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## Patterned orocutaneous therapy improves sucking and oral feeding in preterm infants

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### Abstract

**Aim**—To determine whether NTrainer patterned orocutaneous therapy affects preterm infants' non-nutritive suck and/or oral feeding success.

**Subjects**—Thirty-one preterm infants (mean gestational age 29.3 weeks) who demonstrated minimal non-nutritive suck output and delayed transition to oral feeds at 34 weeks post-menstrual age.

**Intervention**—NTrainer treatment was provided to 21 infants. The NTrainer promotes non-nutritive suck output by providing patterned orocutaneous stimulation through a silicone pacifier that mimics the temporal organization of suck.

**Method**—Infants' non-nutritive suck pressure signals were digitized in the NICU before and after NTrainer therapy and compared to matched controls. Non-nutritive suck motor pattern stability was calculated based on infants' time- and amplitude-normalized digital suck pressure signals, producing a single value termed the Non-Nutritive Suck Spatiotemporal Index. Percent oral feeding was the other outcome of interest, and revealed the NTrainer's ability to advance the infant from gavage to oral feeding.

**Results**—Multilevel regression analyses revealed that treated infants manifest a disproportionate increase in suck pattern stability and percent oral feeding, beyond that attributed to maturational effects alone.

**Conclusion**—The NTrainer patterned orocutaneous therapy effectively accelerates non-nutritive suck development and oral feeding success in preterm infants who are at risk for oromotor dysfunction.

### Keywords

Feeding therapy; Non-nutritive suck; Oromotor control; Suck central pattern generator; Suck spatiotemporal variability

## INTRODUCTION

Suck is a precocial ororhythmic motor behaviour in humans. However, premature infants often demonstrate oromotor dyscoordination and are unable to suck and feed orally (1). This inability to orally feed can delay discharge from the neonatal intensive care unit (NICU) (2,3), result in the infant being sent home on gavage feedings, and hinder the development of coordinated oromotor behaviour.

Infants' readiness to feed is often evaluated by their display of non-nutritive sucking (3). Suck begins *in-utero* between 15 and 18 weeks gestational age (GA) (4), and is stable and well patterned by 34 weeks post-menstrual age (PMA) (5). The characteristic non-nutritive suck pattern consists of a series of bursts and pauses; each burst contains 6–12 suck cycles that occur at approximately 2 Hz (6). Nutritive suck, which has slower suck cycles (1 Hz) and fewer inter-burst pauses (7), differs from non-nutritive suck because the expression of milk requires coordination of suck with swallow and respiration. Mammalian suck is primarily controlled by the suck central pattern generator, which includes bilateral, internuncial circuits within the brainstem reticular formation (8). The minimal circuitry for ororhythmic activity resides between the trigeminal motor nucleus and the facial nucleus in the brainstem (8).

The suck central pattern generator is modified by peripheral input arising from oral mechanoreceptors that encode the consequences of oral movements along central pathways of the trigeminal system (9,10). Mechanosensory stimulation delivered to the baby's oral sensorium can entrain the suck central pattern generator (10,11). Entrainment is defined as the phase locking of centrally generated motor patterns to an applied external stimulus, and is a powerful method of achieving neural synchrony among sensorimotor pathways. Entrainment has also been achieved in infants during respiration (12). Thus, it is not surprising that stimulation of the lips and tongue are common methods used to evoke sucking behaviours (13,14).

Recent application of a new biomedical device, known as the NTrainer, has shown that patterned orocutaneous stimulation can entrain ororhythmic activity and accelerate the development of non-nutritive suck in preterm infants (15). The NTrainer is programmed to synthesize pneumatic pulse trains through a Soothie® silicone pacifier (Soothie® New Brighton, MN, USA), which is presented to the infant for 3-min epochs. This novel orosensory experience mimics the spatiotemporal dynamics of non-nutritive suck, and has been correlated to rapid organization of suck in poor feeders. However, the changes that occur in non-nutritive suck patterns following NTrainer therapy have not been investigated. Objective data concerning the fine structure of the non-nutritive suck compression waveform and the emergence of non-nutritive suck burst pattern formation remain unknown in preterm infants who manifest little or no functional suck in the NICU.

