; Thexton, Crompton, & German, 1998). Negative intra-oral pressures associated with straw drinking have been reported by Nilsson and colleagues (Nilsson, Ekberg, & Hindfelt, 1995; Nilsson, Ekberg, Olsson, & Hindfelt, 1996a, 1996b, 1998; Nilsson, Ekberg, Olsson, Kjellin, & Hindfelt, 1996). These investigators provide important data indicating that the ability to generate negative intra-oral pressure is a physiologic competence that varies across the lifespan (Nilsson, Ekberg et al., 1996a; Nilsson, Ekberg, Olsson, Kjellin et al., 1996) and may be negatively impacted by the presence of disease (Nilsson, Ekberg et al., 1996b; Nilsson et al., 1998).

Previous studies have also described muscle activity in the lips and in the submental region associated with sipping from straws (Ahlgren, 1995; Murray, Larson, & Logemann, 1998) and during suckling (Thexton et al., 1998). There is evidence that increased negative pressure generation is associated with greater perioral muscle activity during sucking on a cigarette and while sucking air through a straw (Mueller, Mucha, & Pauli, 2003), but similar data are lacking with regard to sipping liquid

from straws. An association between submental muscle activity and negative pressure generation has not been documented. However, a pair of studies demonstrated that the lowest tongue movement, as observed by ultrasound, corresponded to peak negative intra-oral pressure during breast-feeding (Geddes, Kent, Mitoulas, & Hartmann, 2008; Geddes et al., 2012). To the extent that surface electromyography (sEMG) of the submental region is sensitive to activity of the hyoglossus during sucking, it would be predicted that increased negative pressure generation would be associated with increased submental sEMG.

A secondary goal of the current project was to explore the effects of a specific clinical innovation. The TheraSIP™ Swallowing Treatment was developed by Speech and NeuroRehab (Pensacola, FL). The system utilizes straws varying in internal diameter and thus offering variable levels of resistance. The therapeutic protocol recommended by Speech and NeuroRehab requires patients to sip from the straws with maximum effort. There is initial evidence demonstrating increased peri-oral muscle activity when participants were instructed to suck "harder" on cigarettes or to suck air through a straw (Mueller et al., 2003).

The current project examined negative intra-oral pressure and submental muscle activity during discrete sips from straws varying in internal diameter performed under two effort conditions. The following hypotheses were tested: 1) Smaller straw diameters will be associated with greater negative intra-oral pressures and higher submental muscle activity; and 2) High-effort sips will be associated with greater negative intra-oral pressures and higher submental muscle activity relative to normal effort sips.

## METHOD

### Participants

This study involved 41 participants with negative histories for speech or swallowing difficulties. Five males (mean age 34, range 22-50) and 36 females (mean age 22.3, range 18 - 59) participated. All participants exhibited grossly normal orofacial structure and function as judged by the examiner and adequate hearing and language capabilities for completing the assessment tasks. Due to data loss (see below), the final sample included four males (mean age 37, range 23-50) and 18 females (mean age 22.7, range 18-59).

