


Electromyography of diurnal bruxism during assessment and treatment

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Diurnal bruxism among individuals with intellectual disabilities is often measured on the basis of its auditory products, thereby precluding the contingent presentation of stimuli during silent bruxism events. Electromyography (EMG) offers a technological solution to the identification of all bruxism events. EMG has not been previously evaluated in nonvocal clients with intellectual disabilities in the context of functional analysis and treatment. In the current series of analyses, we suggest a set of methods to implement EMG technology with this population. In Analysis 1, we propose a strategy for systematically identifying bruxism events. In Analysis 2 we evaluate an EMG staff-training package with naïve interventionists without past experience with EMG technology. Finally, Analysis 3 presents a practical example of this method during the functional analysis and treatment of a client with frequent diurnal bruxism.

Key words: automatic reinforcement, bruxism, electromyography, functional analysis

Diurnal bruxism is a form of self-injurious behavior consisting of grinding and forcefully clenching one's teeth during waking hours. Bruxism is a common problem behavior among individuals with developmental and intellectual disabilities (DeMattei et al., 2007). Some reports suggest a prevalence of over 40% among specific

intellectual disability phenotypes (see for example López-Pérez et al., 2007). Bruxism can also be induced by various medications often prescribed to individuals with developmental and intellectual disabilities (Teoh & Moses, 2019). In addition, it can interfere with the acquisition of adaptive behavior (e.g., functional vocalizations) and can have a number of serious health consequences including sleep problems, damaged bones and gums, temporo-mandibular joint pain, avulsion of teeth, and in extreme cases, tooth loss (Murali et al., 2015). Diurnal bruxism often correlates with sleep bruxism, but when they occur separately, both can lead to chronic facial pain and temporo-mandibular disorders (Sierwald et al., 2015).

Most of the few functional analyses of diurnal bruxism in the literature have produced results that are consistent with an automatic function (e.g., Armstrong et al., 2014). However, Lang et al. (2013) reported the case of

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5-year-old boy with autism who exhibited attention-maintained diurnal bruxism that was effectively reduced using functional communication training. Therefore, an automatic function should not be assumed *a priori*.

Several behavioral interventions have been found to effectively reduce bruxism in this population (see Lang et al., 2009 for a review). These include the use of positive punishment in the form of contingent exercise (Blount et al., 1982; Gross & Isaac, 1982) and the contingent presentation of combined cues; typically, an echoic prompt (e.g., say “ah”) and a physical prompt (e.g., chin pressure) (Armstrong et al., 2014; Barnoy et al., 2009; Bebko & Lennox, 1988; Lang et al., 2013). However, these studies often lack generalization tests or social validity evaluations.

A common limitation of direct observation studies of diurnal bruxism is their reliance on the audible products of the behavior (i.e., teeth grinding sounds). For example, Bebko and Lennox (1988) defined a bruxism event as repetitive teeth grinding that produced an audible squeaking sound. Similarly, Barnoy et al. (2009) defined a bruxism event as the participant grinding his upper and lower teeth with sufficient force to create an audible sound. Studies relying on sound to identify the occurrence of a bruxism episode are likely to underreport the frequency of the behavior because most bruxism episodes may be inaudible (Cash, 1988). In fact, the characteristic sound of teeth grinding is rarely observed during diurnal bruxism and is present in only about 30% of bruxism episodes according to sleep bruxism studies (Lavigne et al., 2001; Macedo et al., 2014). In sum, a measurement system with a significant *floor effect* likely prevents the effective application of operant contingencies to mild (and possibly most) occurrences of diurnal bruxism.

The universalization of mobile and wearable devices has the potential to facilitate behavior-analytic procedures whether they be automated

prompt delivery (e.g., Jimenez-Gomez et al., 2021), ambulatory continuous recording (e.g., Stephenson et al., 2017), or behavior detection through physiological indicators (e.g., Bruno et al., 2020), to mention a few examples. Wireless electromyography (EMG) may provide an alternative to the indirect observation of bruxism. EMG is a noninvasive technique for measuring the electrical activity of the neuromuscular junction of skeletal muscles as they are activated and can precisely quantify the frequency, duration, and magnitude (in microvolts, μV) of bruxism events. EMG has been used in a variety of applied settings including rehabilitation, ergonomics, sport sciences, and clinical psychophysiology (Cacioppo et al., 2016; Konrad, 2006). Several studies have used EMG during the assessment and treatment of bruxism among typically developing individuals (e.g., Baad-Hansen et al., 2007; Lauriti et al., 2014).

In addition, any behavioral interventions using EMG as a dependent measure would require implementation by staff working with individuals with developmental and intellectual disability that engage in bruxism to use this technology. Therefore, preliminary analyses on the potential for implementation of EMG technology in this context would require a staff-training component. The current study evaluates the feasibility of wireless EMG technology among individuals with developmental and intellectual disabilities who engage in frequent bruxism. In Analysis 1 we proposed a threshold-based approach to measuring bruxism in an individual with developmental and intellectual disabilities. Analysis 2 evaluated a brief EMG training protocol for practitioners with no previous EMG experience. Finally, in Analysis 3 we evaluated the proposed approach in the context of a functional analysis and treatment study using a well-established combined vocal and physical prompting procedure (Armstrong et al., 2014; Barnoy et al., 2009; Bebko & Lennox, 1988; Lang et al., 2013).

