Masticatory and Brux-like Motor Patterns in the Freely Behaving Rat: Electromyography and Phase Analysis

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ABSTRACT

Our objective was to develop an experimental platform to examine brainstem commands, and trigeminal neural networks that underlie activation and switching of masticatory and brux-like motor patterns of the jaw. This characterization could help us understand the underlying mechanisms of human bruxism. Sixteen male rats (200-224 g) had EMGs implanted into right superficial masseter (mass: jaw closing, n=16), temporalis (temp: jaw closing, n=8), and anterior digastric (dig: jaw opening, n=8) muscles. We conducted a dual-referent phase analysis in order to assess coordination. We used Rayleigh test to discriminate between uniform and unimodal-clustered phase distributions, and Williams F-test to determine if mean angles differed significantly. We found: 1) Phase differences between jaw closing muscles, the temp and mass ($p<.05$). During a brux-like event, temp and mass fire almost simultaneously. However, during mastication the onset for the EMG burst for the temp occurs after the onset for the mass muscle. 2) Phase differences between jaw opening (dig) and jaw closing (mass) muscles. During mastication we can observe an alternation of jaw opening and jaw closing muscles ($p<.05$). However, during a brux-like event, dig and mass exhibit co-contraction. 3) Brux-like motor patterns elicit shorter, more rapid bursts ($p<.05$), and occurred at a cycle frequency higher than the masticatory patterns ($p<.05$).

Keywords: Bruxism, CPG, EMG, Mastication, Phase analysis

INTRODUCTION

In general, the nervous system generates precise temporal sequences of muscle contractions when the body must produce rhythmic coordinated movements. Brux-like and masticatory rhythmical behaviors are common in mammals, along with respiration and locomotion. Initially, coordinated flexor and extensor alternating movements of the limbs were experimentally observed in the absence of afferent feedback to the lumbosacral spinal cord (Brown 1911).

The term 'central pattern generator' (CPG) is now widely used to refer to neuronal networks that can produce rhythmic motor patterns in the absence of phasic inputs (Grillner 2011). Masticatory motor patterns are generated by a CPG located in the pons and medulla of the brainstem (Nakamura and Katakura 1995). Intraoral mechanoreceptor, muscle spindles in the jaw-closing muscles, and receptors that detect movements in the periodontal ligament affects movement parameters (Hidaka et al. 1997, Lavigne et al. 1987, and Lund and Kolta 2006). Masticatory jaw-movement cycles with foods of different consistency affected the duration of the opening phase of each cycle (domestic male rabbits) (Morimoto et al. 1985).

In general, the masticatory sequence is divided into three consecutive periods: preparatory, reduction, and preswallowing series of cycles (see Schwartz et al. 1989 for review). In brief, the (1) preparatory period begins with a burst of activity in digastric muscles, and the first opening to receive food; the (2) reduction period is characterized by large bursts of the closer muscles; and (3) Preswallowing period begins where EMG bursts become smaller and is finally terminated by swallowing. This study is primarily focused on the rhythmic movements during the reduction period.

While mastication has received significant attention, brux-like behaviors have received far less. Brux-like behaviors might be used for grinding/sharpening teeth, defense, and/or aggression (Schärer 1974, Dubner et al. 1978). Brux-like or "thegotic" tooth-sharpening is also found in many animals including non-human primates (Every 1970, Every 1975). The sharpening of the lower incisors in both mountain beaver (*Aplodontia rufa*) and groundhog (*Marmota monax*), indicate that the motor patterns for incisal functions are distinctly different from those producing mastication (Druzinsky 1995). Rats (*Rattus norvegicus*) also exhibit brux-like behavior in order to grind down the incisors that grow and erupt continuously (Merzel and Novaes 2006). Male baboons (*Papio cynocephalus*) sharpen their canine teeth against specialized lower third premolars in aggressive encounters with other males (Walker 1984). In contrast, human brux-like behavior is generally regarded as a pathological condition. Untreated, human brux-like behavior can lead to worn teeth, lost fillings, fractures, induction of headaches, and numerous types of temporomandibular disorders (Lavigne et al. 2008).