Ideally, a physiological approach to the assessment of suck would investigate the integrity of the neural circuitry driving the suck central pattern generator through an analysis of suck pattern structure and stability. Coordinated non-nutritive suck that is minimally variable from burst-to-burst indicates motor system integrity and is an important foundation for coordination with other emergent behaviours, such as swallow and respiration. A promising measurement technique for analyzing the emergence of stable non-nutritive suck may be the Spatiotemporal Index (16), which has been used to assess kinematic variability and pattern formation in limb (17) and speech (16) motor subsystems. The Spatiotemporal Index is a single numerical value, calculated from the cumulative sum of the standard deviations of an amplitude- and time-normalized set of kinematic trajectories (i.e. movement, force, pressure), and represents the stability of a motor sequence. It logically follows that such a

measure applied to the developing oromotor system in the premature infant, namely the Non-Nutritive Suck Spatiotemporal Index, could provide a quantitative composite index of non-nutritive suck pattern stability. This would significantly advance our understanding of suck pattern formation in preterm infants, compared to previous studies that have utilized feature counts and duration measures on suck cycles or suck bursts (5). Because the Non-Nutritive Suck Spatiotemporal Index is designed to quantify suck over a selected burst pattern epoch, clinicians are provided with a summative index or 'gestalt' of oromotor pattern stability. In a repeated-measures design, this technique provides an inclusive analysis of emergent ororhythmic behaviours. Previous work in our laboratory has shown that the Non-Nutritive Suck Spatiotemporal Index is an objective and efficient quantitative assessment of non-nutritive suck patterns, and can effectively discriminate ororhythmic motor development in preterm infants with progressively severe forms of respiratory distress syndrome (RDS) (18). Degraded non-nutritive suck patterning in infants with RDS is expected, because extensive oxygen therapy alters the oral sensory environment and reduces motor experiences.

The purpose of this study was to assess the efficacy of patterned orocutaneous stimulation on the emergence of non-nutritive suck in preterm infants with dysfunctional suck. It was hypothesized that preterm infants receiving NTrainer patterned orocutaneous therapy would manifest significantly increased non-nutritive suck stability (*lower* Non-Nutritive Suck Spatiotemporal Index values) and increased success with oral feedings when compared to a group of non-treated preterm infants.

## SUBJECTS AND METHODS

### Subject characteristics

This study was approved by the human subjects committees of the University of Kansas Medical Center (Kansas City, KS) and Stormont-Vail Regional Health Center (Topeka, KS). Informed consent was obtained from the infants' parents prior to the study. Participants were 31 preterm infants (15 females, 16 males; GA<sub>mean</sub> 29.3 weeks, SD = 2.57), each enrolled at 32 weeks PMA. The inclusion criteria for all infants were: head circumference within 10–90th percentile of mean for PMA, neurological examination showing no anomalies for PMA (response to light, sound and spontaneous movements of all extremities), and with stable vital signs (heart rate, blood pressure, age appropriate respiratory rate and oxygen saturation >92 SpO<sub>2</sub>) to allow for non-nutritive suck. Exclusion criteria were: intraventricular haemorrhage grades III or IV, intracranial haemorrhage, periventricular leukomalacia, necrotizing enterocolitis, neonatal seizures, culture positive for sepsis or meningitis at time of testing, chromosomal anomalies or craniofacial malformation. No infants in the current study had diagnoses of moderate or severe bronchopulmonary dysplasia at the time of testing.

Upon enrolment in the study, all infants were medically stable, were minimally orally feeding (<25% of nutrition obtained by mouth), and demonstrated minimal/no non-nutritive suck output. Non-nutritive suck output was determined from infants' weekly evaluation using the Actifier (see section *Non-nutritive suck sampling*). A performance average was obtained from infants' most active 2 min of oro-motor output—infants with fewer than three non-nutritive suck bursts per minute, fewer than four non-nutritive suck cycles per burst, fewer than 20 non-nutritive suck cycles per minute, or greater than eight non-suck mouthing events per minute were considered to have minimal/no non-nutritive suck output and were enrolled in the study.