Analysis 1: A Threshold-Based Approach to Measuring Bruxism Episodes

When measuring bruxism, maximum voluntary contraction (MVC) is defined as the maximum EMG signal (in microvolts; μV) displayed by a typically developed participant upon the experimenter's request to bite down/clench as hard as they can (e.g., Haketa et al., 2003). Bruxism studies in individuals without intellectual or developmental disabilities use a fraction of the MVC value, frequently ranging from 20% to 40%, as an individually defined cut-off point to determine the occurrence of a bruxism event. This approach has been found to effectively differentiate between bruxism events, and normal tooth and jaw movements. For example, if one was to assume 30% of MVC as the operational definition of a bruxism event in the case of an individual with an MVC of 200 μV , any EMG event above 60 μV would be identified as a bruxism event. However, some individuals with developmental and intellectual disabilities may not be able to comply with the experimenter's instructions to emit an MVC by biting as hard as possible on command. Therefore, a proxy to MVC for individuals with limited verbal repertoires who often engage in diurnal bruxism is sorely needed. We estimated a proxy to the 30% MVC value by computing the thirtieth percentile of naturally-occurring EMG events, herein referred to as *maximal spontaneous contraction* (MSC).

Although there is no guarantee that a sample of naturally occurring behavior equates to the distribution of MVC, an individual with a known history of frequent bruxism would be likely to emit at least some spontaneous contractions during the sampling period that fell within the range that constitutes damaging behavior. This has been empirically verified by Yoshimi et al. (2009) who found that spontaneous sleep bruxism episodes overlapped almost perfectly with the MVC scale. Specifically, the magnitude of almost every naturally occurring

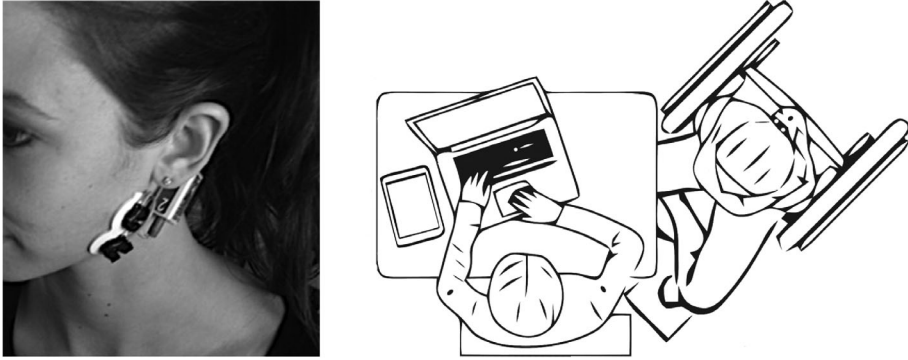
clenching and grinding episode had a magnitude equal to or below the MVC. In addition, evidence that a sample of MSC events is unlikely to be biased can be derived by verifying that observations are normally distributed and unskewed (i.e., near-symmetrical distribution). Finally, the distribution of MSC observations may be more likely to include subthreshold (nonbruxism) contraction events (i.e., false positives) than the MVC, which is composed solely of forceful contraction events. However, this potential source of bias may have clinical utility for interventions targeting bruxism. Specifically, presenting the intervention contingencies upon very low-intensity contraction events may minimize occasions in which low- to medium-intensity contractions are missed by the intervention (see an experimental analysis of intensity-based schedules in Manabe et al., 1998).

In Analysis 1 we present a demonstration of MSC detection, distribution, and threshold estimation.

Method

Participant and Setting

The recruitment facilitator at a residential facility screened the clinical records of residents for the presence of diagnoses of intellectual disability and diurnal bruxism. Two such participants with profound intellectual disability and frequent diurnal bruxism were consecutively admitted into the study. The recruitment facilitator reported that participants did not present any other severe challenging behaviors. One participant repeatedly pulled off the electrodes making it impossible to continue the study because the ethics process overseeing the study directed that an individual's participation had to be discontinued after three failed attempts. The second participant was a 40-year-old female with profound intellectual disability. The participant engaged in occasional noncontextual vocalizations (i.e., vocal stereotypy). The participant was quadriplegic

Figure 1*Electrode Placement and Experimental Setting*

Note. Wireless electrode-transmitter placement and relative location of the experimenter (left) and the participant (right) during sessions.