Vertebrate interneurons that make up different types of CPGs have been found to be involved in the production of different motor pattern forms. Examples include CPGs for scratching (*Felis catus*) (Berkinblit et al. 1978), and respiration during sleep and wakefulness in cat (*Felis catus*) (Lydic and Orem 1979); rhythmic hatching and stepping movements of the legs of chicks (*Gallus domesticus*) (Bekoff et al. 1987); and three different forms of scratching in the turtle (*Trachemys scripta*) (Mortin and Stein 1989). The general principle is that multifunctional interneurons that com-

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prise a CPG may form a core, multipurpose circuit that generates elements of coordinated motor output utilized in several types of motor patterns (Berkowitz et al. 2010). In some cases, CPG units may be interconnected which in some circumstances would allow for two units to mutually excite each other while in other circumstances allow the same two units to inhibit each other (Grillner 1981). This might allow specialized interneuron classes to be selectively activated for specific motor pattern forms (Berkowitz et al. 2010).

Our purpose was to provide an animal model that will allow us to examine the brainstem commands, and trigeminal neural networks that underlie the activation and switching of masticatory and brux-like motor patterns of the jaw. Characterization of the underlying circuitry may allow us to better understand the basic pathology, and lead to the development of more effective pharmacological treatment options. Many investigators have used laboratory rats as an animal model for studying the neurophysiology of mammalian mastication (Hiiemäe and Ardran 1968, Weijs 1975, Weijs and Dantuma 1975, Thomas and Peyton 1983, Byrd and Chai 1988). Experimental brux-like behavior, jaw reflexes, and/or masticatory muscle activity was examined in animals subjected to experimentally induced stressors (Pohto 1979, Landgren and Olsson 1980, Weiner et al. 1993, Richardin et al. 1995, Sitthisomwong et al. 2000). An initial characterization of masticatory and brux-like motor patterns, using electromyogram (EMG) and optoelectronic techniques of the anterior and posterior temporalis (jaw closing) muscle in rat (*Rattus norvegicus*), determined that task related shifts of EMG motor patterns were found between masticatory and brux-like behaviors (Byrd 1997a). "Non-functional" EMG motor patterns were also recorded from the masseter muscle (jaw closing), induced with an occlusal cap (Shoji et al. 1994). The possible existence of a brux-like pattern generator in addition to the masticatory one has been suggested (Byrd 1997a). Evidence from the spinal cord CPG however, suggests the possibility of a combination of multipurpose and specialized circuitry (Berkowitz et al. 2010). In the masticatory brainstem CPG, four types of motor patterns have been induced by electrical stimulation within the cortical masticatory

areas of rabbits (Westberg et al. 1998). In the same study, fictive motor output was recorded with an extracellular microelectrode in the trigeminal motor nucleus. The pre-motor neurons that form the final commands to the trigeminal motor neurons are organized into subpopulations according to the movement pattern invoked (Westberg et al. 1998). Taken together, it suggests that similar techniques could be used to determine if the underlying substrates of the brux-like CPG are shared or separate from the masticatory one.

Previous experimental designs have to be taken into consideration. Some evidence suggests a relationship between restraint stress and masticatory like behavior (Tanaka et al. 1998). Experiments were conducted with animals placed in a tube (Ellison et al. 1987) that restricted the animal's freedom, causing stress. This stress can cause animals to chew on nonedible substances. The response of chewing of nonedible substances may reduce the glucocorticoid stress response (Hennessy and Foy 1987). In addition, aggressive masticatory behavior suppresses the stress-induced decrease in brain-derived neurotrophic factor mRNA and neurotrophin-3 mRNA in the hippocampus (Kubo et al. 2015). Surgically restrained animals were spinally transected which inhibited the display of non-oral behavior (Koshikawa et al. 1990).

