Measuring Breathing and Swallowing Coordination in Human Infants Using the Kay Elemetrics Swallowing Workstation

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This application note describes the way in which infantile breathing-swallowing coordination can be measured using the Kay Elemetrics Swallowing Workstation. Three components provided with the workstation are utilised from which time-locked information regarding the direction of airflow at the nares and the onset of swallowing are recorded. The breathing- swallowing coordination of infants during any method of feeding (including breast), during wakefulness and sleep may be determined using the method described in this application. Although infants over 9 months may be less tolerant of this procedure than neonates, it is still possible to use the equipment on toddlers particularly for breast or bottle-feeding. Understanding patterns of breathing-swallowing coordination may be important clinically; this coordination may be important in preventing the aspiration of ingested fluids (McPherson et al., 1992). Future research may show that the identification of disordered breathing-swallowing coordination patterns in the pediatric patient population should play an important role in clinical decision-making.

Infantile Breathing-Swallowing Coordination

Swallowing always interrupts the breathing of humans, including premature infants (Wilson, Thach, Brouillette, & Abu-Osba, 1981; Weber, Woolridge, & Baum, 1986; Stevenson & Allaire, 1991). This cessation of respiration during swallowing is known as swallowing apnoea. For purposes of this application note, breathing-swallowing coordination is defined by the point in the respiratory phase cycle where swallowing apnoea occurs. Nutritive (feeding) and non-nutritive swallowing apnoea may occur at one of the following four stages in breathing: during expiration, during inspiration, at the transition (cusp) between inspiration and expiration or between expiration and inspiration (Wilson et al., 1981; Bamford, Taciak, & Gewolb, 1992). Infantile nutritive (Lau, Smith, & Schanler, 2003; Mizuno & Ueda, 2003) and non-nutritive swallows (Wilson et al., 1981) may also occur during respiratory pauses that last between 3 and 15 seconds.

The adult pattern of breathing-swallowing coordination during eating and drinking is well established, with 75-95% of swallows beginning in the expiratory phase (Preiksaitis, Mayrand, Robins & Diamant; 1992; Shaker et al., 1992; McFarland & Lund, 1995; Paydarfar, Gilbert, Poppel & Nassab, 1995; Hiss, Treole & Stuart, 2001) compared to 39% in newborns (Bamford et al., 1992). Nutritive swallows of healthy full term infants occur predominantly at the inspiratory-expiratory cusp, otherwise in mid-expiration and occasionally at the expiratory–inspiratory cusp (Selley et al., 1986; Selley, Ellis et al., 1990; Bamford et al., 1992). An infant whose breathing-swallowing coordination during feeding deviates from this pattern could be considered ‘disordered’. For instance, premature infants (33 weeks post-conception), unlike full term infants, swallow predominantly during respiratory pauses (Mizuno & Ueda, 2003). It is important to bear in mind that the functional significance of this deviation is not yet fully understood.

Data Collection

Set-up Procedure on the Workstation

In order to determine where swallows occur within the respiratory phase cycle, three phenomena are measured: the direction of nasal airflow (using a nasal canula), submental muscle activity (using submental surface electromyography) and thyroid acoustics (using a laryngeal microphone). Below is a description of the set up configuration that is used specifically for the Kay workstation in our laboratory when assessing the pediatric population.

The workstation should be configured with a new exam template to allow for these three phenomena to be concurrently recorded. Begin by selecting 'New Exam' on the menu bar, followed by 'Configure Manually'. Under the general 'Options', check 'SEMG', 'Nasal' and 'Acoustics'. Then select the SEMG option and ensure that the configuration is set up as described below. In our experience for ease of viewing patterns of respiration and swallowing of infants, full scale for SEMG is normally set at 100.0 uV (microvolts) with a sampling rate of 250Hz and the time on screen of 30 seconds. A more detailed analysis of individual swallows, by viewing a shorter time span (using the mouse highlight the relevant data and select 'Show Selected Data'), may be done post-data collection. Similarly for the nasal option, the configuration is normally set as follows: full scale display is set at 10 (in our experience, this maximum sensitivity setting is optimal for infants), sampling rate of 250Hz and the time on screen 30 seconds. For acoustic options, the display is typically set at 100 uV, the sampling rate at 4000Hz and 30 seconds of display time is selected. Then click OK. Note that the sampling frequency of the higher bandwidth acoustic channel is substantially higher than that required for the cannula and sEMG signals. The Kay system allows each signal to be sampled at a rate that is optimal for its bandwidth (i.e., independent of other transducers' sampling rates) while maintaining time alignment between the various channels of data. Once the configuration parameters are selected, they can be saved as a template and easily retrieved for future exams by selecting 'File' from the menu bar and 'Save Template As…' Recalling the saved template eliminates the need to go through this set up process for each new session.

