FEED THE TIGER: A METHOD FOR EVOKING RELIABLE JAW STRETCH REFLEXES IN CHILDREN

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ABSTRACT

The human jaw stretch reflex is a short-latency excitatory response of the jaw closing muscles to a rapidly imposed downward stretch of the mandible. Typically, the jaw stretch reflex has been evoked in children by using a hand-held reflex hammer. Understanding the development of the jaw stretch reflex has been hindered due to lack of experimental control of stimulus magnitude, motoneuron pool excitability, and activation of cutaneous mechanoreceptors in the lower face. A new methodology is presented involving closed-loop control of parameters of stimulus displacement, real-time biofeedback of jaw-closer muscle performance, and minimization of effects from activation of extraneous mechanoreceptors. Special consideration was given to developing a task that could be understood and easily performed by young children. To that end, an oscilloscope and a picture of an animal were used to create a “video game” played with the mouth. This strategy proved to be highly successful in obtaining reliable jaw-stretch reflexes in children as young as 5 years of age.

1. INTRODUCTION

The human jaw stretch reflex is classically defined as a short-latency (approximately 7-12 msec onset) excitatory electromyographic (EMG) response of the jaw closing muscles evoked by a rapidly imposed downward displacement of the mandible [1, 2, 3]. This reflex is also described as the “jaw jerk” or “masseter reflex”. In adults, this vigorous response produces a strong increase in jaw-closing force. The reflex stiffness of the adult human mandible approximates the intrinsic muscle stiffness for frequencies between 1 and 8 Hz, likely contributing to functional stability [1].

The jaw stretch reflex is considered to be the trigeminal nerve equivalent of the monosynaptic reflex present in limb muscles and is likely mediated by stretching of muscle spindles located in the masseter (jaw-closing) muscles [4]. At its most basic level, the neural substrate of the human jaw stretch reflex is considered to be a two neuron circuit with the afferent component consisting of projections from muscle spindles that follow the mandibular branch of cranial nerve V, trigeminal, to the trigeminal mesencephalic nucleus [5]. With a synapse in the trigeminal motor nucleus, the efferent component of the reflex loop is formed by fibers from the trigeminal motor root.

Human reflex functions have been used clinically to assess the integrity of segmental pathways or to assess disease states and experimentally to develop theories of motor control. Investigations of segmental reflex function in the lips [6], jaw [7, 8], and limbs [9, 10, 11] have revealed changes in onset latency, increased response specificity, and decreased response variability with development.

Only one study to date has investigated the jaw stretch reflex in children. Jääskeläinen [7] used a reflex hammer to deliver uncontrolled jaw taps to the chin of neonates, infants, and children, and observed responses in all age groups. Although this study provided evidence that the trigemino-trigemino reflex loop was functional early in postnatal life, lack of control of stimulus intensity (applied force or jaw displacement) as well as stimulus duration limits potential interpretation of quantitative measures of reflex responses. In addition, the use of a reflex hammer to deliver taps to the chin likely results in stimulation of low threshold cutaneous mechanoreceptors in addition to muscle spindles of the jaw closing muscles, possibly confounding the reflex response [12].

Although factors of stimulus magnitude and motoneuron pool excitability have been shown to modulate the response properties of reflexes in the lower face [13] and jaw [14], few studies have employed servo-controlled (closed-loop control) stimulator devices in order to control for stimulus magnitude [1, 15] or have utilized measures to standardize motoneuron pool excitability levels. Instead, common methodologies used to investigate the jaw stretch reflex have involved the use of hand-held reflex hammers [7] or various electromechanical stimulator devices operated under open-loop control [16, 17] and most have no provision to control for motoneuron pool activation level.

The current methodology was developed as an attempt to evoke repeatable jaw stretch reflex in children and young adults by employing precision stimulation and recording procedures. It was hypothesized that young participants would demonstrate differences in response variability and onset latency as compared to adults.
2. METHODOLOGY

2.1 System Design

A servo-controlled mechanical stimulator was used to deliver rapid and precise jaw-opening stretches to the jaw-closing muscles of the mandible during static (isometric/isotonic) 5 Newton jaw contractions in children and adults. Stimulus levels of 0.1 mm, 0.3 mm, and 0.5 mm were employed in order to investigate potential magnitude-dependent growth functions of the jaw-stretch reflex, as has been observed for reflexes in the lips and the limbs.

The stimulator used to generate jaw-opening stretches consisted of two parallel stiff cantilever beams (aluminum) on which the participants generated a biting force. The upper cantilever beam (passive) was rigidly attached to a table-mounted support framework. The lower (active) beam was linked via a precision rotational bearing to a powerful electromagnetic linear actuator (Ling Altec Ltd., Model 408) operating under displacement servo control (Figure 1). Force applied to the active beam was transduced by two resistance-wire strain gages, forming half of a Wheatstone bridge circuit. Inter-beam span as measured at the tooth contact points (equating to inter-dental span) was 9 mm for a 0 Newton force level (zero biting force), and approximately 8.8 mm for a 5 Newton force level.

![Figure 1: Jaw stimulator.](image)

At the distal end of each cantilever beam, a polycarbonate cup enclosed a small quantity of semi-hard setting dental acrylic. Prior to data collection, an impression of the participant’s anterior dentition (both the upper and lower dental arches) was made in order to stabilize the biting plane. The dental impression typically encompassed the central and lateral incisors, thereby distributing the force of the stimulus applied to the lower teeth and minimizing potential effects of periodontal afferent stimulation on the reflex response.

2.2 System Performance

The performance of the jaw stimulator system was assessed by evaluating input/output characteristics to both sinusoidal and step input waveforms.

