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Patterned Auditory Stimulation and Suck Dynamics in Full-Term Infants

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Abstract

Aim—To determine if patterned auditory stimuli, designed to mimic the natural burst-pause pattern evident in non-nutritive suck (NNS) with variations to the intra-burst frequency, alter infants' NNS and cardiorespiratory patterning.

Methods—Sixteen healthy full-term infants participated in this study. Infants were fitted with electrocardiogram electrodes and a respiratory belt to measure cardiorespiratory patterning. Infants were offered a custom pacifier attached to a pressure transducer to measure NNS. Prior to the start of the study, a two-minute NNS and cardiorespiratory baseline was attained. Next, three auditory stimulation conditions were presented in the form of sucking clicks at inter-burst frequencies of 1, 2, and 4 Hz. Each of the three frequencies was played for two minutes.

Results—Separate repeated measures ANOVAs revealed significant differences in NNS burst duration ($p=.013$), NNS cycles/burst ($p=.010$), and NNS bursts/min ($p=.005$) across auditory stimulation conditions. No significant differences were evident in the cardiorespiratory outcomes.

Conclusion—We found that patterned auditory stimulation significantly reduced NNS dynamics and had no effect on cardiorespiratory patterning. The findings further suggest that infants attempted to modulate their suck pattern to the patterned acoustic stimuli by shortening their burst durations with fewer cycles per burst.

Keywords

acoustic stimulation; non-nutritive suck; infants; feeding

Introduction

Non-nutritive suck (NNS) is one of the first motor tasks an infant completes soon after birth, and this behavior begins *in utero* as early as 15 weeks gestation (1). NNS is extremely well patterned, occurring at an inter-burst frequency of 2 Hz, and is characterized by bursts of sucking events and pause periods for respiration (2). In 1968, Wolff was the first researcher

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to quantify the serial organization of suck development. He sampled suck from 40 full-term infants who were four days old and found the average frequency of sucks/burst to be 2.13 (± .2), the average number of sucks/burst to be 7.17 (±1.31), and the duration of inter-burst rest periods to be 6.61 sec (± 1.5) (2). Wolff also described a linear increase in intra-burst frequency across ages with a mean NNS frequency of 1.7 Hz between 0–3 days of life and 2.6 Hz between 12–24 months. While Wolff was the first to quantify suck behavior, many researchers since have added to his work by further demonstration variations in suck behavior in various cohorts of infants, term infants the first month of life (3), preterm infants (4), and infants of diabetic mothers (5) to name a few. In addition, many researchers have shown the positive outcomes afforded by NNS stimulation, including improved oral feeding, growth, maturation, behavioral state control, and gastric motility (6, 7).

Many of the benefits evident from NNS are likely due, in part, to its neural control mechanisms within the brainstem. The neural substrates for suck are controlled by the suck central pattern generator (sCPG), a network of interneurons that are easily modified by descending cortical inputs and by sensory inputs from the periphery. These circuits are also capable of modulating their motor output in response to sensory stimuli as evidenced previously by the entrainment of NNS to patterned orocutaneous sensory stimulation in premature infants (8, 9). Therefore, the neural circuitry and pathways utilized during NNS behavior are optimal for motor adaptations deriving from sensory inputs from the periphery, such as auditory stimuli.

Auditory sensory stimulation paradigms have been widely used in the preterm infant population in an effort to improve a variety of clinical outcomes. Music therapy has been a favorable form of auditory stimulation due its potential to soothe the infant as well as improve heart rate, behavioral state, and reduce the length of Neonatal Intensive Care Unit (NICU) stay (10, 11). As more research highlights the importance of early language exposure, researchers have started using maternal voice paradigms with preterm infants and measured its effect on weight gain velocity (12), feeding tolerance (13), behavior development (14), and gross motor activity (15). Recently, in a suck-reinforcement study design, Chorna and colleagues utilized a pacifier-activated music player (PAM) that replaced music with the infant’s mother’s voice. In this study, when infants met a preset suck pressure threshold for a set duration, hearing a recording of their mother singing a lullaby rewarded them, and if they stopped sucking, the mother’s voice would stop. This study found that PAM using mother’s voice improved oral feeding skills in preterm infants (16).