The Transducers

The three required transducers, which are connected to the workstation's data acquisition hardware, are listed below. The positioning of these transducers on an infant can be seen in Figure 1. Suitable SEMG and acoustic equipment are supplied by Kay Elemetrics, however the pediatric (as opposed to adult) nasal canulas have to be purchased elsewhere. It is important to note that older infants (from 9 months of age) will be less tolerant of the use of nasal canula and surface electrodes and thus recording may be difficult. For safety reasons, care should always be taken to ensure that the electrical cables of each piece of equipment are out of the older infant's sight. This may be achieved by grouping and taping the cords to the child's clothing on his/her back. Given the restriction in movement created by equipment placement, mobile infants should be encouraged to stay in one place by an appropriate caregiver or guardian.

1. Nasal <u>prongs/canula.</u> Commercially available pediatric nasal canulas of any size (generally referred to as neonate, infantile or pediatric) e.g., those made by Allegiance Healthcare Corporation (McGaw Park, IL, USA) are directly fitted onto the nasal connector on the Kay Workstation. The correct positioning of the nasal prongs into the nares must be ensured such that the direction of airflow from the nose is detected. For breastfeeding, the nasal canula is ideally fitted prior to commencing a feed given that access to the infant's nose will be limited once feeding has begun. For infants over the age of 9 months, it is recommended that appropriate tape is used to tape the tubing to the cheek to keep the nasal prongs in situ. Be sure to calibrate before inserting the canula into the nares (footnote: select 'Waveform' from the toolbar, then 'Calibrate' and 'Nasal…' options). During quiet breathing, recording will produce alternating positive (green) and

negative (red) waves that correlate with expiration and inspiration, respectively (please refer to Figure 2). During swallowing, the lack of nasal airflow (a reflection of swallowing apnoea) will result in a black flat line at the baseline. The duration of this swallowing apnoea can be measured manually (after the recording has been terminated) using the mouse and highlighting the length of the black apnoeic line. Refer to the section below on data analysis for greater detail.

2. Submental surface electromyography. Adult electrodes (provided with the system) can be used on neonates and infants. In using the adult electrodes, space under the chin may be limited especially in neonates. In this case, the reference electrode may be placed on the forehead (Figure 1). Alternatively, Wilson and colleagues (1981) found that electrodes placed over the chin and hyoid bone, with an ear electrode as a reference point, was "the most reliable and specific method for recording swallow-associated EMG activity" (Wilson et al., 1981, p. 852).

3. Laryngeal microphone. The use of a laryngeal microphone allows for the detection of the acoustics associated with swallowing. Coupled with the SEMG peak, an acoustic burst assists in the identification of a swallowing event. The use of both pieces of equipment is particularly useful in the pediatric population since tongue movements that aren't necessarily associated with swallowing will produce SEMG activity (Figure 3). Microphones have been used in prior research to identify swallows in adults (Takahashi, Groher, & Michi, 1994) and infants (Selley, Ellis et al., 1990; Hanlon et al., 1997; Pinnington, Smith, Ellis, & Morton, 2000). The workstation is supplied with an adult stethoscopic microphone which is too large for usage with the pediatric population. A smaller stethoscopic head can be substituted for the pediatric population, on request from the company. Alternatively, the laryngeal microphone can be custom-made using an omnidirectional condenser microphone, with a sensitivity of 62 +/-3dB and a frequency response of 50-12500Hz. In order to increase the signal to noise ratio, the microphone can be embedded in silicon (Figure 4). A fibre washer, available from any hardware store, may be used to prevent the silicon from covering the microphone's diaphragm. This type of microphone requires a preamplifier (Figure 5) to boost the level of the microphone signal (for example, a Rolls mini-mic preamplifier MP13 with a variable gain of 6-50 dB). The preamplifier is then connected to the acoustic channel on the Workstation.

Data Analysis

In order to determine the coordination of breathing and swallowing, the respiratory phase before and after the swallow must be identified i.e. inspiration or expiration. Swallows may be categorised into one of the following 4 phases: inspiration-swallow- inspiration (II), inspiration-swallow-expiration (IE, e.g., Figure 6), expiration-swallow-expiration (EE, e.g., Figure 7), expiration-swallow-inspiration (EI). Infants may also swallow during respiratory pauses (Wilson et al., 1981; Mizuno & Ueda, 2003; Lau, Smith, & Schanler, 2003) that last between 3 and 15 seconds (Figure 8).