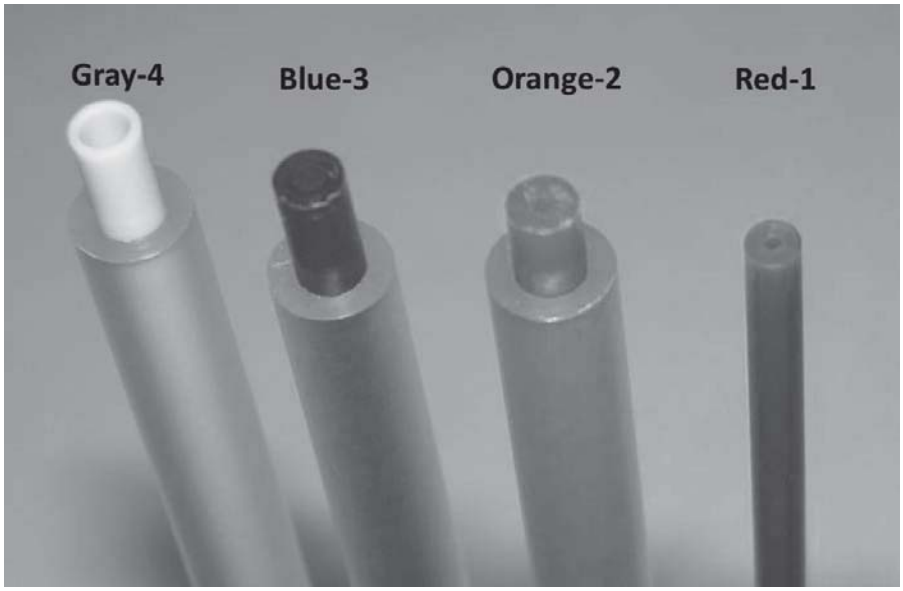
### Materials and Procedures

The experiments utilized the TheraSip drinking straws that vary in internal diameter (Table 1), and are considered "high resistance" because anecdotal reports suggest these straws require high effort to draw liquid. For the current report, each straw is designated by color and by relative internal diameter (e.g., Gray-4 denotes the straw with the largest diameter; Red-1 denotes the straw with the smallest diameter). The three largest straws (gray-4, blue-3, and orange-2) are encased within a larger straw with an external diameter of 5 mm. The smallest diameter straw, red-1, does not have a similar encasement, thus the external diameter of this straw (2 mm) is smaller than the others (Figure 1).

**TABLE 1. Straw Characteristics**

| Straw Identifier | Dimensions (Internal Diameter x Length) (mm) |
|---|---|
| **Gray-4** | 2.0 x 260 |
| **Blue-3** | 1.25 x 260 |
| **Orange-2** | 0.75 x 260 |
| **Red-1** | 0.65 x 260 |

**Figure 1. High Resistance Straws**




Each participant performed the sipping tasks using four high resistance straws and a graduated cylinder containing 100mL of water. In the normal effort condition, the participant was instructed to "take one sip, as normally as possible." In the high effort condition, the participant was instructed to take "one sip, sucking as hard as you can." Each straw condition was performed with two normal effort trials followed by a single high effort trial. Measures obtained for the two normal effort trials in each condition were averaged prior to final analysis. The order of straws was counterbalanced across participants.

Intra-oral negative pressure was measured via the Iowa Oral Performance Instrument (IOPI, IOPI Medical, Carnation, WA). This system is comprised of a soft air-filled bulb coupled to a pressure transducer. The bulb compresses when positive pressure is applied and expands in the context of negative pressure, thereby providing an indirect measure of the magnitude of negative intra-oral pressure. The IOPI tongue bulb was positioned on the anterior hard palate. To limit the effect of positive lingua-palatal pressure that could mask negative intra-oral air pressures, participants were instructed to avoid tongue to bulb contact while they drew liquid from the straws. The waveform generated by the IOPI was digitally sampled by the DSS at 4000 Hz and recorded simultaneously with the submental sEMG signal.

Submental sEMG was recorded using surface electrodes attached below the chin at midline with the two recording leads positioned horizontally in the anterior position and the grounding lead in the posterior position. Signals were digitized at a sampling rate of 250 Hz. The sEMG waveform associated with each sip was identified for analysis. The initiation of the sip was defined as the point at which negative pressure was first detected in the pressure wave. The end of the sip was

defined as the onset of rapid change to positive lingua-palatal pressure associated with swallowing. Peak negative oral pressure and area under the curve (AUC) sEMG during each sip trial was recorded. This measure was selected as the variable of interest because it reflects both intensity and duration of muscle activity. The raw sEMG values were normalized relative to the highest peak sEMG recorded across all tasks completed. Reliability data for the above analyses were obtained by having two independent raters extract data from the waveforms for twelve (29%) randomly selected participants. Intra-class correlations showed good agreement between the two raters (Cronbach's alpha = .931).

For 120 trials (36.5% of all trials), the oral pressure waveform did not drop below 0 kPa, suggesting that tongue-to bulb contact had masked the much smaller negative pressures created to draw liquid from the straw. The absence of a negative pressure trace further prevented identification of the initiation and completion of the sip necessary for selecting the sEMG waveform for analysis. Therefore, negative pressure and submental sEMG data for a given subject were included in the final analysis only if at least one trial in each straw and effort condition included measurable negative pressure. Data from 22 participants met this criterion.