Previous researchers have utilized pharmacological manipulations. EMGs have also been measured in rats that were administered SKF 38393 (D1 receptor agonist). SKF 38393 induced a dose related increase in the total number of purposeless chews (Collins et al. 1993). A similar result was obtained with intraaccumbens administration of SKF 38393. However, LY 171555 (D2 receptor agonist) inhibited purposeless chews (Prinssen et al. 1992).

In the present study, we wanted to measure brux-like and masticatory behavior without restraints or pharmacological manipulation. We measured from the anterior superficial masseter, anterior temporalis, and the anterior digastric respectively. In rodents, the masseter muscles play an important role during the masticatory power stroke. The masseter muscle produces a protraction and retraction of the jaw along with elevation and depression (Langenbach and Eijden 2001). The superficial and deep

masseter contributes to the power stroke during mastication. The deep masseter has a greater vertical orientation than the superficial masseter. As such, the deep masseter is assumed to play an important role generating occlusal forces. On the other hand, the fiber orientation of the superficial masseter suggests a role for jaw protrusion during the power stroke (Sano et al. 2007). The digastric muscle is involved in opening of the jaw, stabilization of the jaw and hyoid together, and is necessary for the positioning of the tongue (Cobos et al. 2001). The anterior digastric muscle (rat and rabbit) can also be active during closing movements (Weijs and Dantuma 1975). In the present study, we wanted to expand on those previous results by conducting a dual-referent phase analysis in order to assess the level of coordination between our selection of both jaw opening and jaw closing muscles together.

Our results enabled us to identify a highly coordinated set of EMG motor patterns that underlie brux-like and masticatory behavior. This will serve a potential basis for the development of reduced preparations that express fictive brux-like and masticatory motor patterns to compare it to.

MATERIALS AND METHODS

Animals and Apparatus

Sixteen male Sprague-Dawley rats (200-224 g) were purchased (Harlan Laboratories, Indianapolis, IN) and housed under controlled 12/12 hour light/dark cycles. The animals had ad libitum access to food (Mazuri, Arden Hills, MN) and water (tap). All procedures were approved by Southern Illinois University Edwardsville's Institutional Animal Care and Use Committee (IACUC).

We created a testing apparatus that utilized a commutator and a pre-amplifier to allow both unrestrained animal movement, and natural (non pharmacologically/electrically manipulated) oral behaviors (see Fig 1).

Electrode Placement

All rats were fasted on the day of the surgery, to increase their appetite during testing the following day. The rats continued to have ad libitum access to water during this time period. The electrodes were implanted under deep anesthesia using Isoflurane
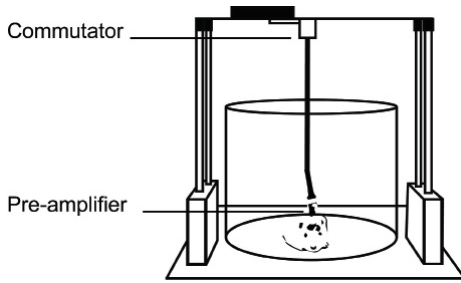
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Figure 1. The animals were placed in a clear Plexiglas rat cage for observation. The headcap was attached to a custom miniaturized preamplifier, and fed through a commutator.

(2-chloro-2-(difluoromethoxy)-1,1,1-tri-fluoro-ethane) liquid inhalation, 2% at 0.2L/min O_2 (E-Z Anesthesia, Palmer, PA) adjusted according to animal weights. The surgical area was prepped by shaving the fur with Oster Mini Max Model 7849-100 electrical clippers (Jarden Corporation,Rye, New York). Two perfluoroalkoxy alkane (PFA) insulated, silver fine-wire electrodes 0.076 mm in diameter (A-M Systems, Sequim, WA) with 0.5 mm exposed tips inserted into the belly of the right masseter (n=16), temporalis (n=8), and anterior digastric (n=8) muscles. All electrode wires were led subcutaneously, with sufficient slack to allow for uninhibited masticatory and brux-like movements. Electrical connections were made to E363 stainless steel gold-plated sockets and secured with Graphite-Filled Conductive Wire Glue (Radioshack, Fort Worth, TX). The sockets were retained inside an electrode pedestal MS363 (Plastics One, Roanoke, VA) with Ethyl Cyanoacrylate, high viscosity adhesive (World Precision Instruments, Sarasota, FL). The rats were held in a stereotaxic instrument (World Precision Instruments, Sarasota, FL), and 1 mm deep holes were hand drilled into the skull with a D#56 drill bit (Plastics One, Roanoke, VA). A total of four 0-80 X 1/8 screws (Plastics One, Roanoke, VA) were screwed 1.0 mm deep into the frontal and parietal bones of the skull. A ground wire was attached to the anterior right skull screw with additional Graphite-Filled Conductive Wire Glue. The electrode pedestal was secured to the screws and built up with methyl methacrylate dental cement (Pearson Dental, Sylmar, CA) to form a custom headcap. Similar headcap methods have been used previously (Shoji