## Groups and treatment

Infants were assigned to groups in a block design—21 infants were assigned to the NTrainer treatment group and 10 were assigned to the no-treatment control group. Group characteristics are summarized in Table 1. Infants assigned to the NTrainer treatment group received 3-min epochs of patterned orocutaneous stimulation during daily gavage feeds using the NTrainer© device (Fig. 1). The NTrainer©, a new biomedical device, was programmed to synthesize a pulse train to dynamically modulate the intraluminal pressure and conformation (shape) of the infant's preferred Soothie® silicone pacifier. The patterned orocutaneous stimulation was programmed to mimic the temporal features of non-nutritive suck. A 16-bit digital-to-analog converter was used to create a synthetic non-nutritive suck train that consisted of a series of 6-cycle bursts and 2-sec pause periods. Individual cycles within-burst were presented at 1.8 Hz. This control signal served as the input to a custom-designed, servo-controlled linear motor operating under position feedback and coupled in series with a pressurized actuator. The unique instrumentation integral to the NTrainer transformed the infant's silicone pacifier into an active stimulator or 'pulsating nipple' to mimic the temporal pattern of a typical non-nutritive suck burst. The resulting dynamic changes in intraluminal pressure yielded a radial expansion of the pacifier nipple of approximately 135 micrometres with a 25 ms rise/fall time. A total of 34 synthetic non-nutritive suck burst-pause trains were presented to the infant during a single 3-min NTrainer session.

Infants in the treatment group received the NTrainer up to four times per day during scheduled gavage feeds. The mean number of NTrainer sessions per day was 3.01 (SD = 0.58). NTrainer therapy was provided until the infant attained 90% oral feeds for two consecutive days. The 'percent oral feed' (ORAL FEED) is defined as the amount in cubic centimetres consumed orally divided by the total amount consumed by the infant. This calculation was performed at the end of each day, and accounts for all feedings for any given day. The mean number of days of NTrainer therapy was 9.81 days (SD = 4.82).

Infants assigned to the Control group did not receive the NTrainer's patterned orocutaneous stimulation, but were given Soothie® pacifiers during their gavage feeds as a control. Infants sucked on these pacifiers until they fell asleep or turned away from the pacifier. ORAL FEED was also recorded for these infants.

## Non-nutritive suck sampling

In order to evaluate non-nutritive suck development in both NTrainer-treated and Control infants, non-nutritive suck nipple compression waveforms were digitized weekly from each infant. Fifteen minutes prior to feeding, the mobile Actifier technology was wheeled cribside in the NICU. The Actifier is a specially designed system that uses a Honeywell pressure transducer (DC-coupled, LP Butterworth @ 50 Hz) coupled to a custom Delrin receiver with a sterile Soothie® silicone pacifier (Children's Medical Ventures, Inc., Pelham, AL, USA) to measure the force generated by the lips, tongue and jaw during sucking behaviour (6). The non-nutritive suck is then digitized in real-time at 3 K samples/sec by custom software developed in our laboratory known as NeoSuck RT©. This software displays the non-nutritive suck pressure waveform in real time, performs parameter calculations, and allows the investigator to objectively examine suck parameters in a fast, efficient manner.

Before each non-nutritive suck evaluation session using the Actifier, the NICU nursing staff performed a brief examination of physiologic state. Each infant was held in a developmentally supportive inclined posture, consistent with the Newborn Individualized Developmental Care and Assessment Program (NIDCAP; 19), and brought to an optimal behavioural state i.e. drowsy to quiet alert (stages 3 or 4 of the Preterm Infants Behavioural

Scale, NIDCAP) before non-nutritive suck data was collected. Three minutes of continuous non-nutritive suck behaviour was digitally sampled for each infant during their weekly Actifier non-nutritive suck assessment sessions.

### Non-nutritive suck analysis

Non-nutritive suck pattern stability was analyzed from the weekly 3-min non-nutritive suck pressure waveform data files using a LabVIEW© software program developed in our laboratory known as the Non-Nutritive Suck Spatiotemporal Index. The result of the Non-Nutritive Suck Spatiotemporal Index program is a single-number index of suck pressure pattern variability.

Source non-nutritive suck data files were preprocessed for each infant to objectively identify 2 min of the most active period of oromotor output using a waveform discrimination-threshold function that tabulated suck cycle peaks greater than 1 cmH<sub>2</sub>O. This 2-min sample was then subjected to the Non-Nutritive Suck Spatiotemporal Index calculation. Within this sample, non-nutritive suck bursts produced by infants vary in length and peak number. In order to measure non-nutritive suck pattern convergence, however, a fixed peak (suck cycle) number must be used for Non-Nutritive Suck Spatiotemporal Index calculations. Also, in order to compare STI values across infants, a fixed burst number must be used. For this reason, the first five peaks from five successive bursts were chosen as the criteria for the current analysis. This allowed for the maximum amount of data to be used for analysis, while still accounting for infants with minimal oromotor output. For infants with a poorly developed non-nutritive suck pattern structure, the first five most burst-like mouthing movements were identified, based on peak period, amplitude and burst duration.

