

Sensorimotor Entrainment of the Respiratory and Orofacial Systems in Humans.

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The objective of the current report is to evaluate current experimental findings on modal and cross-modal sensorimotor entrainment of vocal tract muscle systems, including the chest wall and orofacial complex during patterned motor output. Entrainment techniques have been effective in a variety of animal preparations to regulate and modify the rhythm of central pattern generators (CPGs) involved in the control of cyclic motor behaviors such as stepping and locomotion (Pearson, Ramirez & Jiang, 1992), mastication (Rossignol, Lund & Drew, 1988), and medullary respiratory pattern generators (mRGs) (Dubayle & Viala, 1998). Stimulation of intraoral tissues is also effective in modulating the masticatory cycle in humans (Hannam & Lund, 1981).

Two such centrally patterned motor behaviors that will be considered include non-nutritive suck and respiration. The ability of a neural oscillator to synchronize to an external periodic signal provides adaptive and predictive control that allows fast and reliable responses to external changes (Pavlidis, 1973). This type of control would aid in adapting the rate of both motor patterns to variation in peripheral load dynamics. Factors that modulate entrainment will be considered in the current presentation.

Moreover, the use of entrainment techniques in the study of CPG's is consistent with contemporary ideas on the role of sensory-driven neural activity (Penn & Shatz, 1999) and Bosma's (1973) contention that appropriate oral experiences may be critical in the final weeks of gestation.

Sensorimotor Entrainment of Respiratory and Orofacial Systems in Humans

Abstract. The objective of the current report is to evaluate experimental findings on modal and cross-modal sensorimotor entrainment of neural systems involved in centrally patterned motor behavior in a variety of animal and human models, including data collected in our own laboratories. Special emphasis is directed towards vocal tract muscle systems, including the chest wall and orofacial complex during patterned motor output. Several experiments have demonstrated that central pattern generators, including orofacial systems, can be modified through endogenous and external loads to produce entrainment. This feature of sensorimotor control in the human vocal tract provides adaptive and predictive mechanisms vital to both developing and mature control systems.

Proposal Summary

The motor system is part of the infrastructure of the body, enabling the organism to locomote, feed, flight, respire, and in humans there is speech. The assembly of the neuronal machinery in a number of animal species has shown that motor behavior evolves from dynamic changes that take place at the molecular, cellular, and network level (Grillner, 2001). There are a variety of sensorimotor processes that either drive or provide evidence of this elaboration in structure and function of central neural networks capable of patterned output. Entrainment is one such phenomenon that is defined as the synchronization of an endogenous oscillator to external periodic events (Pavlidis, 1973; Glass & Mackey, 1988; Kriellaars, Brownstone, Noga & Jordan, 1994). For a given stimulus with fixed amplitude and period, a stable phase relationship between the stimulus and oscillator must exist to satisfy the conditions for entrainment. The ability of an oscillator to synchronize to an external periodic signal provides adaptive and predictive control that allows fast and reliable responses to external changes (Pavlidis, 1973). This type of control would aid in adapting the suck or respiratory rate set by higher brain centers to variations in peripheral load dynamics. The effectiveness of a peripheral signal to entrain a motor pattern requires an integration of those signals into the rhythm generating neural circuitry. Entrainment techniques have been effective in a variety of animal preparations to regulate and modify the rhythm of central pattern generators (CPG's) involved in the control of cyclic motor behaviors such as stepping and locomotion (Conway, Hultborn & Kiehn, 1987; Pearson, Ramirez & Jiang, 1992; Pearson, 2000), and mastication (Rossignol, Lund & Drew, 1988). Stimulation of intraoral tissues is also effective in modulating the masticatory cycle in humans (Hannam & Lund, 1981).

Entrainment in the chest wall implies a resetting of the respiratory rhythm such that a fixed temporal relationship exists between the onset of the inspiratory activity and the onset of the mechanical breath. Mechanical ventilation of the human chest wall produces respiratory entrainment, especially during a wakeful state (Baconnier, Benchetrit, Pachot, & Demongeot, 1993; Simon, Zurob, Wies, Leiter, & Hubmayr, 1999; Simon, Habel, Daubenspeck, & Leiter, 2000). For example, chest wall movements were recorded while neonates (N=18) were manually rocked at varying rates between 30 and 60 cycles per minute. Coherence analysis between respiratory movements and rocker signals demonstrated strong entrainment to rocking (coherence spectra >0.85). Natural stimulation associated with rocking a newborn provides a phasic input to its respiratory pattern generator that is capable of resetting the system's oscillation and entraining its

rhythm (Sammon & Darnall, 1994). Infants >35 wk postconceptional age exhibited greater coherence to rocking than infants <35 wks.

Medullary respiratory pattern generators (mRGs) can also be driven by periodic electrical stimulation to the ventral part of the spinal grey at the C5 level in newborn rats (Dubayle & Viala, 1996). These authors developed phase-response curves to determine the parameters of phase resetting for predicting the limits of a stable 1:1 harmonic entrainment. The authors concluded that ascending neural connections from the C5 segment of the spinal cord in rat might be involved in locomotor-respiratory coupling.

Another line of study that has shown the potency of entraining inputs involves a 'breathing' teddy bear (BrBr), which provides an irregularly breathing neonate with a source of optional rhythmic stimulation (Ingersoll & Thoman, 1994). At 33 weeks CA, 19 premies were given a BrBr and 17 premies were given a nonbreathing bear to serve as a control. Respiratory patterning was sampled at 35 and 45 weeks in both groups. BrBr babies showed significantly more quiet sleep, less active sleep, and increased respiratory regularity. The authors suggested that BrBr entrainment facilitates neurobehavioral development of one of the infant's own biological rhythms. This study also clearly demonstrated that a premature infant with an irregular oscillator will entrain to that of a breathing bear (a regular oscillator, or zeitgeber) under the conditions that the BrBr's rate of breathing reflects that of the individual infant.

In the context of neonatal oromotor control, the development and application of an entrainment paradigm suitable for reorganizing a disordered motor control system is appealing. The use of 'natural' forms of stimulation is preferred to preserve the physiologic nature of recruitment pattern in the hopes of synthesizing a sensory experience that can be reinforced through motor learning. The application of entrainment as an habilitation strategy among multiple CPGs, utilizing natural mechanical stimulation, has ecological validity in assisting the infant to produce an appropriate motor output. Moreover, this approach is consistent with contemporary ideas on the role of sensory-driven neural activity (Penn & Shatz, 1999) and Bosma's (1970) contention that appropriate oral experiences may be critical in the final weeks of gestation in the formation of functional central neural circuits.

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