2.2.1 Frequency Response

An analog function generator was used to generate sinusoidal input waveforms to the servo controller for the range of 1.0-70 Hz. Amplitude of the input waveform was adjusted to achieve full-scale displacement at 1.0 Hz and was maintained at that level (5.16V Peak-to-Peak) for the remaining frequencies (Figure 2). The system was characterized by a displacement response that fell in amplitude with frequency and was essentially linear from 1.0-50 Hz. Simple linear regression analysis for the frequencies of 1.0-50 Hz yielded an adjusted $R^2$ of 99.22% (Displacement = 10.2271 - 0.0299*Frequency, p < 0.0001). The phase response of the system demonstrated a pure time delay, with a mean delay of 4.03 msec through all tested frequencies.

![Figure 2: Jaw stimulator frequency response curves. The input was a sinusoidal waveform at an amplitude that yielded maximum peak-to-peak displacement at 1.0 Hz. Active beam displacement is shown as a solid line with filled circles, an input/output time (phase) delay curve is shown with open triangles and a dashed line.](image)

As a functional realization of the frequency response properties of the system, stimulator rise time for a step waveform was calculated using 10 to 90% intercepts on the displacement waveform at three stimulus amplitudes: 0.1mm, 0.3mm, 0.5mm. The mean rise time across all three stimulus levels was 3.39 msec (range 3.33-3.50 msec).

2.2.2 Displacement Linearity Response

The jaw stimulator was a closed-loop system operated under position servo control. To determine the linearity of the position output, a negative-going step input waveform of 450 msec duration and of varying amplitude (0.1V – 8.0V) was applied to the servo controller. The active cantilever beam was preloaded with an elastic load to a level of 2.52 Newtons. A highly linear displacement response was observed at all tested input amplitudes (Figure 3). Simple linear regression analysis yielded an adjusted $R^2$ of 99.99% (Displacement = -0.0024 + 0.0773*Input Voltage, p < 0.0001).
2.3 Experimental Protocol

Thirty participants, 10 in each age group of 5-6 year-olds, 9-10 year-olds, and young adults (age range of 18-30 years), have completed the research protocol. Participants had normal (Class I) occlusion, healthy natural teeth, and were free from speech or feeding impairments. The Purdue University Institutional Review Board approved this study, and informed consent was obtained from each participant and from the parent of each child.

Participants were instructed to bite to a 5 Newton force level on two parallel stiff cantilever beams while a series of jaw-opening step displacements were applied to the mandible (Figure 4). An analog (phosphorus display) oscilloscope was positioned approximately 12” from the participant in direct line of sight, providing a real-time visual display of biting force. Child participants were told that they would be “playing a video game with their mouth” using the oscilloscope display.

A picture of an animal with an open mouth was placed over the oscilloscope screen, masking the entire screen except for a 2 cm diameter hole that was present in the center of the animal’s mouth (Figure 5). The oscilloscope was configured for X/Y display, and the 2 cm hole was centered over the area on the screen that corresponded to a 5 N bite force level, as transduced by the active cantilever beam. The output of the strain gage circuit was coupled to the Y-channel input of the oscilloscope (the X-channel input was unused), therefore an increase in biting force was reflected as elevation of a ball of light on the screen. Participants were instructed to “feed the tiger” by biting on the cantilever bars and thereby placing the ball of light into the animal’s mouth. The ball of light would appear in the hole (animal’s mouth) at force levels that corresponded to approximately a 4-6 Newton range. Thus, the hole in the animal’s mouth acted as a visual guide that aided the participants in achieving and maintaining an approximately 5 Newton isometric contraction of the jaw-closer muscles.

Data channels were digitized using a 16 bit analog to digital converter (Dataq Instruments DI-200) at a sampling rate of 6 kHz. Sampled data included electromyographic activity recorded bilaterally from the masseter muscles (bipolar surface electrodes located over the belly of the muscle, 1 cm inter-electrode separation, gain = 5000, band-pass filtered at 30-3000 Hz), active beam displacement, and biting force. In addition, the control signal sent to the servo controller was digitized as well as a “tag” voltage signal used to identify the stimulus condition (stimulus displacement level) for automatic data processing algorithms. Following data collection, a stiffness correction factor was applied to the jaw stimulator displacement signal in order to compensate for strain (bending) of the cantilever bar. This calculation yielded the true displacement of the active cantilever bar (and correspondingly, the jaw aperture) at the site of lower incisor contact.
3. RESULTS

The methodology detailed in this report has been used successfully in obtaining repeatable and robust jaw stretch reflex responses in children as young as 5 years of age. Representative data from a single stimulus trial from a five year-old participant is shown in Figure 6. The reflex response was of short latency and generated a substantial resultant force increase that peaked at approximately 50 msec following reflex onset.

Figure 6: Representative jaw stretch reflex data for a 0.5 mm stretch stimulus condition recorded from a 5 year-old participant. Raw EMG records are displayed for the right and left masseter muscles. Jaw force is shown as a dashed line.

4. SUMMARY

The neural pathways that subserve the jaw stretch reflex are certainly involved in the production of more complex oromotor behaviors, such as mastication and speech. Jaw stretch reflex responses can provide an index of neural maturation during periods of development in which structure size is undergoing rapid change. Controlling for stimulus magnitude and degree of motoneuron pool activation allows for comparison of reflex responses across subjects and for a variety of tasks. Information gleaned from these potential data sets will be useful in understanding strategies of motor control of the jaw for speech and other behaviors, especially throughout development.

5. REFERENCES