Once the five-peak-burst ensembles had been identified, the Non-Nutritive Suck Spatiotemporal Index software program performed pressure peak detection for each burst to index the time location point for each peak. The start- and end-points for the bursts were calculated by extending the waveform analysis window 300 samples prior to the first peak and 300 samples following the fifth peak, in order to ensure accurate pressure peak discrimination. These five original non-nutritive suck ensembles for one infant are displayed in the top panel of Figure 2.

Amplitude and time normalization of these five bursts were then completed. Time normalization is based on linear reallocation, which projects the five-peak-burst ensembles to an analysis window maxima based on a preset abscissa scale of 10 000 data samples. Amplitude normalization involves rescaling each suck waveform to the peak pressure maxima, while maintaining relative peak proportions within each burst. Therefore, the data are taken from one spatial resolution to another for comparison purposes. The five normalized non-nutritive suck ensembles are displayed in the middle panel of Figure 2.

The resultant Non-Nutritive Suck Spatiotemporal Index represents the cumulative sum of the standard deviations of the normalized non-nutritive suck burst waveforms indexed at 100 sample intervals (bottom panel of Fig. 2). High Non-Nutritive Suck Spatiotemporal Index values result from large standard deviations between the suck pressure waveforms, and thus reveal increased variability in the underlying oromotor pattern. Low Non-Nutritive Suck Spatiotemporal Index values result from small standard deviations between the suck pressure waveforms, and thus reveal stability or invariance in the underlying pattern of ororhythmic activity produced by the suck central pattern generator.

### Intervention phase

In order to compare outcomes of treated infants and Controls, the Controls were age-matched to the treated infants' pre- and post-NTrainer PMAs. Treated infants had a mean

PMA of 35.12 weeks (SD = 1.99) pre-NTrainer and 37.52 weeks (SD = 2.11) post-NTrainer. The grand mean of these two phases (36.4 weeks PMA) served as a division point for the Control infants' non-nutritive suck assessment sessions. Thus, weekly Non-Nutritive Suck Spatiotemporal Index scores obtained from Control infants before 36.4 weeks PMA were PRE scores, and scores after 36.4 weeks PMA were POST scores. Control infants thus had a mean PRE PMA of 35.21 weeks (SD = 0.87) and POST PMA of 37.96 weeks (SD = 1.07). The mean interval between all infants' PRE and POST non-nutritive suck measures was 2.40 weeks (SD = 1.22).

The outcome data for all infants were collapsed into a single PRE and a single POST Non-Nutritive Suck Spatiotemporal Index score, and a single PRE and a single POST ORAL FEED score. For most infants, these single values represented the average of Non-Nutritive Suck Spatiotemporal Index scores across two weekly sessions (mean 7.85 days apart, SD = 5.64). In a few cases, only one recording session was obtained for infants who were unstable or undergoing other medical treatments at the time the second session would have been obtained. For NTrainer infants, only two PRE and three POST scores were derived from a single session. Among control infants, two PRE- and three POST scores were based on a single session. Averaging across two weekly sessions increased the likelihood that the non-nutritive suck samples were representative of the infant's oromotor ability.

### Statistical analysis

The independent variables were treatment group (NTrainer-treated infants vs. no-treatment Controls) and treatment phase (pre-NTrainer [PRE] vs. post-NTrainer [POST]). The dependent variables included the Non-Nutritive Suck Spatiotemporal Index, and the percent of formula or breast milk taken by mouth (ORAL FEED). An SAS (Statistical Analysis System, v.9.1.3) procedure, PROC MIXED, was used to conduct two multilevel analyses in which the Non-Nutritive Suck Spatiotemporal Index and ORAL FEED were each response variables.

Covariates included GA, birthweight, and PMA at the Actifier non-nutritive suck assessment session. The correlation coefficient was calculated for each of these three covariates with the Non-Nutritive Suck Spatiotemporal Index and ORAL FEED. Even though birthweight and GA were highly correlated with each other (0.761,  $p < 0.0001$ ), neither of them were statistically significant covariates in the models. In addition, PRE PMA and POST PMA ages were similar, so co-linearity in the models was avoided by using POST PMA values across both measures.