et al. 1994). However, in the present study we used a miniaturized preamplifier that enabled us to measure long EMG traces with very little movement artifact.

Data Acquisition

The animals were placed in a plexiglas rat cage (Pinnacle Technology, Lawrence, KS) 1 hour after recovery from anesthesia. The headcap was attached to a custom 8442 miniaturized preamplifier (Pinnacle Technology, Lawrence, KS) with a built in x100 gain and 10 Hz high pass filter on all channels. A 4 channel commutator (Plastics One, Roanoke, VA) was mounted above the cage to allow for free animal movement, and to reduce movement artifact (Fig. 1). EMG signals were further amplified with a 1700 Differential AC Amplifier (A-M Systems, Sequim, WA). The analog filters of the secondary amplifier were set with low and high frequency cut-offs of 10 Hz and 10 kHz, respectively. The analog signals were acquired using an analog-to-digital (DAQ) converter Digidata 1440 (Molecular Devices, Sunnyvale, CA, USA), connected to a custom built computer running Windows XP (Microsoft, Seattle, WA). The sampling rate was digitized at 1000 Hz. The entire testing apparatus was held inside a faraday cage (AutoMate Scientific, Inc., Berkeley, CA) grounded to the secondary amplifier. All of the equipment was rack mounted and plugged into a LCR2400 AC line spike and line noise filter (Tripp-Lite, Chicago, IL). In response to being placed into the novel Plexiglas rat cage, the animals would periodically produce brux-like motor patterns for several hours. Brux-like cycles were sometimes elicited by repeatedly tapping two No. 3 scalpel handles above and behind each rat's head until the desired behavior was produced by the anxious rat (Byrd 1997b). Afterwards, individual rat chow pellets (Mazuri, Arden Hills, MN) were given to the animals for the masticatory recordings. Masticatory recordings were made for several hours until the rats became satiated or the electrodes failed. Following testing, rats were sacrificed by decapitation, and electrode placements were confirmed by post mortem dissections.

Data Analysis

Onsets and offsets of EMG bursts were analyzed with Clampfit data acquisition soft-

ware (Molecular Devices, Sunnyvale, CA, USA) and manually recorded (Armstrong and Drew 1984). This computer assisted method allows the experimenter to reject recordings with movement artefacts or spurious noise (Barrett et al. 1985). For our comparisons of cycle periods, we used two sample t-tests with Systat13 software (Systat Software, San Jose, CA).