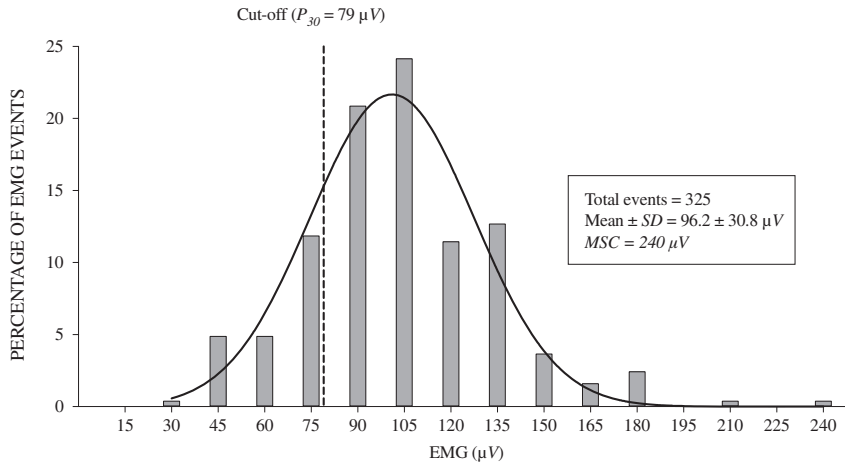
and relied on a wheelchair to ambulate. She did not operate the wheelchair independently. She could engage in neck and head movements. All sessions took place in the common areas in the residential facility where the participant lived. The procedures of the study were approved by the ethics committee of the St. Amant Research Centre, the University of Manitoba, and The University of Auckland.

Apparatus and Response Measurement

EMG recordings were conducted with the Noraxon[®] Clinical DTST[™] EMG system (Noraxon, 2017) controlled by the software EMGworks[®] (Delsys, Inc., 2021) installed on a Windows computer. It took the experimenter less than 10 hr to become fluent in operating the system using only the user manual and hands-on practice with confederates. The system utilizes 9.8 by 5.4 by 35 mm wireless electrodes equipped with double-sided disposable adhesives. The experimenter attached the electrodes to both sides of the participant's jaws over the masseter muscles. Figure 1 presents a visual depiction of the wireless electrode-transmitter placement (see also Appendix A of the Supporting Information for additional apparatus photographs). Reference electrodes were attached to the participant's dorsal neck

in the vicinity of the thyroid cartilage.¹ Electrodes detected the activity of the masseter muscles and wirelessly transmitted information on frequency, duration, and magnitude of EMG signals in real time (Konrad, 2006). The system precision has been documented in the manufacturer technical specifications (Noraxon, 2015) indicating that normal operation of the system can be expected even in the presence of dynamic motion (e.g., the system is often used with athletes; Noraxon, 2015, p. 12). In addition, the system operates with a baseline noise inferior to $1 \mu V$, at least 100 times lower than the modal contraction event of about $100 \mu V$ identified in Analysis 1 (Noraxon, 2015, p. 15). Therefore, the technical specifications of the system suggest that slight variations of electrode manipulation and placement likely had negligible effects on signal detection or processing. Nonetheless, it would be desirable to obtain procedural fidelity data on electrode placement in future studies and its potential impact in signal detection and processing.

¹The detection of the EMG signal is obtained with respect to a reference or ground electrode placed in an electrically inactive location, typically over connective or bone tissue, and at a distance from EMG detecting surfaces (De Luca, 2002).

Figure 2*Distribution of EMG Events and Threshold Determination*

Note. MSC = Maximal spontaneous contraction.

We documented the distribution of all naturally occurring EMG events. We considered all EMG signals departing from the 0 μV line as an EMG event, without any restriction due to signal magnitude, duration, or shape. An event had to be separated by a previous or subsequent event by one second to be considered an independent event. Since event recording was automated, interobserver agreement was not assessed.

Procedure

To establish the threshold for an EMG event to be considered bruxism, we conducted 1-hr recording sessions in the participant's residential facility across several weeks and times of the day (starting at either 10:00 am, 2:00 pm, or 5:30 pm according to her availability). We conducted up to five, but typically one or two, successive 10-min sessions per day. Sessions took place 3 days per week. We conducted a total of fifteen 10-min sessions over a period of 3 weeks with the participant to collect these observations. It took approximately 5 min to set up the software and prepare materials and approximately 3 min to attach the electrodes to the participant.

Observations continued until we had gathered an arbitrary number of EMG events sufficiently large to attain a normal distribution, which is needed to use percentiles. We aprioristically set an arbitrary minimum number of 300 EMG events and proceeded to evaluate normality with the omnibus k^2 D'Agostino-Pearson normality test (D'Agostino, 1986). The dataset was found to be normally distributed ($k^2 = 4.73$, $p = .093$). To evaluate the potential for bias in our sample, we verified that the data distribution was symmetrical with a skewness index between -1 and +1 (Joanes & Gill, 1998). Skewness was 0.67 (standard error = 0.13), and, therefore, roughly symmetrical. Subsequently, we computed the 30th percentile of the resulting distribution of contraction events (e.g., Haketa et al., 2003; Hiyama et al., 2003).