The precise duration of the swallowing apnoea may also be determined by using the mouse and highlighting the apnoeic area on the screen (Figure 7). The duration of the shaded area will appear above the cursor (Figure 7). Please note, that if an infant swallows during a respiratory pause, the duration of swallowing-related apnoea cannot be identified since it will be imbedded in the long respiratory pause.

Clinical Applications

It appears that infants and young children with respiratory and neurological disorders coordinate their breathing and nutritive swallowing in a different way to their healthy counterparts. Post-swallow apnoea and post-swallow inspiration occur significantly more frequently in infants suffering from acute bronchiolitis (which results in tachypnea) than healthy infants (Pinnington, Smith et al., 2000). Children with cerebral palsy (CP) inhale after a nutritive swallow more frequently than neurologically normal children (McPherson et al., 1992). Although it has not yet been established whether there is a direct link between disordered breathing-swallowing coordination and adverse outcomes (e.g., aspiration) in infants and children, evidence from these studies suggests it is likely.

Research is currently underway in our laboratory to determine the maturation process of breathing–swallowing coordination during nutritive and non-nutritive swallowing in healthy infants. Understanding this process might shed light on the neurological processes that govern this function. It appears that nutritive swallowing (breast/ bottle-feeding) occurs predominantly between inspiration and expiration from one week of age. Post-swallow expiration is a likely protection mechanism against aspiration, thus it would make sense that this pattern is robust soon after birth. Although post-swallow expiration is also closely associated with non-nutritive swallowing (during sleep and wake), these patterns appear much less consistent and change throughout early infancy. This is probably a reflection of the maturation of the neural mechanisms controlling this coordination. Further interpretation and comparison of non-nutritive swallowing is yet to be established.

Conclusion

The Kay Swallowing Workstation contains the requisite combination of tranducers, data acquisition hardware, and software features for determining the patterns of breathing and swallowing coordination in the pediatric population. As noted above, using the system with this population is optimized with a few minor modifications from the standard system. With these minor modifications in place, multiple physiologic phenomena can be viewed concurrently. Furthermore, the maturation of breathing swallowing coordination may also be determined and compared to specific clinical pediatric populations that may demonstrate aberrant breathing/swallowing coordination patterns. Future research may provide information important to the clinical management decisions of these patients.

References

Bamford, O., Taciak, V., & Gewolb, I. H. (1992). The relationship between rhythmic swallowing and breathing during suckle feeding in term neonates. Pediatr Res, 31(6), 619-624.

Hanlon, M. B., Tripp, J. H., Ellis, R. E., Flack, F. C., Selley, W. G., & Shoesmith, H. J. (1997). Deglutition apnoea as indicator of maturation of suckle feeding in bottle-fed preterm infants. Dev Med Child Neurol, 39(8), 534-542.

Hiss, S. G., Treole, K., & Stuart, A. (2001). Effects of age, gender, bolus volume, and trial on swallowing apnea duration and swallow/respiratory phase relationships of normal adults. Dysphagia, 16(2), 128-135.

Lau, C., Smith, E. O., & Schanler, R. J. (2003). Coordination of suck-swallow and swallow respiration in preterm infants. Acta Paediatr, 92(6), 721-727.

McFarland, D. H., & Lund, J. P. (1995). Modification of mastication and respiration during swallowing in the adult human. J Neurophysiol, 74(4), 1509-1517.

McPherson, K. A., Kenny, D. J., Koheil, R., Bablich, K., Sochaniwskyj, A., & Milner, M. (1992). Ventilation and swallowing interactions of normal children and children with cerebral palsy. Dev Med Child Neurol, 34(7), 577-588.

Mizuno, K., & Ueda, A. (2003). The maturation and coordination of sucking, swallowing, and respiration in preterm infants. Journal of Pediatrics, 142(1), 36-40.

Paydarfar, D., Gilbert, R. J., Poppel, C. S., & Nassab, P. F. (1995). Respiratory phase resetting and airflow changes induced by swallowing in humans. J Physiol, 483 (Pt 1), 273-288.

Pinnington, L. L., Smith, C. M., Ellis, R. E., & Morton, R. E. (2000). Feeding efficiency and respiratory integration in infants with acute viral bronchiolitis. Journal of Pediatrics, 137(4), 523-526.