To accommodate multiple significance tests, a significance level of .001 was adopted for all tests of main effects. Follow-up comparisons utilized family-wise error rates with a significance level of .05.

## RESULTS

**Negative Intra-oral Pressure**

The mean peak negative intra-oral pressures associated with sips from each of the high resistance straws under normal and high effort conditions are listed in Table 2. Repeated measures ANOVA revealed main effects of straw condition [$F(3, 63) = 6.86$, $p = .000$] and effort [$F(1, 21) = 76.005$, $p = .000$] with no significant interaction (Figure 2). Bonferroni follow-up comparisons revealed the Gray-4 straw elicited significantly smaller negative pressures than the Orange-2 and Red-1 straws.

**Submental Muscle Activity**

The mean normalized submental muscle activity (AUC) associated with sips from each of the high resistance straws under normal and high effort conditions are listed in Table 2. Repeated measures ANOVA revealed no main effect of straw condition [$F(3, 63) = 4.59$, $p = .008$] but a significant main effect of effort [$F(1, 21) = 76.96$, $p = .000$] with no significant interaction (Figure 3).

**Table 2. Volume, Negative Pressure, and Muscle Activity Associated with Each Straw**

| | Peak Negative Pressure Mean (SD) (kPa) | | Normalized Submental Muscle Activity Mean AUC (SD) (microvolts) | |
|---|---|---|---|---|
| **Straw** | **Low Effort** | **High Effort** | **Low Effort** | **High Effort** |
| **Gray-4** | -4.13 (3.53) | -8.15 (3.48) | .320 (.204) | .596 (.276) |
| **Blue-3** | -5.34 (2.78) | -8.75 (3.13) | .433 (.189) | .696 (.241) |
| **Orange-2** | -5.83 (2.68) | -10.37 (2.60) | .377 (.149) | .800 (.262) |
| **Red-1** | -6.12 (2.38) | -9.3 (3.12) | .596 (.276) | .689 (.226) |

**Figure 2. Mean peak negative pressures generated during sips from straws varying in diameter and during normal and high effort sips**