Results and Discussion

Figure 2 presents the distribution of EMG events. We observed 325 EMG events. Throughout the assessment, we anecdotally noted that the EMG events were both audible and inaudible. However, we did not record the

proportion of bruxism events with an auditory product. The maximal spontaneous contraction (MSC) was $240 \mu V$. The mean magnitude was $96.2 \mu V$ and the 30th percentile was $79 \mu V$ (used here as a proxy to 30% MVC). Thus, for the purposes of subsequent analyses, any EMG event with a maximum magnitude equal to or above $79 \mu V$ was considered a bruxism event for this participant.

Analysis 2: Human Detection of Bruxism Episodes

The value of the proposed procedure for people with intellectual disabilities hinges on the ability of practitioners, and potentially caregivers, to implement this technology. To this end, Analysis 2 evaluated a staff training procedure to teach naïve participants to use an EMG system and identify bruxism events.

Method

Participants and Setting

Three undergraduate female psychology students volunteered to participate in the study (age range, 21 to 25). Participants had no known learning or sensory disability or experience in the assessment of bruxism using EMG technology. All sessions took place in a private testing room with a table and two chairs. During generalization sessions, participants worked with the client described in Analysis 1. Generalization sessions took place in a room of approximately 5 m by 5 m with a table and two chairs located at the residential facility where the participant lived. The experimenter sat across from the participant (see Figure 1). On some occasions a data collector sat diagonally from the participant.

Design

We used a concurrent multiple baseline design across three participants to evaluate the staff-training package.

Response Measurement and Accuracy

We used the definition of bruxism event described in Analysis 1. We evaluated the participants' accuracy in identifying bruxism events using a set of EMG data streams that had previously been selected and evaluated by the experimenter. Percentage of correct identifications and percentage of false identifications served as dependent measures. The percentage of correct identifications was computed as the number of EMG events correctly identified by participants as a bruxism episode divided by the number of EMG events in that session multiplied by 100. We computed the percentage of false identifications as the ratio between nonbruxism events identified as bruxism events and the number of EMG events in that session multiplied by 100. Dependent variables were computed with respect to the recordings of a second reference observer (the first author). Thus, the percentage of correct identifications may be considered a proxy to interobserver agreement. Therefore, additional interobserver agreement analyses were not conducted.

Procedure

Baseline. During baseline, an experimenter asked participants to identify bruxism events on a set of prerecorded data outputs played on a desktop computer simulating a real time EMG data stream. Participants recorded events in real time by pressing a button on a touchscreen tablet synced to the desktop computer as the target events crossed through a static vertical red line in the screen. The data stream moved from right to left at a pace of approximately 1 cm per second. Each baseline session was approximately 5 min in duration and included 20 simulated EMG events: 10 simulated targets (bruxism events) and 10 distractors (e.g., talking, pulling the electrodes, yawning). Interevent time varied between 1 and 10 s, the duration of an event varied between 1 and 6 s, and the magnitude of a bruxism event varied from 30% to 100% of the MVC obtained from a volunteer who helped to generate the simulated data streams (30%

MVC = 30 μ V). A different 5-min data stream was used in every baseline session. Participants were not given any information on bruxism and received no feedback during baseline.

Training and Posttraining. During training, participants received a two-page instruction sheet based on the criteria described in Haketa et al. (2003), and the EMG system user manual (Konrad, 2006; see Supporting Information, Appendix B). The instruction sheet included examples of nonbruxism events: swallowing saliva (stable magnitude but no longer than 1.5 s), talking (very low and stable magnitude, < 20% MVC), mouth opening and closing (distinct signal shape), yawning (distinct signal shape), head rotation (very low magnitude with fluctuations), pulling or pushing electrode lines (unstable magnitude with fluctuations), electrode detachment and attachment (unstable magnitude, fluctuation, and saturation of the electrode), terminal extraction (change to symmetric and fixed magnitude), and terminal insertion (change from fixed magnitude). A different 5-min data stream was used in every training session. The participants did not receive training on electrode placement nor were they educated in any other aspect of EMG technology. In the current study, only the experimenter was involved in electrode placement.

After studying the instructions (Supporting Information, Appendix B), participants took a mastery test that included five screenshots depicting EMG outputs from the EMG system. These images consisted of simulated data created by the experimenter. Three of the images demonstrated bruxism events (e.g., high frequency and strength). Two of the images demonstrated nonevents (e.g., lower magnitude, low in strength, limited fluctuations).

The participant was required to correctly identify bruxism events and nonevents with 100% accuracy. Participants wrote their responses on the paper in the space provided under the image, and the experimenter marked the mastery test as soon as it was completed.

All participants reached 100% accuracy on the mastery test on their first attempt.

Posttraining sessions were identical to baseline sessions. Participants were not exposed more than once to a given simulated EMG signal dataset.