To determine the level of muscle coordination during masticatory and brux-like movements, a dual-referent phase analysis was conducted using methods that were previously used to characterize turtle limb movements (e.g. Berkowitz and Stein 1994, and, Welch and Currie 2014). In the current study, phase values were calculated with an Excel 2013 spreadsheet (Microsoft, Seattle, WA). The masseter muscle EMG burst pattern was selected as the "referent." When load is encountered, the sensory inputs from the muscle spindles and from the periodontal mechanoreceptors modulate the rhythmic activity of the jaw-closing muscles (Hidaka et al. 1997, Lavigne et al. 1987, and Morimoto et al. 1985). In the present study, we want to observe how the underlying CNS maintains coordination with other muscles. The temporalis and anterior digastric muscles were selected as respective "targets." The mean angle of the vector (μ) is the average phase value on a circular scale ranging between 0.0 and 1.0. The length of the mean vector (r) indicates the directional concentration of values around the mean vector angle. In phase EMG patterns were defined by phase values of 0.0 and 1.0. Antiphase EMG patterns were defined by a phase value of 0.5. Phase values were imported into Oriana 3.0 (Kovach Computing Services, Anglesey, Wales, UK) in order to obtain circular statistics, which are appropriate for cyclical events (Batschelet 1981, Zar 2009, Mardia and Jupp 1999). We used the Rayleigh test to discriminate between uniform and unimodal-clustered phase distributions and the Williams F-test to determine if the mean angles differed significantly (Fisher 1993, Mardia and Jupp 1999, Zar 2009).

RESULTS

In the Masseter/Temporalis group one rat (d11) was removed from the study due to unresolved electrical noise. In the Masseter/Digastric group two rats (jt25 and jt30)

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were both removed due to unresolved electrode/headcap failure.

Cycle Period and Burst Duration

We compared the cycle periods between mastication and brux-like motor patterns with all three respective muscles (Fig. 2). A cycle period was defined as the time between the onset of an EMG burst to the onset of the next. We also compared the burst duration (Fig. 3). We found that brux-like motor patterns elicit shorter, more rapid bursts for all of our selected muscles ($p<.05$).

Phase Analysis

When brux-like motor patterns were produced we found that the Masseter and Temporalis EMG bursts were nearly in phase with each other (Fig. 4A). After several hours the brux-like behavior would diminish, and we would place rat chow into the cage to encourage eating. During mastication, the temporalis EMG burst would occur during the middle of the masseter EMG burst (Fig. 4B). The mean phase angles of the selected jaw closing muscles during brux-like verses masticatory behaviors are distinctly different ($p<.05$).

EMG traces of the digastric and masseter muscles during mastication were also observed. During brux-like behavior, the digastric and masseter EMG bursts were in phase, despite the fact that they are antagonist muscles (Fig. 5A).

In contrast, during mastication, the digastric and masseter EMG bursts were in antiphase (Fig 5B). The mean phase angles of the selected jaw closing and opening muscles during brux-like verses masticatory behaviors were also distinctly different ($p<.05$). These observations were further demonstrated when we examined the circular mean of mean phase values from multiple animals plotted together (Fig 6).

DISCUSSION

Our primary objective was to specifically compare the coordination of muscles that produce masticatory and brux-like motor patterns of the jaw. Our data conclusively demonstrates that the temporalis, masseter, and anterior digastric muscles all display highly coordinated task-dependent motor patterns that are determined by the respec-
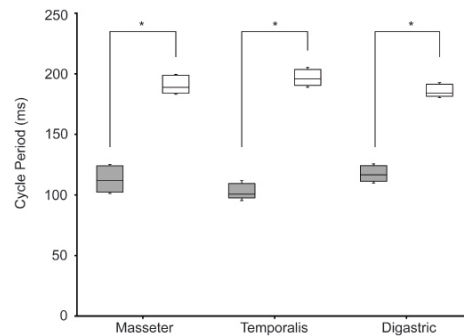

Figure 2. EMG Cycle Periods. A comparison of mean cycle periods of brux-like (gray) versus mastication (white) among the masseter, temporalis, and digastric muscles. Masseter, n=13 (2720 cycles); temporalis, n=7 (1420 cycles); digastric, n=6 (1300 cycles). The median (line) and ± SE are presented. The difference in cycle periods can be used to discriminate these two distinct motor patterns for all three muscles ($p<.05$).
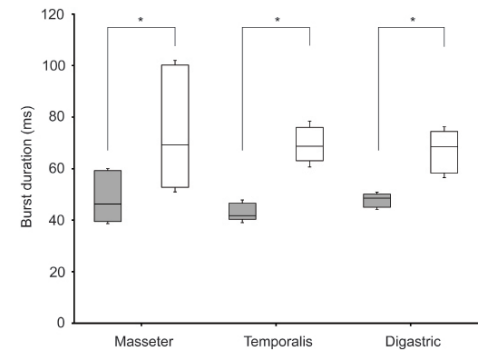

