

Non-Nutritive Suck Assessment Tool Development to Characterize Sucking Patterns in Infant with Various Hunger Levels

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Abstract

Sucking abilities are critical in early infant development, and the patterns of non-nutritive suck (NNS) have been found to potentially predict neurodevelopmental issues in the future. Proper NNS assessments are essential to ensure valid conclusions. Previous studies have shown that the level of infant arousal significantly affects NNS patterns. However, the author did not find any studies that observed the influence of infant hunger levels on NNS patterns. Therefore, this study aimed to develop an NNS assessment tool to characterize NNS patterns in infant with various hunger levels. The NNS assessment was conducted using a pressure transducer connected to a pacifier. The results showed that the level of hunger significantly affected the intra-burst frequency and the sucking pressure. The more hunger the infant, the more frequent the intra-burst frequency became, while the sucking pressure tended to decrease. The intra-burst frequency of infant sucking was 2.3, 2.46, and 2.5 Hz on average for relative hunger index of 0.67, 0.83, and 1.0, respectively. The NNS pressure of infant's sucking were 6.31, 4.51, and 2.62 kPa on average for relative hunger index of 0.67, 0.83, and 1.0, respectively. This study's results suggest that during NNS assessments, the measurement time should consider the next feeding schedule for the infant.

Keywords: sucking abilities, non-nutritive suck patterns, hunger level, NNS assessment tool

1. Background

Suckling without obtaining nutrition, such as on a dummy (a pacifier, his/her thumb, or other objects) or an empty breast, is one of the infants' initial abilities. It is known as non-nutritive suck (NNS) [1]. Wolff (1968) [1] was the first to characterize the NNS pattern, and since then, numerous researchers have studied its emergence and development [2-9]. The NNS pattern consisted of suck bursts and respiration intervals (pause). Several important parameters in the NNS pattern are the burst structure (NNS intra-burst frequency) and suction strength (NNS pressure). Recently, NNS assessments were used for a comparative study between full-term and preterm infants [10,11] and infants of two different ages [12]. Examining the NNS pattern could also be used to identify central nervous system problems and neurodevelopmental issues later in life [13], and to predict which premature infants would have feeding difficulties [14,15].

Generally, the NNS equipment consists of pacifiers connected to a pressure transducer

equipped with a data acquisition system. Zimmerman, Forlano, & Gouldstone (2007) [3], Zimmerman, Carpenito, & Martens (2020) [16], Martens *et al.* (2020) [12] utilized the Honeywell TruStability HSC Series, ADInstruments PowerLab, and LabChart as pressure transducer, data acquisition system, and user interface, respectively. Estep *et al.* (2008) [17] utilized the National Instruments PCI-6052E for real-time data acquisition and Neosuck RT as a software program that can automatically tag the individual pressure cycles of an NNS burst. Developing NNS assessment tools not only focuses on the data acquisition system, but the software algorithm is also a concern in development. Liao *et al.* (2019) [18] has been developed a graphical user interface that provides automatic NNS signal preprocessing.

The NNS pattern is influenced by the level of arousal. Pineda *et al.* (2019) [4] classified infant arousal levels into six categories: deep sleep, light sleep, drowsiness, quiet awake, active awake, and crying, with scores of 1, 2, 3, 4, 5, and 6, respectively. Thus, it is critically important to consider the state



of the infant during assessment. Frequently, NNS assessments are performed in an active-awake state [3,12,19]. Changes occur in the infant NNS structure throughout a suck sample [16]. Zimmerman et al. (2020) [16] suggested that is change might be due to fatigue, state or behavioral changes, habituation to the NNS task, or hunger signaling. However, no study has quantitatively identified infant NNS patterns at various hunger levels. Nonetheless, it is worth noting that hunger levels have been demonstrated to impact NNS in dairy cows, without intending to draw a direct comparison between infants and dairy cows [20]. Therefore, this study aimed to develop an NNS assessment tool and apply it to determine changes in NNS parameters at different hunger levels. The developed NNS assessment tool is simple, affordable, and open source.

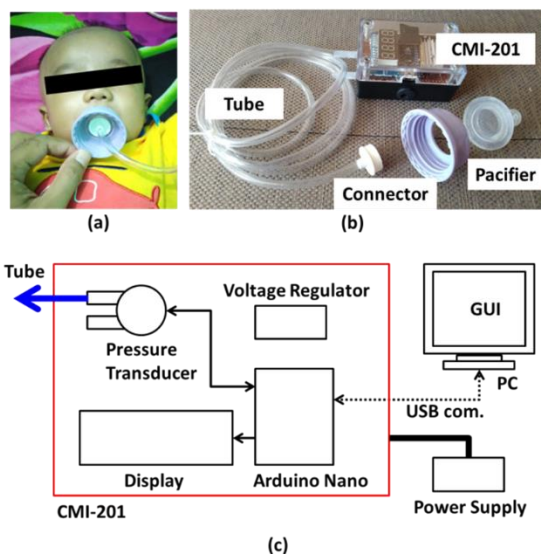


Figure 1. (a) A photograph of the use, (b) an NNS assessment tool, and (c) its block diagram.