## RESULTS

The mixed model multilevel analysis of the Non-Nutritive Suck Spatiotemporal Index scores revealed a highly significant interaction between phase and group ( $F[1,26] = 11.51$ ,  $p = 0.002$ ). Both NTrainer-treated and Control infants entered the study with similar Non-Nutritive Suck Spatiotemporal Index scores, but only treated infants demonstrated a significant and disproportionate improvement in their scores. An example of the difference in non-nutritive suck pattern formation for a Control and NTrainer preterm infant is shown in Figure 3. The upper block illustrates the progression of suck patterning in an untreated Control infant sampled at 35 and 38 weeks PMA based on five non-nutritive suck bursts (left panels) and their normalized counterparts with the Non-Nutritive Suck Spatiotemporal Index calculations (right panels). The resultant suck pattern progression is small and is associated with only a limited reduction in the Non-Nutritive Suck Spatiotemporal Index value, from 85 to 81 units. The lower block illustrates the progression of suck patterning in a preterm infant who received the patterned orocutaneous NTrainer intervention. The PRE-intervention non-nutritive suck performance sampled at 35 weeks PMA yielded a Non-



Nutritive Suck Spatiotemporal Index of 85 units. Following the patterned orocutaneous stimulus regimen (38 weeks PMA), this infant produced highly organized suck bursts (lower left) and the corresponding normalized ensemble illustrates the stability of the non-nutritive suck pattern (lower right). This dramatic transformation in the output of the suck CPG is reflected by the significantly improved Non-Nutritive Suck Spatiotemporal Index value of 35 units.

Infants who received the NTrainer intervention manifest significantly improved Non-Nutritive Suck Spatiotemporal Index scores as a function of the patterned orocutaneous treatment: mean PRE Non-Nutritive Suck Spatiotemporal Index = 85.07 (SD = 9.96) and mean POST Non-Nutritive Suck Spatiotemporal Index = 56.52 (SD = 11.65), or a 39.9% decrease in the Non-Nutritive Suck Spatiotemporal Index. Control infants demonstrated a minimal decrease in Non-Nutritive Suck Spatiotemporal Index of only 12.5% over the 2.5-week study period: mean PRE Non-Nutritive Suck Spatiotemporal Index = 83.61 (SD = 7.87) and mean POST Non-Nutritive Suck Spatiotemporal Index = 73.16 (SD = 7.62). This modest improvement may be attributed to maturation, as indicated by marginal significance for PMA at session [ $F(1,26) = 4.28, p = 0.049$ ], or to small sample size. Models including the various interactions of PMA and/or GA with phase and group showed no significant interactions.

The mixed model multilevel analysis of percent oral feeds (ORAL FEED) revealed a highly significant interaction between phase and group as well ( $F[1,26] 15.03, p = 0.0006$ ). Both NTrainer-treated and Control infants entered the study with similar percent oral feeding, but only treated infants demonstrated a significant and disproportionate increase in their percent oral feeding. Infants who received the NTrainer intervention manifest significantly improved percent oral feeding as a function of the patterned orocutaneous treatment: mean PRE ORAL FEED = 4.28% (SD = 10.17) and mean POST ORAL FEED = 72.07% (SD = 26.25), or a 16.8-fold increase in percent oral feeds. Control infants demonstrated a minimal increase in percent oral feeding of only 3-fold over the 2.5-week study period: mean PRE ORAL FEED = 11.61% (SD = 18.44), mean POST ORAL FEED = 35.74% (SD = 25.36). Models including the various interactions of PMA and/or birthweight with phase and group showed no significant interactions.

In addition, not only are the Non-Nutritive Suck Spatiotemporal Index and ORAL FEED each related to NTrainer treatment, but are also independently related to each other. The coefficient between the Non-Nutritive Suck Spatiotemporal Index and ORAL FEED after partialing out PMA was  $-0.65$  ( $p < 0.0001$ ). This indicates that the spatiotemporal stability of non-nutritive suck pressure trajectories and oral feeding success are highly related.

## DISCUSSION

The decrease in non-nutritive suck spatiotemporal variability following NTrainer therapy demonstrates the potent effect of patterned orocutaneous stimulation on ororhythmic development among preterm infants in the NICU. The brainstem-mediated suck central pattern generator is highly responsive to peripheral input (10,11,14) and adapts to changes in the local environment. The NTrainer capitalizes on the responsiveness of the suck central pattern generator by providing infants who have poor oromotor skills with a controlled regimen of spatiotemporal orocutaneous cues, thereby ‘jump-starting’ non-nutritive suck activity.

