The Effects of Vestibular Stimulation Rate and Magnitude of Acceleration on Central Pattern Generation for Chest Wall Kinematics in Preterm Infants

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Supported by: NIH R01 DC003311

2011 ASHA Convention: Speech Science
Vestibular Development

- Womb is an optimal, stimulating & interactive environment (Montagu, 1978)
- Fetal flotation in amniotic fluid stimulates, protects, and provides potent vestibular stimulation (Korner, Kraemer, Haffner, & Cosper, 1975; Rice, 1979)
- Response to vestibular stimulation has been observed as early as 25 weeks GA (Hooker, 1969)
- The restrictive environment of the crib/isolette in the NICU limits vestibular activity among preterm infants
Semicircular Canals:
- Three semicircular canals (horizontal, superior & posterior)
- detect angular acceleration through inertial forces
- Head rotation encoded along the three orthogonal axes
  - yaw, pitch, and roll

Otoliths:
- Composed of the utricle and saccule
- Respond to changes in gravity and linear acceleration
  - Connectivity to respiratory system in the brainstem

Background: Control of Breathing

Resides in the brainstem respiratory central pattern generator (rCPG)
Rocking Studies

- Natural way to elicit vestibular stimulation
  - mimics certain features (rhythmicity) of maternal walking and infant movement *in utero* (Korner, 1990)

- Reduces apneic attacks and decreases the need for respiratory therapies (Farrimond, 1990; Korner, et al., 1975; Tuck, Monin, Duvivier, May, & Vert, 1982)

- Increases: NNS, feeding skill, weight gain, & growth rates (Farrimond, 1990; Korner, et al., 1975; Tuck, Monin, Duvivier, May, & Vert, 1982)

- Helps to stabilize behavioral states and sleep cycles (Balaban, 2002; Korner, et al., 1983; Kramer & Pierpont, 1976)
Purpose

- Assess the effect of vestibular inputs on respiratory and oromotor systems in preterm infants utilizing a new system developed at the University of Kansas, known as the **VestibuGlide** system.

3-Phase Linear DC Motor

Lift-Locks

Deterministic Control and Data Acquisition

National Inst **cRIO™ FPGA**
real-time DAC and stimulus control

- Rib cage/abdominal motion
- Pulse
- SpO₂
- NNS compression pressure
- Glider Acceleration
- Linear motor signals:
  - Encoder input/output
  - Linear potentiometer

Primary Hypothesis

- Linear gliding stimulus, systematically varied in frequency and acceleration, will:
  - encourage respiratory patterning, sucking, and feeding skills
  - reduce the length of stay in the NICU

Study Population

VestibuGlide infants: Stormont-Vail Healthcare, Topeka, KS
Control infants: Stormont-Vail Healthcare and Overland Park Regional Medical Center, Overland Park, KS.

Inclusion criteria: ≤ 5 days of O₂, stable vital signs and PMA 32 weeks @ study initiation.

Exclusion criteria: IVH (grades III, IV), PVL, NEC, SZ and culture-positive sepsis or meningitis at time of testing, chromosomal anomalies or craniofacial malformation, CNS anomalies, cyanotic congenital heart disease, gastroschisis, omphalocele, IDM, diaphragmatic hernia, major GI anomalies, and/or not ready for oral feeds.

<table>
<thead>
<tr>
<th>Group</th>
<th>Number</th>
<th>Mean Birth GA</th>
<th>Mean Birth weight</th>
<th>PMA @ Start of Testing</th>
<th>Mean VestibuGlide Sessions</th>
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</thead>
<tbody>
<tr>
<td>VestibuGlide</td>
<td>12 (7F/5 M)</td>
<td>32;6</td>
<td>1927.92</td>
<td>34</td>
<td>24</td>
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<tr>
<td>Control</td>
<td>15 (8F/7M)</td>
<td>33;5</td>
<td>1888.13</td>
<td>34;3</td>
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</table>

Gliding Protocol

**VestibuGlide** infants: gliding protocol 3x/day 15 min before scheduled feed for 10-days
- Respitrace™ bands
- Pulse-O₂ sensor

**Control** infants: held and offered a pacifier 3x/day for 15 min before scheduled feed for 10-days but **did not receive** vestibular stimulus