2. Methodology

2.1 Development of NNS Assessment Tool

The NNS assessment tool (referred to as CMI-201) was used in this study, as shown in Figure 1(a). The pacifier, which had a flat base, type-A (soothie) shaped with a base diameter of 33 mm, a height of 4 cm, and a tip diameter of 13 mm (Size M, Pigeon Corp., Japan), was connected to a pressure transducer through an 8 mm tube. The connector used was originally a flow regulator in a 120 ml milk bottle (Pigeon Corp., Japan). CMI-201 consists of a



pressure transducer (Model MPX5010DP, Freescale Semiconductor, Inc., USA), an Arduino Nano board, a seven-segment display, and a voltage regulator (Model LM7805, Texas Instruments, Inc., USA), as shown in Figure 1(b-c). The CMI-201 is a simple and affordable self-designed differential pressure measurement device. CMI-201 originally had a multipurpose application; in this study, it was used for the NNS assessment. The voltage regulator provides a constant and stable 5V supply. The Arduino Nano board with an ATmega328 core was programmed to read the pressure measurement results by the pressure transducer, send pressure data to a PC (for further processing), and display it via seven segments (for a simple measurement feature). The use of an Arduino development board makes it easier to replicate by others. Several researchers have also used Arduino boards to develop robotic arm [21] and monitor heart conditions [22–24].

A graphical user interface (GUI) for CMI-201, named CMI_{dp}, has been developed to aid in data acquisition, as depicted in Figure 2. CMI_{dp} automates the calculation of various NNS parameters, such as intra-burst frequency, cycles/burst, and pressure amplitude.



Figure 2. Front view of CMI_{dp} graphical user interface.

2.2 Implementation Trial

In this study, the hunger level of an infant was quantified using the relative hunger index (H). The relative hunger index is defined as the ratio of the length of time from the last feeding to the interval between scheduled feedings. This definition is proposed considering that the length of time since the last feeding is correlated with the infant's level

of hunger. The longer the time from the last feeding, the more infant becomes a hungrier. The relative hunger index (H) was calculated as follows:

$$H = \frac{T_{LF}}{\Delta T_F} \quad (1)$$

where T_{LF} and ΔT_F are the length of time from the last feeding and interval time between feedings, respectively.

3. Result and Discussion

A simple and cost-effective NNS assessment tool was successfully developed. It consists of hardware (CMI-201) and user interface (CMI dp). The NNS assessment tool was used to measure the NNS patterns of a full-term 17-week-infant. Several attempts have been conducted while observing the condition of the infant during experiments. The results of the non-nutritive suck (NNS) measurements are shown in Figure 3.

The NNS pattern was observed at relative hunger index (H) of 0.67, 0.83, and 1.0. As mentioned in the method section, e.g., $H = 0.67$ means that the infant already has 0.67 times of interval-time between-feeding schedule. Except for $H = 1.0$, after 7.5 s (indicated by the black arrow), the infant started to fuss, so the data was atypical with short bursts in 15-17, 22-25, and 32-34 s. At 45 s, the measurement was stopped because the infant started crying. Neiva *et al.* (2014) [25] also neglected to conduct an assessment when the infant exhibited signs of distress such as crying, hiccups, and choking. Meanwhile, at $H = 0.5$ and < 0.5 , we did not find the typical NNS pattern. At $H = 0.5$, there were irregular bursts because the infant was more likely to want to reject the pacifier.

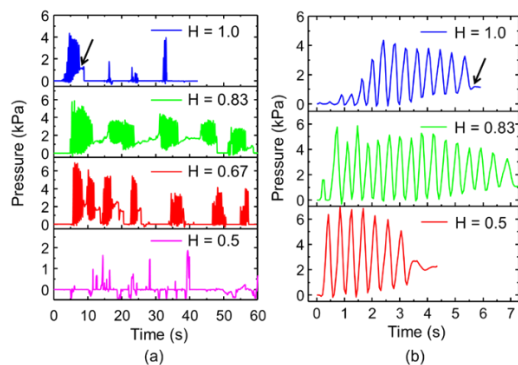


Figure 3. (a) NNS burst for $H = 0.5, 0.67, 0.83,$ and 1.0 . (b) First burst for $H = 0.67, 0.83,$ and 1.0 . A typical NNS pattern was not observed for $H = 0.5$.



Figure 3 displays the burst patterns of the initial bursts at $H = 0.67, 0.83,$ and 1.0 , providing a clearer representation of the NNS pattern. The burst pattern at $H = 0.83$, indicating hungrier infants than at $H = 0.67$, exhibited a longer duration, with 16 cycles/burst compared to 8 cycles/burst at $H = 0.67$. The cycles of the first burst at $H = 1.0$ were more than those at $H = 0.67$, although the cycles/burst at $H = 1.0$ could not be compared due to constraints imposed by the infant's condition, as previously mentioned.