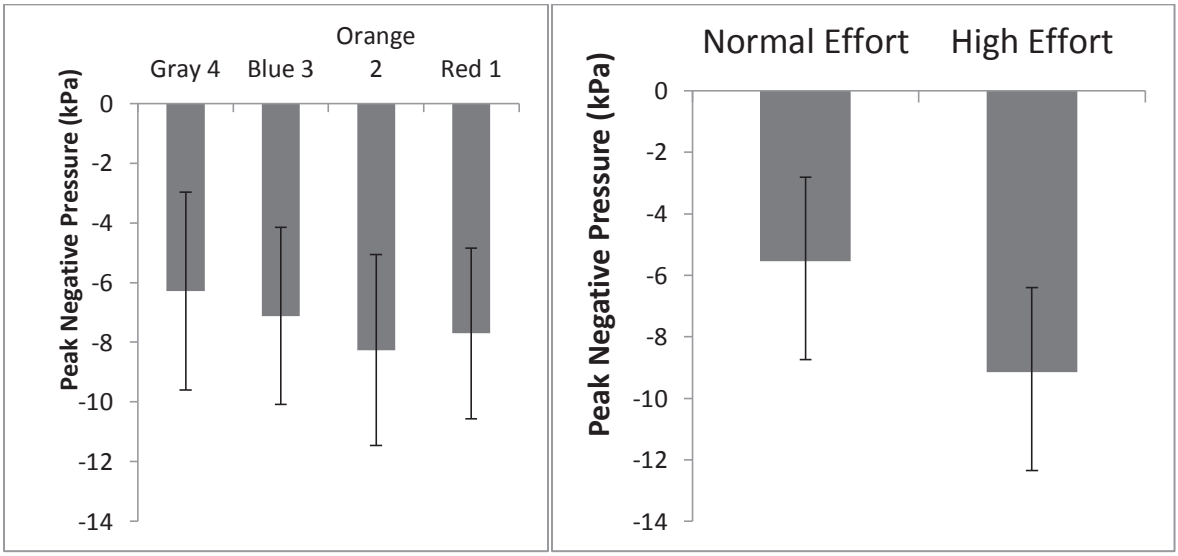
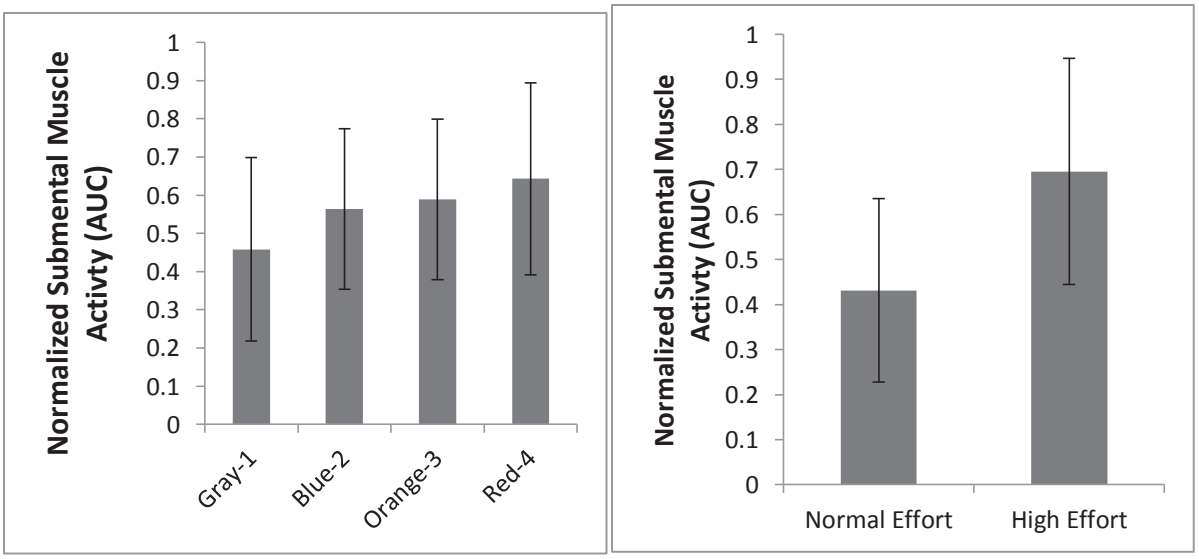



**Figure 3. Mean submental muscle activity during sips from straws varying in diameter and during normal and high effort sips**



## DISCUSSION

In this experiment, healthy adults performed discrete sips of water from straws varying in diameter under conditions of normal and high effort. Outcome measures included negative intra-oral pressure and submental muscle activity.

### Effects of Straw Diameter

The a priori predication that straws with smaller diameter would be associated with higher levels of negative intraoral pressure was upheld by the significant main effect of straw diameter on negative intra-oral pressure. However, a similar main effect failed to reach statistical significance for submental muscle activity. Visual inspection of the data (Figures 1 & 2) suggests that the effects of straw diameter were somewhat dissimilar for the two dependent variables. Mean peak negative pressure generation was highest in the orange-2 straw condition. In contrast, mean sEMG AUC was highest in the red-1 straw condition. This apparent discrepancy may be explained by the difference in operational definition for these variables. sEMG area under the curve (AUC) captures both the intensity and duration of muscle activity. The current findings suggest that although participants created the greatest negative intra-oral pressures when sipping from the orange-2 straw, creating this greater peak pressure likely did not require the sustained muscle activity associated with sips from the red-1 straw.

The current findings speak to the potential benefit of using straws of decreasing diameter in a progressive strengthening program. Although the effects failed to reach statistical significance, the data suggest a trend for increased muscle activity associated with sips from straws of smaller diameter. Therefore, it is hypothesized that straws of decreasing diameter could be exploited to systematically increase overload during a strength-training program. Additional research is needed to test this hypothesis as well as to explore whether other straw features (e.g., length, shape) have similar overloading effects.