The orocutaneous stimulation provided by the NTrainer results from the dynamic modulation of a pneumatically coupled Soothie® silicone pacifier by a servo-controlled pump. This unique orosensory experience is physiologically salient and mimics the pressure

dynamics, temporal organization, and burst-pause structure of non-nutritive suck. This form of stimulation serves to facilitate activity patterns of mechanoreceptor populations located in the neonate's lips, tongue and jaw and applies a basic principle of pathway formation—namely, neurons that fire together will wire together (20). The resultant synchronous pattern of sensory flow is encoded by trigeminal primary afferents that project centrally to internuncial relays in the brainstem and ventroposteromedial nucleus of the thalamus to ultimately influence the firing patterns of facial, trigeminal and hypoglossal lower motor neurons.

Experiments with healthy infants have produced harmonic oromotor entrainment (1:1) during non-nutritive suck (11). The richness of the orocutaneous experience offered by an entraining pacifier nipple presents new and exciting neurotherapeutic applications for the habilitation of the developing oromotor system. As demonstrated in the present study, the NTrainer orocutaneous therapy accelerates the development of non-nutritive suck, and this change is efficiently registered using a new quantitative measure, the Non-Nutritive Suck Spatiotemporal Index.

An infant's ability to produce patterned non-nutritive suck is an important developmental precursor to oral feeding. Notably, successful oral feeding is based not only on suck, but also requires competent swallow, respiration and coordination of suck-swallow-respiration. However, the ability to coordinate non-nutritive suck indicates motor system integrity and positive neurodevelopment, which may support the coordination of the multiple systems needed for successful oral feeding (9).

The findings of the current study demonstrate that without the beneficial effects of the NTrainer on suck development, infants make only modest developmental gains in oral feeding proficiency, but with NTrainer therapy, are able to quickly progress to oral feeding. This alone indicates that the NTrainer is in some way supporting oral feeding and influencing neural networks within the brainstem, which regulate swallow and airway control. However, the present study also found that non-nutritive suck skill (Spatiotemporal Index) and oral feeding skill (percent oral feeding) are highly correlated. This evidence strengthens and extends the hypothesized role of patterned orocutaneous stimulation in not only accelerating the development of non-nutritive suck, but also having a facilitatory effect on the acquisition of nutritive feeding skills.

Previous studies have predicted that non-nutritive suck may improve oral feeding, yet have resulted in mixed outcomes. This is likely due to the fact that some studies have provided increased opportunities for non-nutritive suck (21), while others have made attempts to habilitate non-nutritive suck (13,14). The current study represents a unique approach to actively habilitate non-nutritive suck through the use of a motorized pacifier nipple, rather than simply assuming the premature infant who has a dysfunctional or absent suck could self-habilitate if provided additional opportunities for non-nutritive suck with a simple pacifier. A recent review examined the influence of increased opportunities for non-nutritive suck on numerous variables, such as weight gain, energy intake, heart rate, oxygen saturation, intestinal transit time and age at attainment of full oral feeds (22), and found a significant benefit of non-nutritive suck on length of hospital stay only. Again, the mixed results obtained from these studies likely result from the lack of active habilitation of non-nutritive suck, and may become salient when non-nutritive suck is habilitated with the synthetically patterned orocutaneous stimulation afforded by NTrainer therapy. These predictions merit further investigation.

Timely transition to oral feeding is important for premature infants because it demonstrates motor system integrity and allows earlier hospital discharge. Poor feeding skills in infancy



can continue to be problematic later on, for months or even years. Children who were preterm make up nearly half the population in feeding disorder clinics (3). Many premature infants also continue to have feeding difficulties in the early years post-discharge, and are unable to manage the transition to a solid food diet (23).

Oromotor dyscoordination, however, is not isolated to feeding issues, but may serve as a powerful clinical marker for neurodevelopment as well (7,9,24). Research has shown that infants with perinatal distress and neurologic impairments demonstrate a significantly slower mean rate and greater variability of non-nutritive suck (25). Also, children with severe neurodevelopmental problems at 18 months tend to have arrhythmic nutritive expression/suction patterns as premature infants (9).