The important parameters in the NNS pattern are the burst structure (NNS intra-burst frequency) and suction strength (NNS pressure). It was found that the frequency of intra-bursts tended to increase, while the suction pressure tended to decrease with increasing hunger level (see Figure 4). The intra-bursts frequency of infant's sucking were 2.3 Hz (Standard Deviation, SD = 0.14 Hz and Standard Error, SE = 0.05), 2.46 Hz (SD = 0.3 Hz, SE = 0.07 Hz), and 2.5 Hz (SD = 0.2 Hz, SE = 0.05 Hz) for relative hunger index of 0.67, 0.83, and 1.0, respectively. The NNS pressure of infant's sucking were 6.31 kPa (SD = 0.65 kPa, SE = 0.25 kPa), 4.51 kPa (SD = 1.02 kPa, SE = 0.25 kPa), and 2.62 kPa (SD = 1.6 kPa, SE = 0.43 kPa) for relative hunger index of 0.67, 0.83, and 1.0, respectively.

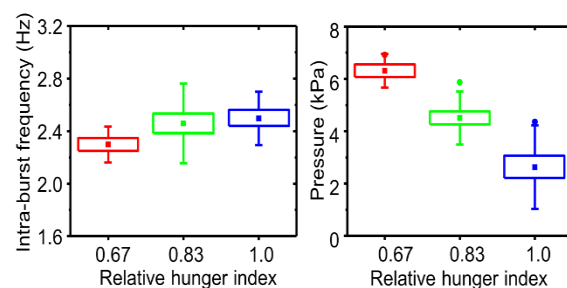


Figure 4. Box plot of (a) NNS intra-burst frequency and (b) pressure in various relative hunger indexes. The box and whisker indicate the standard error and standard deviation, respectively. The square and circle dots indicate the average and maximum value.

The increase in intra-burst frequency indicates that the infant's mouth movement effort increased due to hunger. The increase in intra-burst frequency observed in this study is likely a reflection of the infant's increased effort to obtain milk from the mother's breast. This increased effort may also result in increased fatigue and reduced energy reserves, which could contribute to the

observed decrease in suction pressure. These results indicate that the infant's condition (hunger level, or practically the condition of the infant's readiness for NNS assessment) can be a concern in NNS assessment. Considering the infant's readiness to suckle, the NNS assessment could be used to differentiate between infants with and without compromise due to bronchopulmonary dysplasia [26]. However, on the other hand, failing to consider the infant's readiness to suckle can lead to a misinterpretation of the results obtained during the NNS assessment.

This study showed that the NNS pattern depends on hunger levels. The NNS duration, intra-burst frequency, cycles/burst, and pressure can also be affected by the pacifiers used [3]. A typical pattern was observed at one hour after feeding (hunger level > 0.5). However, the measurement was only performed on one infant. Thus, the results of measuring the NNS pattern at various hunger levels may not allow general conclusions to be drawn. It should be noted that this article focuses more on discussing the development of the NNS assessment tool. Meanwhile, testing for various hunger levels was used to show that the tool could assess NNS patterns at several variations in infant hunger levels. More samples will be used in the next research. Nevertheless, the results presented are sufficient to describe the changing pattern of NNS during hunger. This result suggests how to perform NNS assessment properly; if the length between feedings was two hours, it could carry out less than one hour (hunger level > 0.5) before the infant's scheduled feed. As in Estep *et al.* (2008) [17], Zimmerman *et al.* (2017) [3], and Martens *et al.* (2020) [12], NNS was assessed one hour before the infant's scheduled feed.

4. Conclusion

A simple and affordable non-nutritive suck (NNS) assessment tool, CMI-201, was developed. The CMI-201 consists of a pressure transducer, an Arduino Nano board, a seven-segment display, and a voltage regulator. A graphical user interface (GUI), CMIdp, was also developed for data acquisition and automatic processing. In this study, the CMI-201 was used to assess infants at various hunger levels (quantified as the relative hunger index). The results showed that the burst structure and suck

strength depend on the hunger level. The intra-burst frequency of infant sucking was 2.3, 2.46, and 2.5 Hz on average for relative hunger index of 0.67, 0.83, and 1.0, respectively. The NNS pressure of infant's sucking were 6.31, 4.51, and 2.62 kPa on average for relative hunger index of 0.67, 0.83, and 1.0, respectively. The cycles/burst at a relative hunger index of 0.83 also found to be higher than that at a relative hunger index of 0.67. The intra-burst frequency and cycles/burst tended to increase as more hunger indicated that the infant tried more intensely to suckle. Unfortunately, the suck strength decreased with increasing hunger. As a limitation, this study did not examine the effect of infant drowsiness; therefore, measurements were performed while the infant was in an active state.

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