### Effects of Effort

The hypothesis that muscle activity and negative intra-oral pressure generation would increase with high effort was upheld. The lack of a significant interaction between straw condition and effort confirms that participants could volitionally increase muscle activity and negative intra-oral pressure by increasing effort, regardless of which straw was being used. This is consistent with previous research demonstrating increased muscle activity when participants were instructed to “suck hard” (Mueller, et al., 2003). This finding also has relevance for strength-training programs that incorporate high resistance drinking straws, in that it suggests that patients should be encouraged to perform exercises with maximum effort, regardless of the amount of resistance offered by the straw.

### Comparison to Previous Findings

The mean negative pressures measured in this study ranged from -10.37 to -4.14 kPa. These pressures are smaller than those reported in an earlier study of healthy adults sipping from a 5mm diameter straw (90 mm Hg; 12.0 kPa) (Nilsson, Ekberg, Olsson, Kjellin, et al., 1996). This finding is not unexpected given that the Nilsson studies measured negative pressure within the straw, an area of constriction within the system and therefore likely associated with larger pressures than would be measured in the oral cavity. Moreover, the pressure readings recorded in the current study were an indirect measure of intra-oral negative pressure; direct measures of negative intra-oral pressure would be expected to be larger. Therefore, although the absolute values reported in this study are not directly comparable to previous studies measuring negative pressure using different methods (Mueller et al., 2003; Nilsson, et al., 1995; Nilsson, Ekberg et al., 1996a, 1996b; Nilsson et al., 1998; Nilsson, Ekberg, Olsson, Kjellin et al., 1996), the relative change in negative pressures associated with sips from straws varying in diameter remains the most relevant finding.

### Study Limitations

The current study has several limitations. First, the method of data capture for negative intra-oral pressure was not ideal as it provided an indirect measure of intra-oral pressure. Furthermore, even though participants attempted to avoid tongue-to-bulb contact while drawing liquid from the straws, the absence of negative pressure recordings resulted in a large number of invalid trials. It is noteworthy that while 22 of 41 participants had

valid trials for all of the conditions examined, only five participants had no valid trials, suggesting that most participants were able to generate negative intra-oral pressure without making lingual contact with the bulb. Therefore, this limitation *could be minimized in future studies by on-line* monitoring of each trial to ensure that negative pressures have been detected and by including multiple trials under each condition.

Because the current study did not include measures of muscle activity associated with maximal contraction, sEMG values were normalized relative to the highest recorded value during the sample. Therefore, the current findings may not be directly comparable to studies using other normalization methods (Netto & Burnett, 2006; Stepp, 2012).

The placement of the electrodes further influences the conclusions that can be drawn from the findings. The submental electrode placement was selected to be consistent with other studies examining muscle activity during swallows. However, the hyoglossus muscle contributing to the lingual retraction and depression that is thought to help create negative intra-oral pressure is farther from the submental recording site than the musculature responsible for other tongue and hyolaryngeal movements associated with swallowing (Palmer, Luschei, Jaffe, & McCulloch, 1999). Therefore, the surface recordings in the current study may have not captured the muscle activity of the lingual musculature most relevant to generating negative intra-oral pressure.

Finally, the current study examined the performance of healthy adults. It is unknown whether children or individuals with orofacial myofunctional, speech or swallowing disorders demonstrate the same pattern of negative intra-oral pressure and muscle activity during sips from straws varying in diameter. Because the clinical hypotheses tested relate to rehabilitative strategies, it will be important to explore these issues in the populations of interest.

## SUMMARY

The current study generally supported the clinical hypotheses: 1) Smaller straw diameters were associated with greater negative intra-oral pressures. A non-significant trend for higher submental muscle activity associated with smaller straw diameters was also observed; and 2) High-effort sips were associated with greater negative intra-oral pressures and higher submental muscle activity. These findings provide initial support for the use of high resistance straws in a progressive resistance strengthening program and confirm previous recommendations of using high effort to elicit greater muscle activity during the targeted movements.

Future reports will describe findings of studies exploring other clinical hypotheses regarding high resistance drinking straws. Specifically, the effects of straw diameter on the intensity of subsequent swallows and the effects of a four-week training program using the straws will be detailed. Additional research is needed to explore these effects in disorder populations and to examine the benefit of high resistance straws for improving orofacial myology, speech production, and swallowing effectiveness.

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**Conflict of Interest**
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