Figure 3. EMG Burst Duration. A comparison of average burst duration of brux-like (gray) versus mastication (white) among the masseter, temporalis, and digastric muscles. Masseter, n=13 (2720 bursts); temporalis, n=7 (1420 bursts); digastric, n=6 (1300 bursts). The median (line) and ± SE are presented. The differences in burst duration can be used to discriminate these two distinct motor patterns for all three muscles ($p<.05$).

Table 1. Phase Analysis Summary

	Masseter/Temporalis	Masseter/Digastric
Circular Mean brux-like (in phase)	0.09	0.019
Circular Mean mastication phase (anti-phase)	0.448	0.668

tive oral behavior. Initially, studies on jaw movements focused on anatomical dissection or through zoological comparisons (Fox 1965). It has been argued (Schärer et al. 1967), that initial investigations on oral behaviors were rather undetailed, neglecting the variety of motor patterns and functions. Moreover, much of the later work was limited to the examination of jaw closing muscles, such as the temporalis (Byrd 1997b). To expand on previous results, we conducted dual-referent phase analyses in order to assess the level of coordination between a selection of both jaw opening, and jaw closing muscles simultaneously. The primary purpose was to distinguish each respective motor pattern quantitatively. Earlier behavioral experiments found spontaneous occurring perioral movements in laboratory rats that primarily consisted of "purposeless chewing" with occasional episodes of "facial tremor" (Collins et al. 1993). In the present study, we were able to listen for tooth grinding sounds and visually observe brux-like motor movements when the cages were free of food. We compared this to direct observations of eating in the same animal.

The first major result is that phase differences found between two jaw closing muscles, the temporalis and masseter. During a brux-like event, the temporalis and masseter fire simultaneously (see Fig. 4A). However, during mastication the onset for the EMG burst for the temporalis occurs after the onset for the masseter muscle (see Fig. 5B). For all muscles examined, the brux-like motor patterns occurred at a cycle frequency higher than the masticatory patterns (Fig. 2).