Preiksaitis, H. G., Mayrand, S., Robins, K., & Diamant, N. E. (1992). Coordination of respiration and swallowing: effect of bolus volume in normal adults. Am J Physiol, 263(3 Pt 2), R624-630.

Selley, W. G., Ellis, R. E., Flack, F. C., & Brooks, W. A. (1990). Coordination of sucking, swallowing and breathing in the newborn: its relationship to infant feeding and normal development. Br J Disord Commun, 25(3), 311-327.

Selley, W. G., Ellis, R. E., Flack, F. C., Curtis, H., & Callon, M. (1986). Ultrasonographic study of sucking and swallowing by newborn infants. Dev Med Child Neurol, 28(6), 821-823.

Shaker, R., Li, Q., Ren, J., Townsend, W. F., Dodds, W. J., Martin, B. J., et al. (1992). Coordination of deglutition and phases of respiration: effect of aging, tachypnea, bolus volume, and chronic obstructive pulmonary disease. Am J Physiol, 263(5 Pt 1), G750-755.

Stevenson, R. D., & Allaire, J. H. (1991). The development of normal feeding and swallowing. Pediatr Clin North Am, 38(6), 1439-1453.

Takahashi, K., Groher, M. E., & Michi, K. (1994). Methodology for detecting swallowing sounds. Dysphagia, 9(1), 54-62.

Weber, F., Woolridge, M. W., & Baum, J. D. (1986). An ultrasonographic study of the organisation of sucking and swallowing by newborn infants. Dev Med Child Neurol, 28(1), 19-24.

Wilson, S. L., Thach, B. T., Brouillette, R. T., & Abu-Osba, Y. K. (1981). Coordination of breathing and swallowing in human infants. Journal of Applied Physiology, 50, 851-858.

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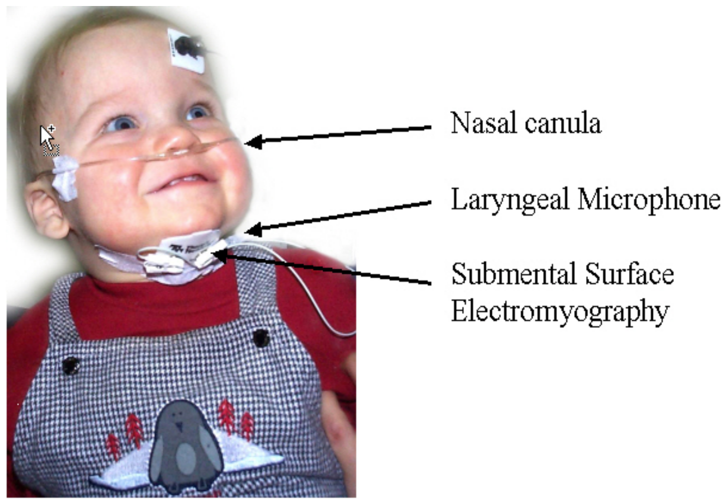

Figure 1: An 8-month old infant with transducers attached for determining breathing and swallowing coordination patterns.