A few previous studies have examined the role of auditory stimuli on NNS dynamics in young infants. Daniel and colleagues examined the role of auditory (complex noise) and taste (sucrose) stimuli on sucking, heart rate, and movement in the newborn (17). They found that the presentation of low intensity complex sounds shortened suck latencies compared to the no-sounds trials. This finding was consistent with a previous finding by Sameroff and colleagues who showed that auditory stimuli shortened infants’ sucking bursts and lengthen the duration of their suck interval (18). Similarly, Fischel and colleagues examined suck behavior when infants were presented with a brief presentation of complex sounds. One group of infants heard these sounds at the initiation of sucking bursts and the other group heard these sounds during pause periods between sucking bursts. They found

that infants who were presented with the complex sounds during the pause periods showed significantly more activity levels in response to the sounds than those exposed during suck bursting (19). They also suggested that bursting and pausing were not similar contexts for responding to acoustic stimuli. Taken together, these studies showed that auditory stimuli in the form of noise of complex sounds degraded suck in infants (18, 19). However, Moon and colleagues found that infants initiated bursts of sucking more frequently during maternal syllable exposure compared to the quiet condition (20). These previous studies have shown that there appears to be a neural-physiological link between auditory stimulation and sucking skills, and that the *type* of acoustic stimuli (noise vs. speech) and *when* the sounds are presented (during bursts of sucking or during pause periods for respiration) influence suck behavior.

While these previous studies provided a tremendous amount of information regarding how complex sounds impact suck responsiveness, to our knowledge, no study has examined how *patterned* auditory stimuli presented *continuously* can modulate NNS and whether this type of stimuli alters cardiorespiratory patterning in healthy infants. Therefore, the current study aimed to determine whether infants' NNS and cardiorespiratory patterning could be influenced by patterned auditory stimuli designed to mimic the natural burst-pause pattern evident in NNS with variations to the intra-burst frequency (1, 2, and 4 Hz). We hypothesized that infants would modify their suck dynamics to the patterned acoustic stimuli while maintaining stable cardiorespiratory patterning.

Methods

The effects of patterned auditory stimulation on NNS and cardiorespiratory patterning were tested on 16 full-term (birth weight range 5.6 to 11.2 lbs), healthy infants (12 male/4 female), six months and younger (testing age range: 1 month 4 days to 6 months 20 days), who had no medical complications. We chose to study infants less than six months of age because once infants commence eating soft foods and purees, they tend to lose interest in the pacifier (2). In addition, previous research by Wolff showed that frequency of suck patterning changes minimally (2.0–2.8 Hz) between 1 and 6 months of life (2). Exclusion criteria included preterm birth, serious medical diagnoses, hearing difficulties as diagnosed by newborn hearing screenings, and/or diagnosed feeding problems. The institutional review board approved the study and parental consent was attained prior to the start of the study. Parking was paid for and parents were compensated with a small baby gift.

Parents brought their infants to the lab approximately one hour before their infant's scheduled feeding. This time was purposely chosen to ensure that infants would be in an alert state ready to partake in NNS as previous research has shown that neonatal reflexes, like sucking, are tied to the infant's ability to attain and maintain an alert state (21). As part of an initial intake form completed by the mothers prior to the study, we asked if their infant used a pacifier at home and if so which pacifier. Overall, we did not find maternal report of pacifier usage to influence the NNS results and a majority of the mothers reported that their infant used a variety of pacifiers on a daily basis. After all of the intake forms were completed, infants were fitted with a Pneumotrace respiratory belt transducer (ADInstruments) to measure respiratory rate (RR), and Softrace small radiotranslucent

electrodes to measure cardiac data (heart rate [HR] and heart rate variability [HRV]). The cardiac signals were amplified using a BioAmp (ADInstruments). The study took place in the Infant Discovery Room within the lab, which is a sound treated room with a fabric wrapped acoustic panel on one wall designed to reduce noise. Next, infants were offered the Soothie pacifier, which was connected to a custom measurement system to detect and measure the infants' NNS pattern. The system utilized a pressure transducer (Honeywell TruStability™ HSC Series Pressure Sensor) that measured the pressure within the pacifier during infant sucking. The input voltage was 5 volts direct current (VDC), the output voltage was 0–5 VDC, the measurement range was 0–138.4 inches H_2O, and the pressure transducer was housed within the pacifier handle. The pressure transducer was calibrated prior to each participant.