The second major result is that the phase differences found between the masseter (jaw closing) and anterior digastric (jaw opening) muscles. During mastication we can observe an alternation of jaw opening and jaw closing muscles (see Fig. 5B). However, during a brux-like event, the temporalis and masseter exhibit co-contraction (Fig. 5A). In humans, protective co-contraction can be a non-pathological CNS response to injury or threat of injury. This has also been referred to as protective muscle splinting (Bell 1986). In essence, the normal sequencing of muscle activity can be modified to protect the body from injury (Lund and Olsson 1983). A co-contraction
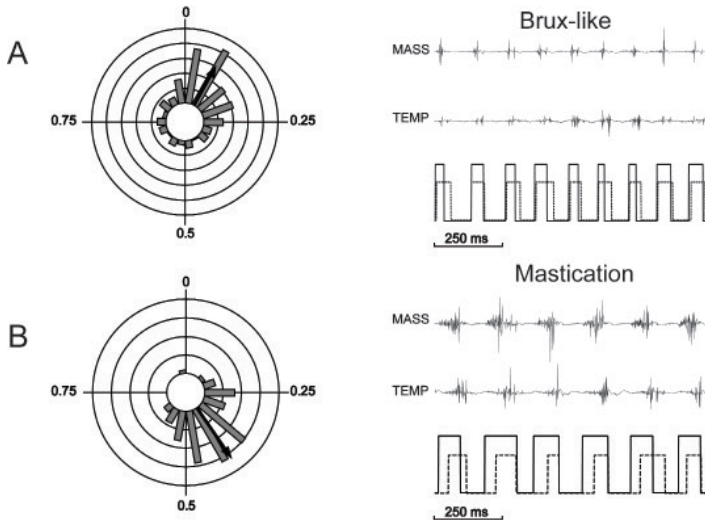
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Figure 4. Dual-referent phase analysis of masseter and temporalis EMGs during brux-like (A) and masticatory behaviors (B). Raw EMG traces of masseter and temporalis muscles during brux-like behavior (A) and mastication (B) (right). Onsets and offsets of EMG bursts of masseter (solid) and temporalis (dashed) displayed below the actual EMG traces. Circular histograms (left) were used to demonstrate phase differences from an individual animal (jt36). The direction of the vectors (arrows) indicates the circular mean phase, and the vector length indicates the strength of coupling (r) on a scale of 0.0 (innermost circle) to 1.0 (outermost circle). A. Each grid line = 10 cycles. Mean brux-like phase = 0.080, r = 0.558. (205 cycles). B. Each grid line = 5 cycles. Mean mastication phase = 0.404, r =0.768 (78 cycles). These are distinct motor patterns (p<.05).
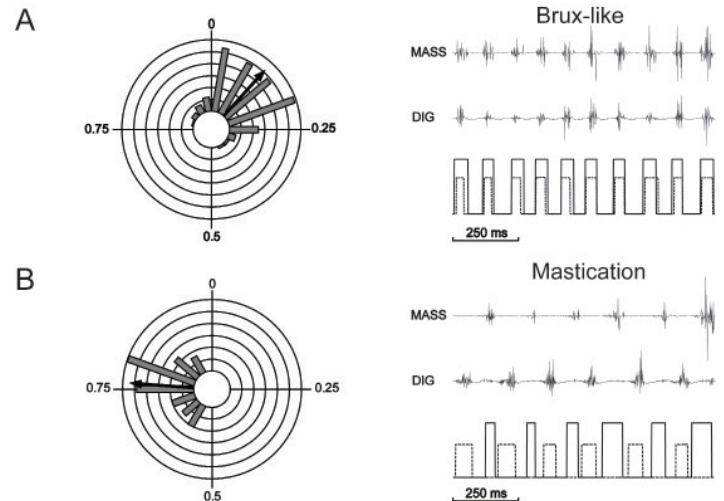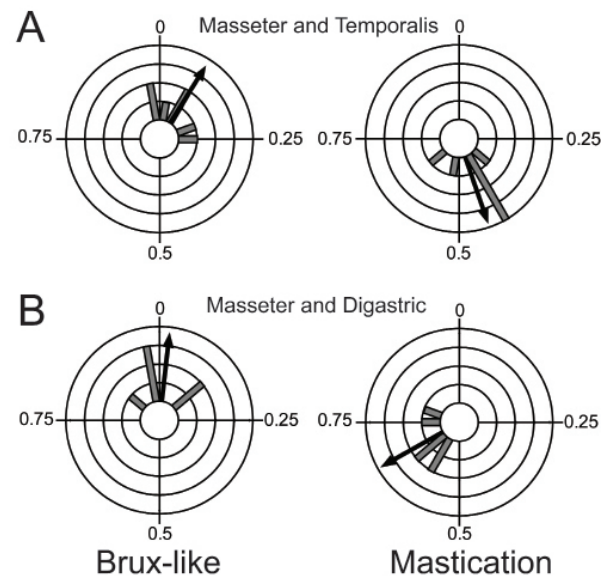
Figure 5. Dual-referent phase analysis of masseter and digastric EMGs during brux-like (A) and masticatory behaviors (B). Circular histograms indicate phase values from an individual animal (jt26). Onsets and offsets of EMG bursts of masseter (solid) and digastric (dashed) are displayed below the actual EMG traces. The direction of the vectors (arrows) indicates the circular mean phase, and the vector length indicates the strength of coupling (r) on a scale of 0.0 (innermost circle) to 1.0 (outermost circle). A. Each grid line = 5 cycles. Mean brux-like phase = 0.117, r = 0.812 (134 cycles). B. Each grid line = 2.5 cycles. Mean mastication phase = 0.762, r = 0.847. (51 cycles). These are distinct motor patterns (p<.05).