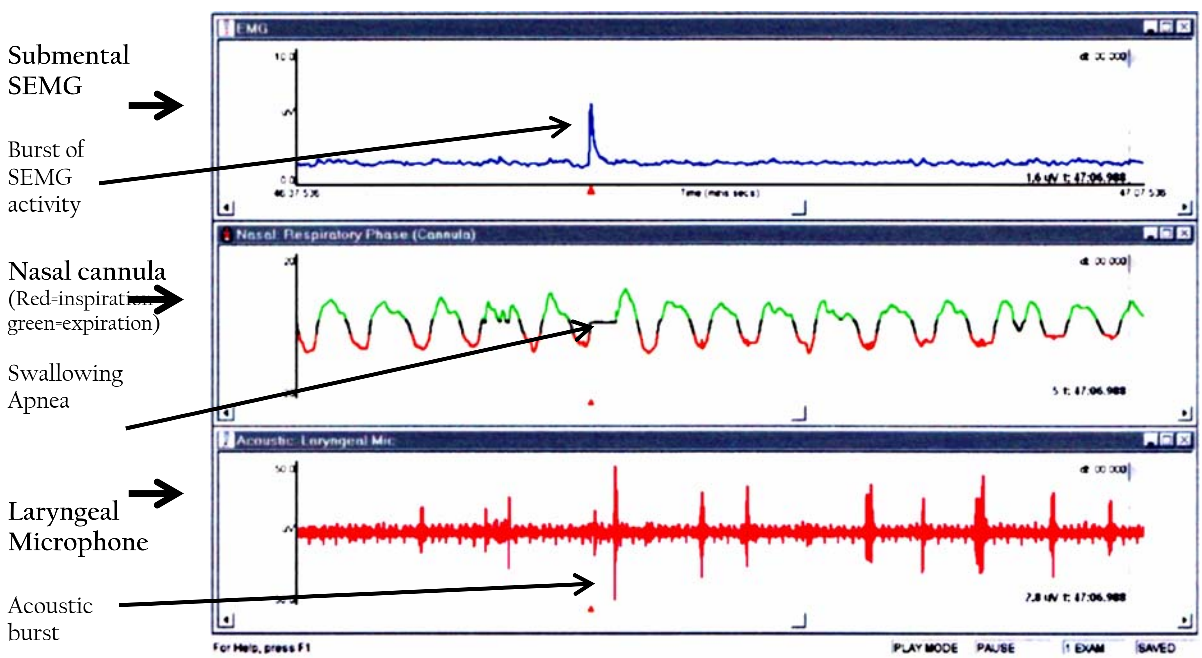

Figure 2: A sleep swallow (demarcated by the red arrow) at the inspiratory-expiratory cusp, of a healthy 6-month old female.

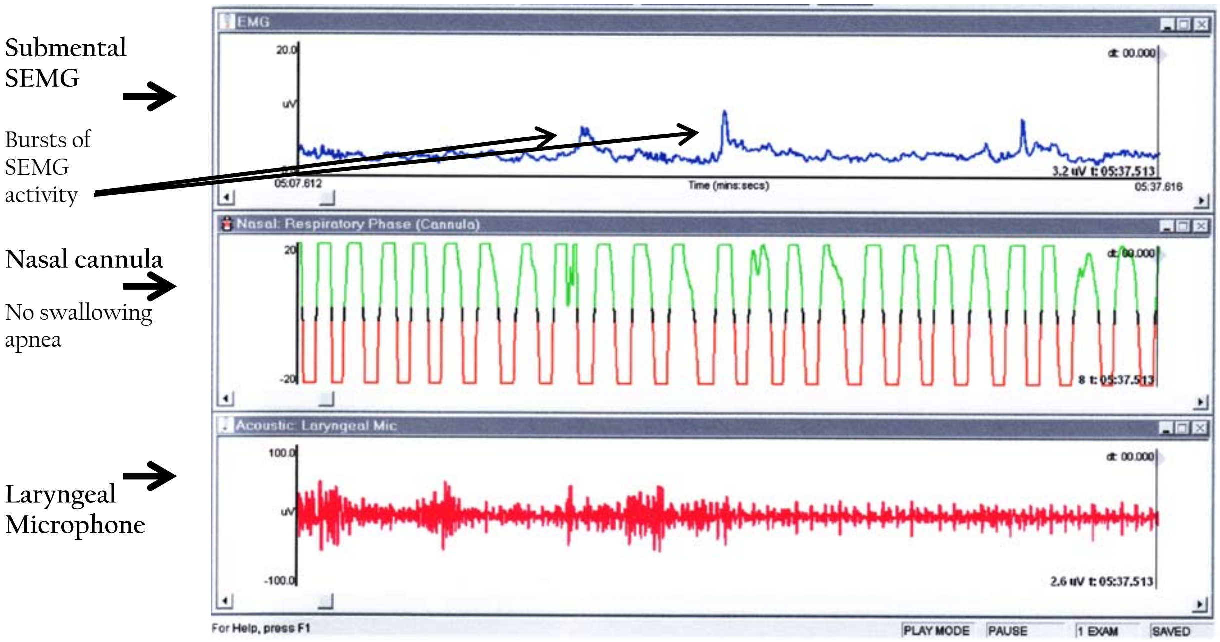

Figure 3: An example of tongue movement of a healthy 6-month old female resulting in SEMG activity in the absence of a swallow.