Once the study started, the specialized noise reducing and fully sealed door to the room was closed in order to keep excess noise levels within the room to a minimum. In addition, the mothers were instructed not to speak during the study unless it was an emergency. During the study, infants were positioned on the caregivers' lap approximately one meter from the loud speaker and they faced a white wall. At the beginning of the study, the infant sucked on a pacifier for two minutes to attain baseline for suck and cardiorespiratory patterning. After the two-minute baseline, the patterned acoustic stimuli were presented to the infant via a loudspeaker. These sounds were played at a safe listening level (i.e., 80 decibel peak sound pressure level due to their short duration) and sound level was tested prior to the start of every session. The acoustic stimuli consisted of patterned suck clicks made by an adult NNS expert by clicking her tongue against the roof of her mouth. The recorded burst contained 7 cycles in an effort to replicate the average cycles per burst of a "typical" suck pattern described by Wolff in 1968. Next, the burst recording was mixed in Audacity® (version 2.1.2) so that the subsequent burst sounds were copied and pasted from the original recording with a set pause period between bursts of 6.5 seconds, again to replicate the typical inter-burst pause period previously described by Wolff. We then altered the original burst recording in Audacity® so that the intra-burst frequencies were 1, 2, and 4 Hz in an attempt to modulate the infant's suck (Figure. 1). We purposely chose to have an adult make the suck click sounds so that we could have more control over the acoustic stimuli. Each intra-burst frequency (1, 2, 4 Hz) was presented for two minutes each. Presentation orders of acoustic frequency conditions were counterbalanced and randomly assigned among participants. Data acquisition was completed using the ADInstruments PowerLab (16/35) and Labchart Pro software was used to analyze cardiorespiratory and NNS dynamics. These suck dynamics included NNS burst duration (sec), NNS cycles per burst, NNS cycles per minute, NNS bursts per minute, NNS frequency (Hz), and NNS amplitude (cmH_2O), see Figure 2.

Results

Sixteen full-term infants completed this study; however, only twelve infants provided data that could be analyzed due to behavioral-related issues (e.g., crying, refusal to suck, etc.). The infants who fully completed the study were observed to be relaxed and comfortable in the environment throughout the study session. The infants who experienced difficulty cooperating were often hungry or agitated. Separate repeated measures ANOVA were

completed to examine the effect of patterned auditory stimuli on each dependent variable (see Table 1). No statistically significant differences were observed between patterned acoustic stimuli and the cardiorespiratory outcomes. However, statistical differences were found between acoustic patterned stimuli and the following NNS variables: NNS burst duration (sec), NNS cycles/burst, and NNS cycles/min.

NNS burst duration was found to be significantly (*p=0.013*) different for auditory conditions. Pairwise comparisons revealed that infants had significantly (*p=0.002,* 95% CI [.314, 1.480]) longer NNS burst durations during the baseline compared to the 2 Hz acoustic stimuli. The baseline condition produced an average NNS burst duration of 3.32 sec (± 2.14); whereas, the 2 Hz condition produced a shorter NNS burst duration of 2.42 (± 1.78) sec.

NNS cycles/burst was found to be significantly (*p=0.010*) different for auditory conditions. A pairwise comparison revealed that the baseline condition significantly (*p=0.007,* 95% CI [.500, 3.457]) increased the NNS cycles/burst compared to the 2 Hz acoustic stimuli. The baseline condition produced an average NNS burst duration of 7.16 cycles/burst (± 4.23); whereas, the 2 Hz condition produced a reduced amount of NNS cycles/burst of 5.18 (± 3.44).

NNS cycles/min was significantly (*p=0.005*) different for auditory stimuli. A pairwise comparison revealed that the baseline condition significantly (*p=0.043,* 95% CI [.311, 23.92]) increased the NNS cycles/min compared to the 1 Hz acoustic stimuli. The baseline condition produced an average NNS cycles/min of 38.96 cycles/min (± 26.21), while the 1 Hz condition produced a reduced NNS cycles/min of 26.84 (± 20.63).

Discussion

In this study, we examined whether patterned and continuous auditory suck stimuli that varied in intra-burst frequencies (1, 2, and 4 Hz) could alter infants' suck and cardiorespiratory patterning. We found that certain frequencies of patterned auditory stimulation significantly reduced NNS outcomes, such as NNS burst duration, NNS cycles per burst, and NNS cycles per minute. These findings are consistent with previous literature showing that auditory stimulation presented while sucking reduced NNS behavior (18, 19). With each significant dependent measure, pairwise comparisons showed that the largest differences were evident when comparing the baseline vs. either the 1 or 2 Hz conditions. It is likely that the 4 Hz stimuli was too different from the infant's natural suck frequency for adaptation to occur; whereas, in the 1 and 2 Hz conditions modulation was more feasible.