Generalization. Participants recorded bruxism events over several 10-min free play sessions (free access to leisure items) with the participant of Analyses 1 and 3 (see below). The EMG system was used as described in Analysis 1. The number of bruxism events in each 10-min generalization session varied. Participants were required to identify bruxism events by pressing a button at any time that a bruxism event occurred using a specialized behavioral observation app (Romanczyk et al., 2011). The experimenter simultaneously marked each event as a correct identification or as a false identification on another tablet or smartphone using the same behavioral observation app. The percentage of correct identifications during generalization sessions was computed as the number of events marked as correct identifications by the experimenter divided by the total number of events recorded by the participant in that session and converting that ratio into a percentage. The percentage of false identifications during generalization sessions was computed as the number of events marked as false identifications by the experimenter divided by the total number of events recorded by the participant in that session and converting that ratio into a percentage.

Social Validity. Participants completed an eight-item social validity questionnaire (see Appendix C in the Supporting Information) to assess the acceptability of the training procedure. All items were scored over a 5-point Likert scale. Items focused on the perceived importance of training practitioners to assess bruxism using EMG (*goal*), the relevance of the training procedures (*procedures*), and the extent to which they believed they had learned these procedures after receiving the training (*effects*) (Wolf, 1978). High average scores would

indicate that respondents perceived the study goal, procedures, and effects as relevant and effective (see Supporting Information, Appendix C).

Results and Discussion

Participants required an average of 40 min to complete the training including the time needed for reading the two-page instructions document and completing the mastery test. Unexpectedly, participants showed a relatively high level of baseline performance (range, $\approx 40\%$ to $\approx 60\%$), which may have been due to the conspicuous inverted-V shape of bruxism events in the graphic display (see *reference material* in Appendix B of the Supporting Information). All participants reached 100% of correct identification in the mastery test following training. Accuracy increased immediately after training and remained stable, whereas false identifications decreased to near-zero levels following training. Despite the relatively high baselines, all participants demonstrated at least a 30% increase in their correct identification performance during posttraining (Figure 3). The frequency of bruxism was high and variable during generalization sessions (range of bruxism events in a 10-min session = 1 to 254 events) suggesting that these sessions were more demanding than training and posttraining sessions. Yet, accuracy remained at posttraining levels.

The graph participants viewed when scoring bruxism events had horizontal gridlines at $10\ \mu V$ intervals, possibly making it easy for participants to discern the $30\ \mu V$ threshold. This fact raises the question of whether future studies would benefit from highlighting the event threshold line within the data stream. Finally, the results of the social validity questionnaire suggested that participants found the study goal to be important (5.0) and the procedures to be adequate (5.0). They also agreed to having learned to identify bruxism signals from an EMG recording (4.5) (the social validity questionnaire is available in the Supporting Information, Appendix C).

In sum, the proposed staff training strategy helped three naïve observers to accurately identify bruxism events using only simulated and real-time EMG signals. Nonetheless, the question remains as to whether EMG-naïve undergraduate students are comparable to caregivers and frontline workers in an ecological setting (e.g., parents, caregivers, behavioral technicians). This may be a topic for future research.

Analysis 3: EMG Detection during Functional Analysis and Treatment

To evaluate whether the procedures developed in Analysis 1 and the ability to train EMG scoring demonstrated in Analysis 2 would be practical in a typical clinical scenario, we conducted a functional analysis and treatment evaluation with the participant from Analysis 1 using the same EMG system. We used a combined prompting procedure involving the contingent presentation of vocal and physical prompts (Armstrong et al., 2014; Barnoy et al., 2009; Bebko & Lennox, 1988; Lang et al., 2013). This analysis also helped to establish the treatment validity of the proposed measurement procedure as a primary benefit.