Figure 6. Circular histograms indicate the mean of mean dual-referent phase values from all animals. The direction of the vectors (arrows) indicates the circular mean phase, and the vector length indicates the strength of coupling (r) on a scale of 0.0 (innermost circle) to 1.0 (outermost circle). Each grid line is equal to the circular mean of one animal. The phase values were not uniformly distributed for brux-like (p<.05) and masticatory (p<.05) behaviors (Rayleigh test). A. Masseter and Temporalis (n=7). Left: The mean brux-like phase = 0.09, r = 0.828. The mean number of phase cycles per animal was μ = 203 (1420 total). Right: The mean masticatory phase = 0.448, r = 0.859. The mean number of phase cycles per animal was μ = 267 (1869 total). B. Masseter and Digastric (n=6). Left: The mean brux-like phase = 0.019, r = 0.847. The mean number of phase cycles per animal was μ = 217 (1300 total). Right: The mean masticatory phase = 0.668, r = 0.878. The mean number of phase cycles per animal was μ = 222 (1329 total). These are distinct motor patterns (p<.05).

of muscles may be considered a normal protective or guarding mechanism. A clinical example in human beings is a dental patient that might experience co-contraction in the presence of a high crown (Okeson 1995). In the present study, the gnashing of the rat incisors during brux-like activities suggests involvement of a similar protective feedback mechanism.

The masticatory system may also respond to input from the sympathetic nervous system. A dysfunctional occlusion was systematically induced in non-human primates (*Macaca irus*) by inserting occlusal splints into the maxilla. This created a significant increase in urinary cortisol concentration, indicating emotional stress (Budtz-Jør-

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gensen 1980). This data may help explain the relationship between dysfunctional occlusion, emotional stress, and bruxism. In the current study, brux-like motor patterns were most frequent when the rats were first placed into the cage. This suggests the novel environment acted as a stressor. This is consistent with previous studies where brux-like cycles were more frequent when the rats were anxious (Pohto 1979, Byrd 1997b). Taken together, this supports the conclusion that stress serves as a factor for inducing brux-like behaviors (Sano et al. 2007, Budtz-Jørgensen 1980).

The masticatory cycles of human subjects with bruxism were found to exhibit 1) a shorter interval between cycles 2) irregularly shaped envelopes of motion, 3) sudden changes in direction, and 4) a loss of the typical 'tear-drop' pattern seen in human chewing cycles (Faulkner 1989). Some of these changes might be due to changes in occlusion or muscles due to chronic mechanical stress. In the rat, bilateral muscle changes following the insertion of a unilateral occlusal splint may occur in human jaw muscles (Muller et al. 2000). A study using transcranial magnetic stimulation in human suggests that bruxism may be mainly under the influence of brainstem networks (Gastaldo et al. 2006). Clench and tooth-grinding jaw-movement tasks were evaluated in a fMRI human subjects study, suggest motor planning and initiation, particularly during the act of clenching, are less prominent in individuals with oromotor parafunctional behaviors (Byrd et al. 2009). A study that examined cortically induced jaw movement in the monkey (*Macaca fascicularis*) revealed that different cortical regions might be differentially involved in the selection of different masticatory patterns and modulation of this pattern via sensory feedback (Huang et al. 1989).

CONCLUSION

Our results suggest that this experimental platform can be used to examine the brainstem commands, and trigeminal neural networks that underlie the activation and switching of masticatory and brux-like motor patterns of the jaw. The results from the current study could help us examine these circuits in a reduced fictive preparation (e.g. isolated brainstem). A major question remaining is whether there are multifunc-

tional interneurons that comprise a single CPG that form a core, multipurpose circuit (Berkowitz et al. 2010), or a separate masticatory and a brux-like CPGs (Byrd 1997b) in the brainstem. A detailed pharmacological investigation could lead to additional treatment options for human bruxism. The rat brux-like motor pattern found in the laboratory rat may serve as an excellent animal model to investigate these types of fundamental questions.

CONFLICT OF INTEREST

All authors listed have no conflicts of interest to disclose.

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