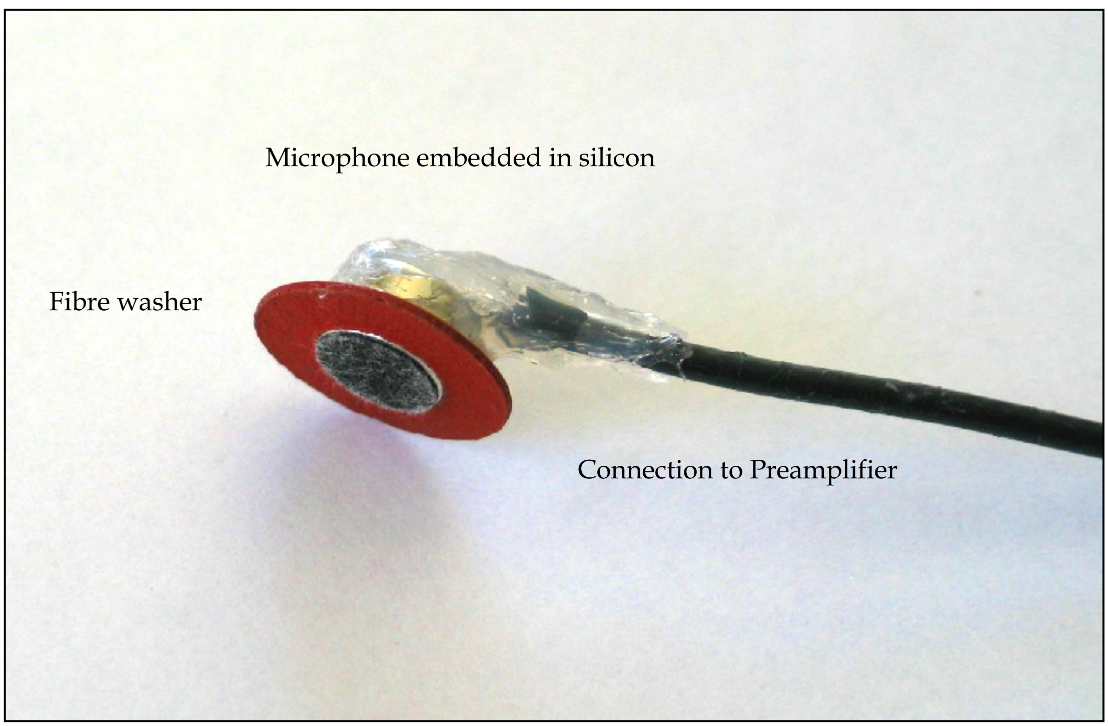

Figure 4: An omnidirectional condenser microphone embedded in silicon and a fibre washer.