In the NICU, non-nutritive suck and oromotor evaluation is still quite subjective. Typically, non-nutritive suck is evaluated by placing a gloved finger in the infant's mouth to observe the rhythmicity, strength, cycle frequency and burst duration (2,26). Clinical observations can then be characterized with validated scales, such as the Neonatal Oral-Motor Assessment Scale (NOMAS®), (27) which was designed to assess sucking patterns in preterm infants and monitor changes over time, or the Early Feeding Skills Assessment (28), which is a checklist of suck-swallow coordination and physiological stability.

An objective and quantitative measure of oromotor ability would greatly benefit neonatal intensive care diagnostics and treatments (26,29). The Non-Nutritive Suck Spatiotemporal Index serves this need by providing investigators and clinicians with a composite metric of sucking ability, which could be sampled periodically to monitor oromotor patterning and predict the transition to oral feeds. The Non-Nutritive Suck Spatiotemporal Index is preferable to other simple quantitative measurements of non-nutritive suck pressure waveforms, such as feature counts, in that it is a gauge of the kinematic invariance and pattern formation that characterizes mature motor control.

The Non-Nutritive Suck Spatiotemporal Index represents an efficient measurement tool to document the NTrainer's ability to shape non-nutritive suck development. Patterned orocutaneous stimulation is highly effective in accelerating the development of ororhythmic motor output in preterm infants with delayed or disordered suck and poor feeding skills. Reductions in the spatiotemporal variability of non-nutritive suck following NTrainer treatment reflect an improvement in the brain's ability to organize the ororhythmic motor system for non-nutritive patterning. This skill appears to be an important adjunct or precursor to the higher-order complexities involved with oral feeds, and may even predict success in later-developing oromotor skills, such as mastication, babble and speech (9,30). Further research on the Non-Nutritive Suck Spatiotemporal Index among various clinical populations in relation to other scales of suck and feed development will expand our understanding of suck pattern generation and provide clinicians with a non-invasive, quantitative tool for predicting oral feed readiness and nervous system integrity.

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## Abbreviations

<b>GA</b>	gestational age
<b>NICU</b>	neonatal intensive care unit
<b>NIDCAP</b>	Newborn Individualized Developmental Care and Assessment Program
<b>PMA</b>	post-menstrual age
<b>RDS</b>	respiratory distress syndrome