While no statistical differences were evident in NNS frequency, infants sucked the fastest (2.17 Hz) during the 2 Hz stimuli and the slowest (2.09 Hz) during the 1 Hz stimuli, thereby demonstrating minimal suck modulation around 2 Hz. This finding is consistent with previous literature that reporting NNS frequency to range from 2.0–2.8 Hz between birth and 6 months of life (2). This minimal frequency adaptation is likely due to the reflexive nature of NNS and the health status of our subjects. Previous research by Barlow and colleagues found that healthy preterm infants manifested significantly longer NNS burst

structure with different NNS burst formation compared to premature infants with respiratory distress syndrome (22).

It is clear that infants modulate their suck activity while acoustic stimuli are presented; however, the exact pathway and mechanism for this neural connectivity remains unknown. We speculate two mechanisms that might be involved. One possibility is that acoustic stimuli changes the infant's state control which then alters the infant's suck patterning. This is consistent with previous research showing that neonatal reflexes, like sucking, are tied to the infant's ability to attain and maintain an alert state (21, 23). Another possibility is the connectivity between the auditory system and the sCPG. Previous studies have shown entrainment of the sCPG to patterned orocutaneous stimulation (8, 9). While, we did not see evidence of entrainment in our study, we speculate that lack of entrainment could be due to the brief, one time exposure of the auditory stimuli in this study.

The infants in our study had only a short (2 minutes for each frequency), one-time exposure to the patterned acoustic stimuli and modified their NNS burst duration, NNS cycles/burst, and NNS cycles/min thereby indicating suck adapting to acoustic stimuli relatively quickly. This type of quick modulation has also been shown in orocutaneous suck stimulation paradigms (8, 9). These studies found quick modulation (the day of the stimuli) but also modulation over time (10 days) after repeated exposures to these stimuli. Therefore, it is likely that an extended period of exposure to the patterned auditory stimuli over time could be beneficial in revealing the clinical effectiveness of this type of stimuli. Such studies would determine if using patterned auditory stimulation as a therapeutic intervention could enhance NNS for infants with delayed suck behaviors, particularly premature infants in the NICU. This is an important next step as therapies that increase the neural drive to the sCPG have the potential to reduce the intensity on internal needs and allow the infant's focus to be more on external needs, such as responding to one's local environment (24), an essential part of early learning. As such, future studies should also focus on a larger number of infants, as well as different cohorts of infants, such as infants born prematurely.

Understanding how auditory stimulation impacts NNS skills is clinically important because sucking is an innate skill that is essential for proper growth and development. Many speech-language pathologists (SLPs) assess suck in a variety of environments (NICU, home, clinics, etc.), and results from the current study suggest that assessing NNS in infants while a patterned auditory stimulus is present degrades suck patterning. Therefore, SLPs and other developmental specialists should consider the acoustic environment (noise versus quiet) when assessing suck patterning.

Lastly, in our study we found that infants were able to modulate to their suck patterning to patterned acoustic stimuli while maintaining stable cardiorespiratory control. We speculate that this is likely due to the fact that our infants were healthy and born full-term. This finding was not surprising as a previous study from our lab showed that healthy infants maintained stable cardiorespiratory patterning across feeding phases (25). However, ensuring this level of stability in healthy infants is imperative before moving to more at-risk populations who will likely have more difficulty with this task. For example, infants born

prematurely often have more difficulty achieving the balanced stimulation of sympathetic and parasympathetic pathways (26) needed for adequate cardiorespiratory stability.

There were several limitations to this study. This study included a small sample of healthy infants that were tested at a single time point. This approach was purposeful as the primary goal of this work is to examine the auditory stimuli-NNS relationship in healthy infants before presenting it to more at-risk populations. More research needs to be completed to examine how populations with poor suck patterning would adapt to this form of auditory stimuli.

Conclusions

The results of this study indicated that patterned auditory stimuli presented continuously altered suck patterning in full-term infants. Infants had significantly longer NNS burst duration, a greater number of cycles per burst, and more cycles per minute during the baseline condition compared to the patterned acoustic stimuli conditions.