<table>
<thead>
<tr>
<th>Stimulus</th>
<th>Freq (Hz)</th>
<th>RPM</th>
<th>Disp (in)</th>
<th>Accel ( (m/s^2) )</th>
<th>SP ( (m/s) )</th>
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</thead>
<tbody>
<tr>
<td>B1</td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>S1</td>
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<td>30</td>
<td>3.18</td>
<td>0.36</td>
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<td>S2</td>
<td>0.65</td>
<td>40</td>
<td>1.77</td>
<td>0.36</td>
<td>1.08</td>
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<td>S3</td>
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<tr>
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<td>0.78</td>
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<td>S5</td>
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<td>1.02</td>
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<td>S7</td>
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<tr>
<td>B8</td>
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* Gliding sequences were counterbalanced among the seven stimulus types.
Touch Screen Operation and Real-Time Data Display
VestibuGlide Video (Entire Chair Movement)
VestibuGlide Video (Faster Stimulus Rate)
VestibuGlide Video (Slower Stimulus Rate)
Glider Rate Effects on BPM

Aim: To examine the role of vestibular stimulus rate on chest wall motor patterning in preterm infants

Glider Rate Effects on BPM

- Multi-level regression GMM
- Covariates:
  - Birthweight
  - Oxygen hx
  - Caffeine
- Stimuli 2-7 were all significantly different than average baseline condition

Glider Acceleration Effects on BPM

Aim: To examine the role of vestibular stimulus \textit{acceleration} on chest wall motor patterning in preterm infants

Stimulus 7 (fastest acceleration) was significantly different than:
- stimuli 1, 4, 5 for the rib cage
- stimuli 1, 4 for the abdomen
- Vestibular stimulus acceleration had a significant effect on chest wall motor patterning in preterm infants

Vestibular Stimulation and Control of Breathing

Resides in the brainstem respiratory central pattern generator (rCPG)
Coherence: describes the correlation between physical quantities (e.g., frequency content) of waveforms

A coherence analysis was completed to assess entrainment between the glider waveform and abdominal wall outputs.

The highest coherence value between the glider and abdomen was .023 which was in response to stimulus 7 (highest acceleration).

Coherence outcomes were very low (≤.023) providing negative evidence for entrainment between the glider and abdominal wall motion.

Vestibular stimulation had no effect on within-burst NNS measures

- Mean NNS pause periods increased during stimulus conditions compared to baseline \( [F(7,77) = 3.52, p < .01] \)

- No significant difference \( [F(1,22) = .25, p = .625] \) in the oral feed growth slopes between the VestibuGlide and control infants

- **VestibuGlide** infants: oral feeds grew at **8.17%/day**
- **Control** infants: oral feeds grew at **9.47%/day**

Length of Stay

- LOS $[F(1,26) = 4.82, p=.03]$ 
- Discharged from the NICU 9 days sooner than control infants 
- Significant savings $$$
- Improvements: state control, pattern generation, & parental involvement

Bars are One Standard Error from the Mean

### Subjective Observations

- Infants appear to enjoy the stimulus
  - Oxygen saturation and pulse WNL
- Stimulation encourages eye movement
  - Vestibular stimulation has been shown to encourage later emerging sensory modalities including more accurate visual and auditory pursuits (Korner, et al., 1975; Korner, Schneider, & Forrest, 1983; Neal, 1969)
- Infant state
Alert State Post-VestibuGlide Stimulation
Summary

- Vestibular stimulation delivered to the preterm infants between 32 and 34 weeks PMA:
  - Effectively modulates respiratory rate and resets the rCPG
  - Reduced LOS by 9 days

Special Thanks

Topeka NICU
- Sue Hall, MD  Director Neonatal Medicine  
  Stormont-Vail Healthcare, Topeka, Kansas  
- Joy Carlson, NNP  
- Kendi Knox, RN

Overland Park NICU
- Kathleen Weatherstone, MD  Director  
  Sunflower Neonatology, Overland Park  
  Regional Med Ctr, Overland Park, Kansas  
- Diane Thompson, PhD

Biostatistics
- Jaehoon Lee, PhD

CNL Team
- Steven Barlow, PhD  
- Austin Oder, BA  
- Ashley Sakumura, BA
Acknowledgments

"The VestibuGlide study was very beneficial to my son...they did not believe he would take a bottle or pacifier as soon as he did. Once he started the glider he slowly began to finish more bottles. By day six, his skills took off and he became more alert and continuously progressed in suck, swallow, breath techniques. My son physically enjoyed the study, he was alert and maintained eye contact…the study also gave him the opportunity to be held more and receive more contact. I truly believe it made my son leave the NICU sooner."

-Parent of Infant W9

Thank you!