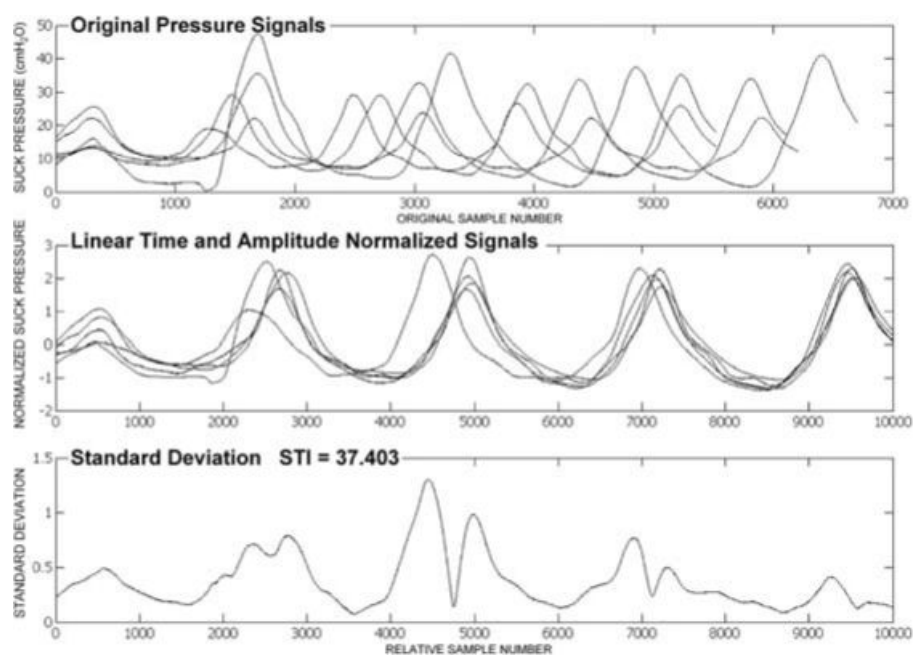
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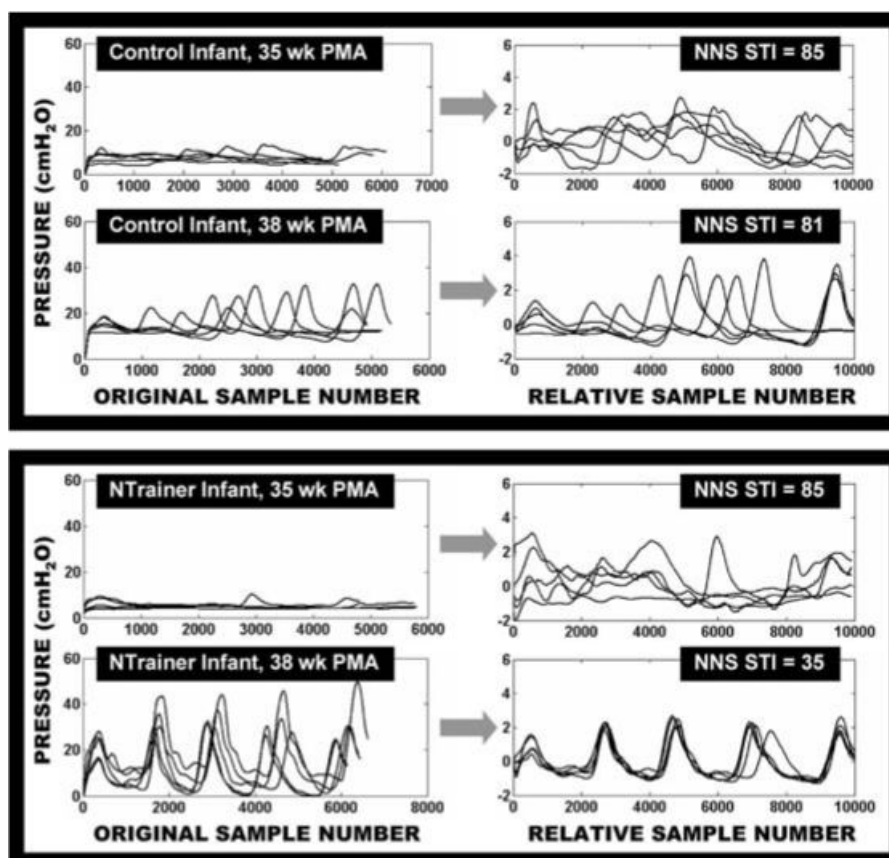
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**Figure 1.**  
(left) Infant is treated with the NTrainer© patterned orocutaneous therapy. (right) The NTrainer© device is wheeled cribside in the Neonatal Intensive Care Unit (NICU).



**Figure 2.**  
Steps for Non-Nutritive Suck Spatiotemporal Index calculation for one infant.



**Figure 3.**

PRE and POST suck pressure samples and Non-Nutritive Suck Spatiotemporal Index calculation for a Control and NTrainer-treated infant. Left side of each panel includes non-nutritive suck source pressure signals for five five-peak bursts. Right side of each panel includes the same set of bursts after time- and amplitude-normalization for Non-Nutritive Suck Spatiotemporal Index calculation. Organized non-nutritive suck resulting from NTrainer treatment (Non-Nutritive Suck Spatiotemporal Index = 35) can be seen in the bottom panel.



**Table 1**

Clinical characteristics of study infants, expressed as mean (SD). SESSION refers to non-nutritive suck assessment session with the Actifier. ORAL FEED is the mean daily amount of formula or breastmilk consumed orally by the infant divided by the total amount consumed.

	<b>Control PRE (n = 8)</b>	<b>Control POST (n = 9)</b>	<b>Ntrain PRE (n = 21)</b>	<b>Ntrain POST (n = 21)</b>
Gender (males: females)	5:3	7:2	9:12	9:12
Gestational age (weeks)	28.90 (2.30)	29.70 (3.24)	29.22 (2.31)	29.22 (2.31)
Birth weight (grams)	1098.50 (362.34)	1033.50 (358.47)	1218.29 (417.98)	1218.29 (417.98)
Average oxygen history (days)	38.25 (27.75)	43.22 (32.91)	40.42 (28.20)	40.42 (28.20)
PMA at first oral feed (weeks)	35.55 (1.69)	36.60 (1.65)	35.68 (2.27)	35.68 (2.27)
PMA at session (weeks)	35.21 (0.87)	37.96 (1.07)	35.12 (1.99)	37.52 (2.11)
ORAL FEED at session (%)	11.61 (18.44)	35.74 (25.36)	4.28 (10.17)	72.07 (26.25)