Method

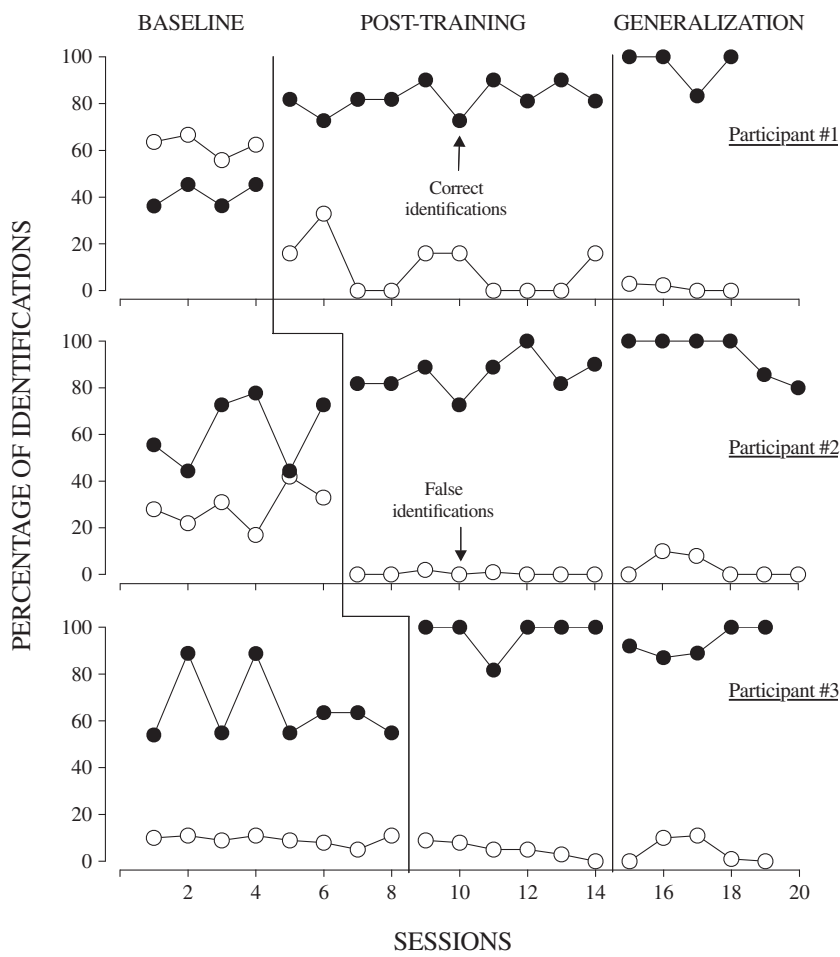
Participant and Setting

The participant described in Analysis 1 participated in Analysis 3. All sessions were conducted in a private testing room described for the generalization sessions of Analysis 2.

Response Measurement and Interobserver Agreement

The definition of a bruxism event was identical to that of an EMG event presented in Analysis 1 with the addition of the 30th percentile of the MSC ($79\ \mu V$) as a threshold. Specifically, all EMG events of a maximum magnitude equal or above $79\ \mu V$ were considered bruxism events. The data stream was comprised of a moving line graph portraying μV over time.

Figure 3
Staff Training Evaluation



The *y*-axis was scaled in 50 μV numbered intervals with unnumbered secondary axis intervals and horizontal gridlines every 10 μV . The *x*-axis was scaled in 0.5 s numbered axis intervals and vertical gridlines (see Supporting Information). Observers conducted in-vivo event recordings using the same system as Analysis 2. Sessions were divided into 10-s intervals. A secondary observer identified bruxism events during 36% of all live sessions across all study phases. We computed mean count per-interval interobserver agreement of bruxism events by dividing the smaller count

of events by the larger count of events by either observer for a given 10-s interval and converted that ratio into a percentage. We then computed the mean interobserver agreement across all 10-s intervals in a session and across all sessions with interobserver agreement recordings. Interobserver agreement for bruxism events was 96% (range, 86% to 100%).

Design

We used a multielement design during the functional analysis. The effects of both

the vocal cue and physical prompting procedure and the schedule manipulation were demonstrated by way of a mixed ABAB withdrawal and parametric design.

Procedure

Functional Analysis. To confirm an automatic function, we conducted a functional analysis according to the methods by Iwata et al. (1982/1994). Although an abbreviated assessment would have been possible (cf. Querim et al., 2013) the authors considered that a more extended assessment would provide a better opportunity to evaluate the measurement procedure in an ecologically valid context. During the functional analysis, the participant and the experimenter sat across a table from one another (see Figure 1). In the no-interaction condition, the experimenter did not interact with the participant and no consequences were provided contingent on bruxism. During the attention condition, the experimenter provided the participant with two items that had been identified as moderately preferred using a single-stimulus preference assessment according to the method described by DeLeon et al. (1999). The experimenter also provided attention (i.e., verbal response and physical contact) contingent on bruxism. The forms of attention used during the functional analysis were identified using caregiver reports and a choice assessment according to the method proposed by Fisher et al. (1996). In the control or play condition, the participant had access to two highly preferred items and the experimenter provided noncontingent social attention every 30 s. Finally, in the demand condition, the experimenter continuously prompted the participant to engage in low-preference listener responses presented by a staff member as demands (e.g., “head up,” “head down”). The staff member ceased to present demands for 30 s contingent upon the occurrence of a bruxism event. We provided a 2-min break between functional analysis sessions. The electrode-

transmitter units were not removed between sessions.

Vocal Cue and Physical Prompting Procedure. The baseline phase of the vocal cue and physical prompting procedure was comprised of a series of no-interaction sessions identical to the ones described for the functional analysis. The vocal cue and physical prompting procedure have been found effective for diurnal bruxism (Barnoy et al., 2009; Bebkö & Lennox, 1988). Barnoy et al. (2009) have suggested three candidate processes as being responsible for the effects of this procedure: “(a) response effort given the physical cue, (b) the presentation of the physical cue acting as a punisher for bruxism, or (c) the physical cue blocking access to automatic reinforcement” (p. 848).