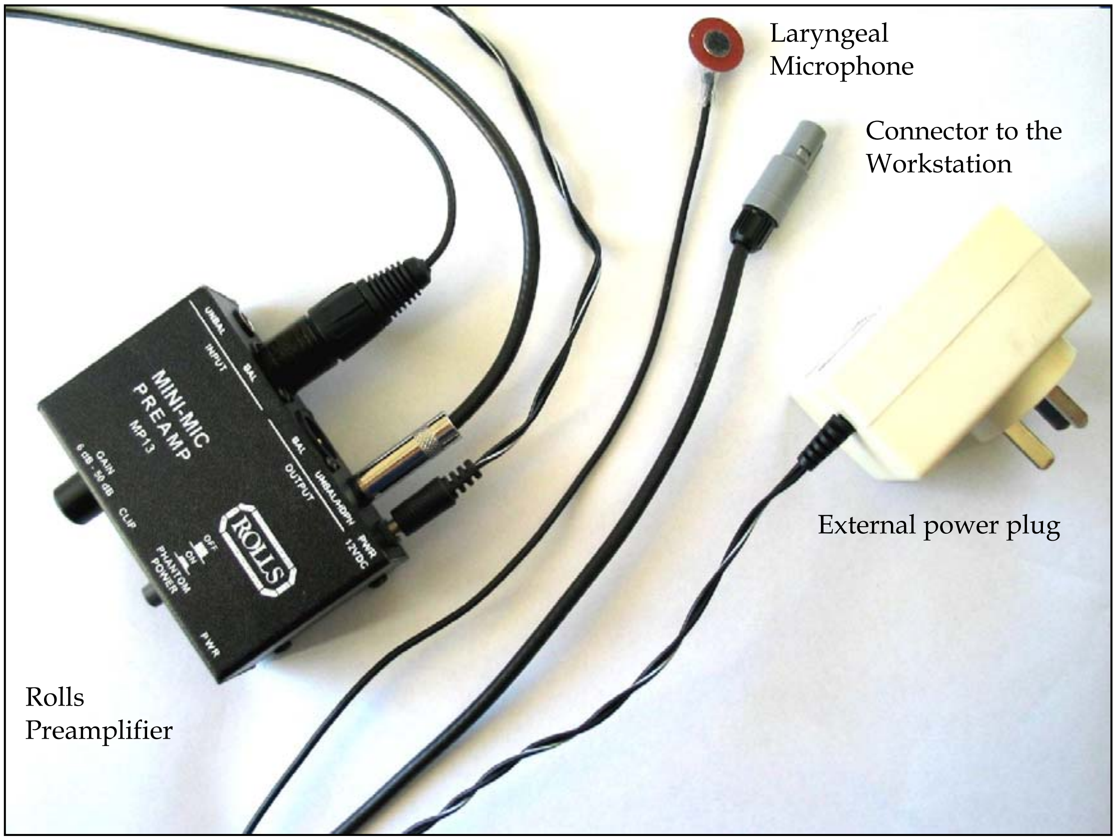

Figure 5: The laryngeal microphone, preamplifier (Rolls mini-mic preamplifier MP13) and connections to the acoustic channel on the Workstation.

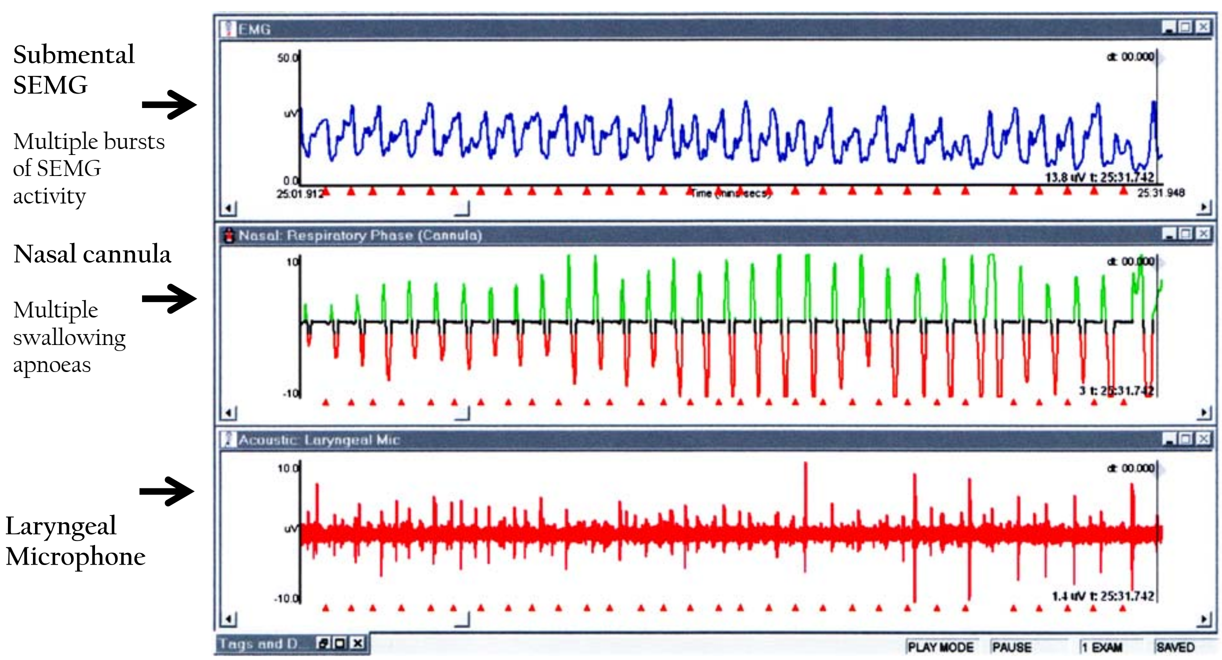

Figure 6: Multiple inspiratory-expiratory swallows of a healthy 48-hour old female during breast feeding.