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Abbreviations

HR	Heart Rate
HRV	Heart Rate Variability
NICU	Neonatal Intensive Care Unit
NNS	Non-nutritive suck
PAM	Pacifier Activated Music
RR	Respiratory Rate
sCPG	suck central pattern generator
VDC	Volts Direct Current

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Key Notes

- Little is known about how patterned auditory cues can influence non-nutritive suck patterning in healthy infants.
- Infants attempted to modulate their non-nutritive suck in response to auditory stimuli by reducing their suck activity with significantly fewer suck bursts that lasted a shorter duration with less suck cycles per burst.
- Future studies are needed to further explore the connectivity between auditory stimuli and non-nutritive suck behavior.

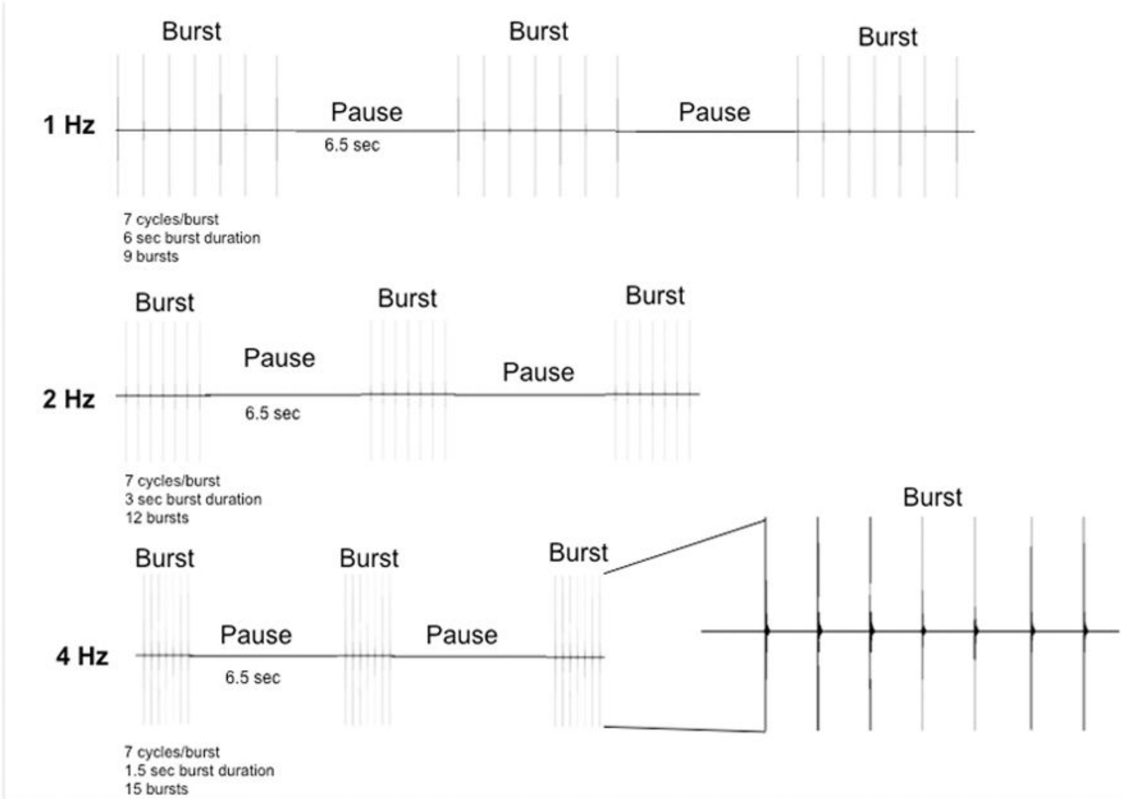

Figure 1.

An example of the patterned auditory stimuli. These sounds were essentially suck sound clicks that were presented to the infant. The patterned stimuli mimicked the burst/pause pattern that is characteristic of NNS and all stimuli were 7 cycles/burst with a 6.5 second inter-burst pause period. The stimuli conditions differed in their intra-burst frequency and burst duration.