During baseline sessions, the experimenter sat in close proximity to the participant but did not interact or provide any consequences contingent upon the occurrence of bruxism. During treatment sessions, the experimenter sat in close proximity to the participant and simultaneously presented a vocal (i.e., “say, ‘Ah’”) and a physical cue (i.e., slight pressure to the chin using the index finger for 3 s) contingent upon each bruxism episode. The muscles around the chin area (*mentalis*) are physically distant and anatomically independent from the masseters. Therefore, the chin pressure cue was compatible with continued bruxism events and bruxism recording. The experimenter viewed a computer screen presenting EMG signals in real time and recorded the occurrence of the target behavior on a tablet or smartphone in the same manner as described in Analysis 2. Figure 1 presents a visual depiction of the relative positions of the experimenter and the participant during baseline and treatment sessions. It was not required that the participant open her mouth while the physical prompt (chin pressure) was being applied.

To evaluate potential schedule effects, we implemented the vocal cue and physical

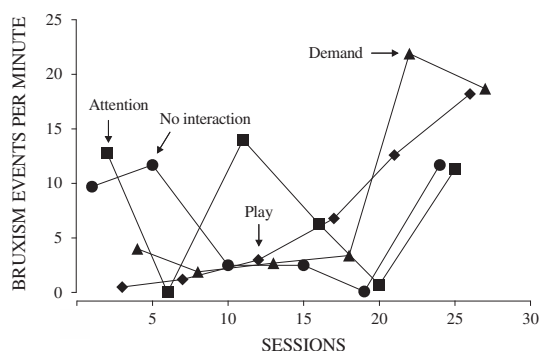
prompting procedure during either 100% or 50% of occurrences in a parametric manipulation across phases. During the 50% vocal cue and physical prompting procedure sessions, every other occurrence of bruxism was followed by the combined prompting procedure, whereas the remaining occurrences were not followed by any programmed consequences. Assessment and treatment sessions were 10-min in durations and were scheduled two or three times per week. As many as five sessions were conducted in a single visit. Visits were approximately 1 hr in duration. Participants kept the electrodes in place during inter-session breaks.

Results and Discussion

During the functional analysis the participant engaged in high and variable levels of bruxism across all conditions (Figure 4), thereby suggesting that it was maintained by automatic reinforcement. Consistent with the functional analysis, bruxism persisted at high and variable rates during the baseline phases of the treatment evaluation (Figure 5). With the introduction of treatment, the frequency of bruxism events decreased steadily to near-zero levels. Subsequently, we observed a steady increase of bruxism events during the baseline reversal followed by a sudden decrease to near-zero levels in the treatment reversal. Interestingly, it took over 15 sessions of the first treatment implementation phase to attain reliably low levels of problem behavior, whereas response reduction was almost immediate in subsequent treatment reversals. We speculate that bruxism omission was maintained initially by escape from the prompts and, eventually, by avoidance.

During the 50% vocal cue and physical prompting procedure phase, the rate of bruxism increased to baseline levels. The treatment gains of the 100% vocal cue and physical prompting procedure were replicated in the last phase of the study. Thus, the vocal cue and physical

Figure 4
Functional Analysis

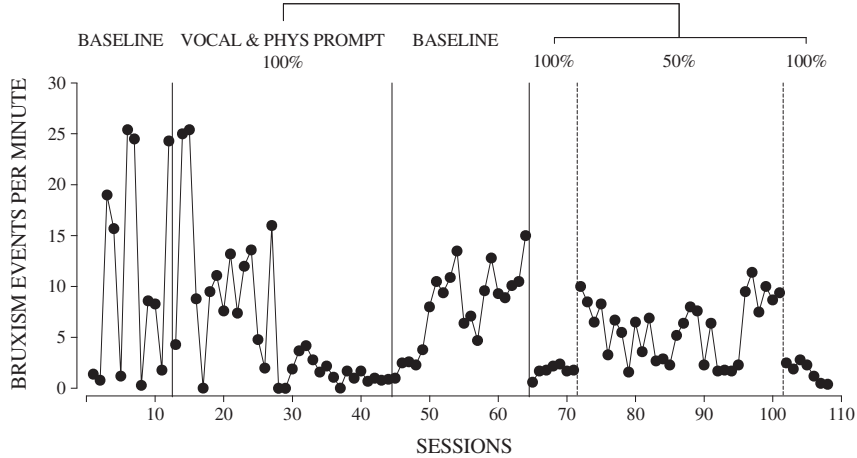


prompting procedure only reduced bruxism when presented upon every occurrence of bruxism. Overall, Analysis 3 illustrates that EMG technology can be used successfully as the basis for measuring bruxism events and presenting operant consequences during assessment and treatment.

General Discussion

Analysis 1 showed that an empirically derived threshold helped to establish a proxy to the MVC value in an individual with intellectual disability and minimal communication skills. This finding makes it possible to operationally define bruxism events in this population solely on the basis of the EMG signal of the masseter muscles. Analysis 2 demonstrated that a 40-min staff-training package could generate near-perfect accuracy in the identification of bruxism events among naïve participants using that same EMG system. Analysis 3 illustrated the potential for clinical implementation of this technology by showing that EMG could be used to successfully conduct an experimental functional analysis of bruxism and subsequent intervention.