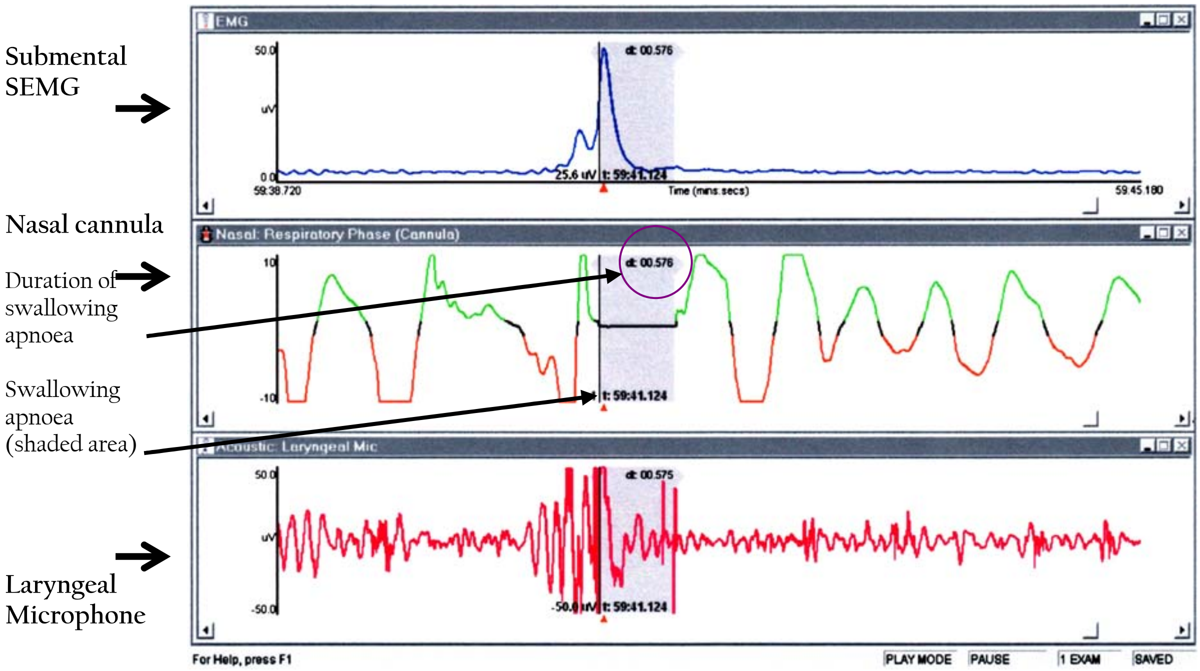

Figure 7: Measuring the duration of swallowing apnoea of a mid-expiratory sleep swallow of a healthy 48-hour old female.

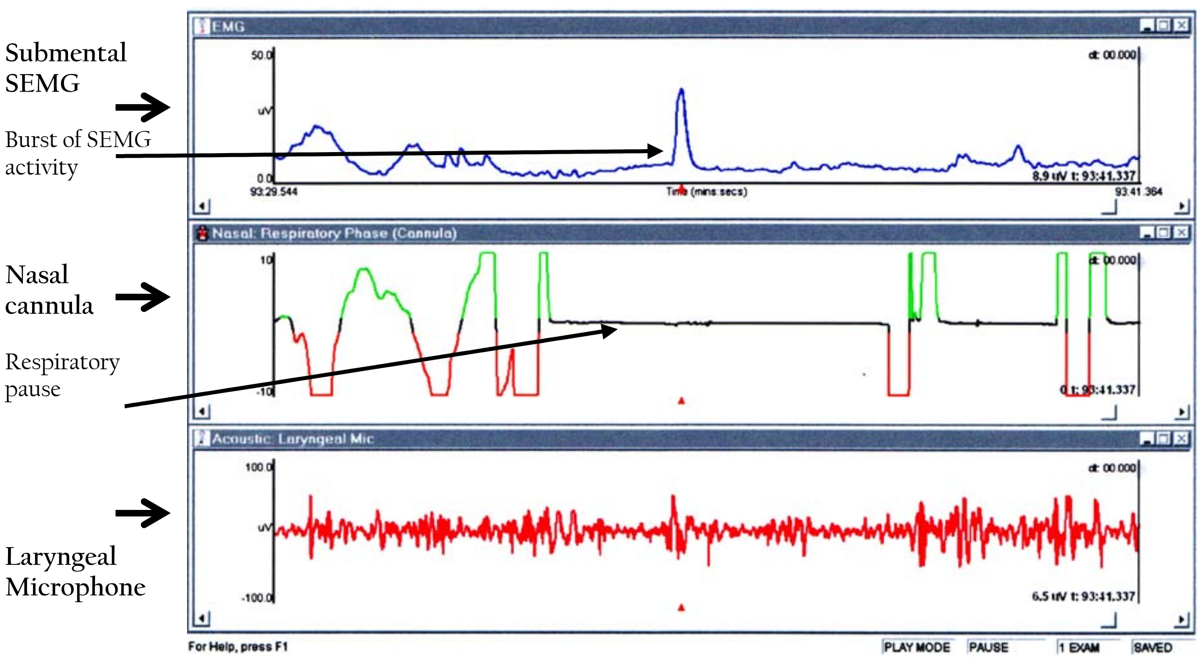

Figure 8: A sleep swallow of a healthy 1-week old female during a 4.5 second respiratory pause.