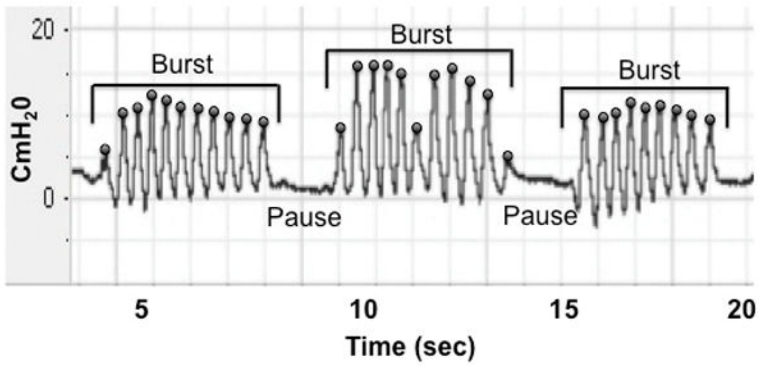

Figure 2.

NNS is organized in bursts (black brackets) of sucking and pause periods for breathing. Each burst contains approximately 6–12 cycles (black circles). The suck pressure amplitude is measured in cmH_2O. The suck dynamics included in our study included the following: NNS burst duration, NNS cycles per burst, NNS cycles per minute, NNS bursts per minute, NNS intra-burst frequency (Hz), and NNS amplitude (cmH_2O).

Table 1

Dependent Variable	Baseline	1 Hz	2Hz	4Hz	RM ANOVA	Pairwise Comparisons
Respiratory Rate (BPM)	62.77 (±12.31) 52.70–90.96	58.42 (±10.21) 46.12–87.17	64.50 (±22.16) 39.93–131.67	64.20 (±14.28) 45.24–87.31	F(3, 36)=.903, *p=.449*	
Heart Rate (BPM)	143.42 (±16.87) 139.53–170.33	143.02 (±17.44) 109.10–166.55	142.07 (±19.58) 91.11–160.76	146.34 (± 14.36) 118.09–168.93	F(3, 36)=.293, *p=.829*	
High HRV (%)	19.80 (±11.1) 7.20–42.01	24.70 (±19.92) 5.26–67.65	20.83 (±16.33) 3.69–59.23	20.19 (±14.08) 5.33–51.79	*F(3, 33)=.456, *p=.655*	
Low HRV (%)	74.10 (±25.16) 1.87–92.46	73.03 (±22.32) 21.50–93.72	77.57 (±18.22) 33.20–96.34	78.06 (±15.92) 43.76–94.61	*F(3, 33)=.254, *p=.748*	
LF/HF (%)	7.86 (±5.51) 1.87–20.53	7.50 (±6.10) .35–17.81	10.29 (±12.28) .61–39.2	8.78 (±8.06) .89–26.76	*F(3, 33)=.301 *p=.668*	
NNS Amplitude (CmH20)	91.41 (±26.36) 43.41–124.53	93.63 (± 21.84) 55.67–140.37	86.37 (±29.32) 54.40–139.04	88.99 (±35.97) 29.27–167.80	F(3, 36)=.507 *p=.680*	
NNS Frequency (Hz)	2.11 (±0.25) 1.63–2.62	2.09 (±0.28) 1.69–2.59	2.17 (±0.29) 1.61–2.58	2.12 (±0.32) 1.46–2.73	F(3, 36)=.588 *p=.627*	
NNS Bursts/Min	5.00 (±2.51) 1.00–9.00	4.62 (±2.38) 2.00–9.00	4.38 (±2.36) 1.00–7.50	3.58 (±1.62) 1.00–6.00	F(3, 36)=2.11 *p=.115*	
NNS Cycles/Burst	7.16 (±4.23) 2.33–17.00	5.31 (±2.38) 2.00–8.50	5.19 (±3.44) 2.00–14.75	6.04 (±3.73) 2.00–13.20	F(3, 36)=4.34 *p=.010*	**Baseline vs. 2 Hz (*p=.007*)
NNS Cycles/Min	38.96 (±26.21) 2.50–82.00	26.85 (±20.63) 5.50–59.50	26.15 (±23.23) 2.50–78.50	23.88 (±18.45) 2.00–66.00	F(3, 36)=5.13 *p=.005*	**Baseline vs. 1 Hz (*p=.043*)
NNS Burst Duration (sec)	3.32 (±2.14) 1.01–9.01	2.44 (±1.10) 1.11–4.55	2.42 (±1.78) .88–7.81	2.80 (±1.85) .91–6.98	F(3, 36)=4.10 *p=.013*	**Baseline vs. 2 Hz (*p=.002*)

* Greenhouse-Geisser Correction

** Bonferonni Post-hoc Adjustment