Several limitations of the current set of analyses should be noted. First, while Analyses 2 and 3 provide indirect means to lend some

Figure 5*Vocal Cue and Physical Prompting Procedure Treatment Analysis*

validity to the MVC proxy approach, direct validation strategies may have been possible by, for example, correlating the MVC values in individuals who would emit jaw clenching on command with the MSC values while they engaged in either diurnal or nocturnal bruxism. However, the fact that bruxism observations in Analysis 1 were normally distributed and roughly symmetrical, and that the overlap between MVC and MSC has precedent in the literature (Yoshimi et al., 2009), made our inferential leap acceptable for the purposes of this technical report. For example, Yoshimi et al. (2009) found that spontaneous sleep bruxism episodes overlapped almost perfectly with the MVC percentage scale. Namely, the magnitude of almost every naturally occurring clenching and grinding episode had a magnitude equal or below the MVC. The only inferential leap in our *maximal spontaneous contraction* (MSC) and percentile approach is the assumption of normality, which we verified. We believe that Analyses 2 and 3 are more powerful strategies for validation as they involve criterion validity analyses with reference to socially important standards. Namely, the proposed measurement process can be used by

prospective practitioners after minimal training, and can be integrated in an assessment and treatment study.

In addition, although the current report has a technological emphasis, future studies should present additional evaluations of social validity and acceptability. These may include reports from teachers, parents, and clinicians, as well as more detailed staff training evaluations. For example, the training provided to observers as part of Analysis 2 was narrowly focused on signal detection. More thorough staff training programs that would include general EMG technology, electrode placement, and signal processing should be evaluated.

Second, the present findings need between-subject replications; particularly, among topographically diverse bruxism cases. For example, our participant presented highly frequent short-duration bruxism episodes. It would be important to evaluate the potential of EMG technology among participants with bruxism episodes of varying frequencies, magnitudes, and durations; and among participants with greater mobility, which could potentially interfere with signal detection. Moreover, between-subject replication could also inform

acceptability. For example, we attempted Analysis 1 with one other participant that repeatedly pulled off the electrodes making it impossible to continue the study as per our ethics process. By contrast, we did not observe any reactivity responses nor lack of compliance in our main participant. A better understanding of the prevalence of reactive responses is warranted.

Third, our study does not provide a direct comparison with alternative measurement systems (e.g., recording the frequency/duration/magnitude of teeth grinding sounds). Arguably, an advantage of measuring bruxism events by way of EMG may be the identification of silent bruxism episodes. The parametric analysis in Analysis 3 showed that systematically missing occurrences of bruxism can degrade the efficacy of an intervention. Unfortunately, we did not evaluate the proportion of silent bruxism episodes that we were able to detect. The analyses available in the literature suggest that silent bruxism episodes may account for as many as 70% of all bruxism events (Lavigne et al., 2001).

Fourth, although the focus of the current set of analyses was on measurement and only indirectly on treatment evaluation, we cannot minimize the demand that the constant observation and implementation would pose on caregivers and practitioners. In addition, it is possible that the presence of the electrode-transmitter unit could have acquired stimulus control over bruxism. Optimizing this treatment model would require adding reinforcement-based interventions (e.g., DRA, DRO, DRI) and gradually fading vocal and physical prompting and the presence of the electrode-transmitter unit. Implementation of the procedure for relatively longer intervals may be possible due to the miniaturization that EMG technology has undergone over the last decades. Even since the completion of the current project, lighter and more portable wireless systems have become available, some weighting as little as 7 g (e.g., Cometa S.R.L., n.d.). However, it is not

currently possible to automate the delivery of vocal and physical prompts.

Additional practical constraints of the proposed procedure should continue to be evaluated. For example, a latency-based procedural integrity evaluation of the combined cue procedure seems, in retrospect, highly relevant. Specifically, it may be difficult for a therapist to reliably identify an instance of bruxism quickly and deliver the intended consequence within seconds. The integration of signal processing routines to automatically cue the therapist of the occurrence of a target event would be desirable and likely to impact treatment acceptability and integrity.

Finally, the fact that one of the participants recruited did not tolerate the EMG system raises questions about the generality of the procedure or the need for tolerance training ahead of the intervention (see some examples of antecedent-based procedures in Cox et al., 2017, and Sivaraman et al., 2020). In addition, due to major motor impairments, the participant who did complete the study would have had difficulty in physically removing the apparatus. We evaluated the participant's discomfort and assent on a continuous basis by attending to potential signs of distress including motor agitation and vocalizations. A more detailed assessment of generality of the proposed procedure, and of wearable technology more generally, is warranted.

The three analyses presented here provide a basis for others interested in using this technology to replicate our findings. We believe that there is room for optimization. For example, it is possible that fewer than 300 observations may suffice to obtain a valid cut-off value for identifying bruxism events. Finally, Analysis 2 is most relevant to those interested in training students or staff, whereas training of parents may be more clinically relevant. Overall, our study suggests that EMG technology provides a feasible and valuable measurement strategy for diurnal bruxism during assessment and treatment.

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