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Waking-state oral parafunctional behaviors: specificity and validity as assessed by electromyography

Richard Ohrbach, Michael R. Markiewicz, Willard D. McCall Jr

Department of Oral Diagnostic Sciences, School of Dental Medicine, State University of New York at Buffalo, Buffalo, NY, USA

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In contrast to sleep-related oral parafunctional behaviors, little is known about waking oral parafunctional behaviors. The Oral Behaviors Checklist contains terms referring to a variety of non-observable behaviors that are reliable when prompted (e.g. 'clench') but validity data are absent. Our goal was to assess whether (i) each behavioral term is distinct electromyographically, and (ii) temporomandibular disorder (TMD) subjects differ from non-TMD subjects in their performance. Surface electromyographic (EMG) activity was used to measure bilateral masseter, temporalis, and suprahyoid muscles while subjects (27 patients with TMD; 27 healthy controls) performed ten oral behaviors without explanation. Electromyographic data were averaged between bilateral muscles and two trials. A multivariate construct (jaw muscle activity) was analyzed using Wilks lambda within multivariate analysis of variance (MANOVA). Obvious behaviors (e.g. clench, read, tongue press) exhibited expected EMG patterns, and patients and controls produced identical profile plots of the EMG data. Of 10 tested behaviors, nine were found to be associated with significantly differing proportions of amplitudes across muscles and were thus unique. Behaviors with similar terms were associated with different EMG patterns. The present data support the specificity of behavioral terms and performances. Implications include causation related to TMD based on subtle behaviors that occur at a high frequency.

Dr Richard Ohrbach, 355 Squire, State University of New York at Buffalo, Buffalo, NY 14214, USA

Telefax: +1–716–8293554
E-mail: ohrbach@buffalo.edu

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The term 'oral parafunctional behaviors' collectively refers to behaviors different from those required for, or associated with, expected jaw functional demands such as mastication, swallowing, communication, or breathing. Sleep-related oral parafunction is primarily bruxism (tonic, phasic, or both), whereas waking oral parafunction, by contrast, is more diverse and includes clenching, excursive positioning, holding the jaw rigid, and tongue pushing, among others (1, 2). These behaviors share a common characteristic related to overuse of the masticatory muscles. In contrast to sleep-related oral parafunctional behaviors (1, 3–7), little is known about waking oral parafunctional (or overuse) behaviors (2, 8–14).

Identifying the presence of waking-state oral parafunctional behaviors in the natural environment is difficult because of their tendency to be largely unobservable and their propensity to occur outside usual conscious awareness. Compared with sleep behaviors, waking behaviors are less reliably detected and have no apparent pathognomonic symptoms (7, 15); typical styles of interview questions include direct (e.g. 'Do you clench your teeth during the day?') or via self-awareness probe (e.g. 'Are you aware of whether you clench … ?'). Such methods are problematic, however, because they assume that the individual has conscious access to the putative behavioral patterns and that the individual knows what the term (e.g. clench) means; moreover, restricting the domain of assessment to just 'clenching' may also reflect limited content validity.

Moss *et al.* (16) measured several intentional oral parafunctional behaviors based on electromyographic (EMG) activity from three muscles of the face (bilateral masseter, temporalis, and orbicularis oris) in healthy subjects. This study showed, not surprisingly, that each of the targeted behaviors is associated with its own magnitude of EMG activity. The limitations of that study included: (i) testing only a limited number of behavioral patterns that did not include those putatively related to temporomandibular disorders (TMD); (ii) restricting analysis to a single muscle (despite multiple muscles being measured); and (iii) not including subjects who reportedly exhibit the behaviors at a high rate.

Using waveform templates, Gallo *et al.* (7) demonstrated specificity of the EMG patterns within a single muscle which were associated with parafunctional behaviors that occur during sleep and with some common oral functional behaviors that occur during the waking state. Given this specificity of EMG patterning associated with at least some oral behaviors, the mapping of labels to the associated waking parafunctional behaviors should be examined and compared for possible differences between TMD and non-TMD patients. For example, an expert panel (see Material and methods) suggested possible behaviors of 'touching the teeth', 'pressing the teeth together', and 'holding the teeth together'; whether these are all just different labels for one underlying behavior, or whether these represent different behaviors, is not known. Similarly to guarding behaviors involving the back (17), concepts related to possible oral behaviors include 'tense the muscles' and 'hold the jaw rigid (with teeth separated)', but whether these are different labels for the same behavior or point to different behaviors is unknown.

Enhancing the content validity of the domain of waking oral behaviors resulted in a prototype instrument, the Oral Behaviors Checklist (R. Ohrbach, unpublished), for assessing self-reported awareness of the presence and extent of about 18 waking oral behaviors. It is not known whether every one of the behavioral terms on the instrument maps to specific behaviors, as opposed to exhibiting overlap across two or more actual behaviors. For example, does 'clenching' refer to the same behavior for all individuals and, moreover, is that behavior different from the one referenced by 'bracing'? Specificity among behaviors and the related terms represented via self-report is critical if any type of self-report (instrument or interview) is going to provide useful measurement (18).

In a previous report (19), we assessed the consistency of intentional performance as an index of whether each individual clearly understood a meaning of the respective terms that were adapted from the Oral Behaviors Checklist; our reported EMG intertrial reliabilities associated with each term were in the range of 0.60–0.95, and there was no systematic pattern in the reliability coefficients that distinguished patients from controls. The aims of the present study were to assess (i) whether each behavioral term is distinct electromyographically, and (ii) whether there are differences between groups (TMD vs. non-TMD) in terms of EMG patterns. This study does not address causal relationships between diagnostic status and behavioral patterning.

Material and methods

Individuals from two populations (TMD and non-TMD, matched for gender) were recruited to form the study sample. Individuals with TMD were selected based on the reported high rate of occurrence of various overuse behaviors in that group (20), whereas non-TMD subjects were selected based on the assumption that they do not perform such behaviors very frequently. By recruiting subjects from these two populations, we endeavored to create a study sample that would represent a distribution in which the frequency of performing these behaviors varied.

Subjects with TMD, recruited from a university-based orofacial pain practice, were selected if they met research diagnostic criteria (RDC)/TMD diagnostic criteria (per history and examination) for any disorder except for intermittent locking (21), whereas non-TMD subjects, recruited from the community, were defined as having a lifetime of absence of reported pain and jaw problems (per history). Subjects included 27 subjects with TMD [six men, mean age 34.3 yr, standard deviation (SD) 13.6 yr; 21 women, mean age 43.2 yr, SD 13.0 yr) and 27 non-TMD controls (six men, mean age 44.6 yr, SD 10.1 yr; 21 women, mean age 36.1 yr, SD 12.9 yr). The Institutional Review Board, in conformance with the Declaration of Helsinki, approved the study, and informed consent was obtained from each subject.

Variables

The Oral Behaviors Checklist (OBC) was developed with expert input by the RDC/TMD Validation Study Group (see the Acknowledgements) as part of a larger study regarding diagnostic reliability and validity for TMD. The present report is one of a series of studies assessing the OBC and, in particular, the goal was to examine specific unobservable behaviors within the OBC. Several observable behaviors were included as reference tasks. A laboratory version of the OBC (L-OBC) was constructed to address the hypotheses of the present study, and the L-OBC included the following behaviors: (i) clenching, (ii) touching, (iii) pressing, and (iv) holding the teeth together; (v) holding or tensing the muscles of the face; (vi) holding the jaw in a rigid position; (vii) holding the jaw forward or to the side; (viii) pressing the tongue forcibly against the teeth; (ix) sustained talking; and (x) yawning. For each item, the subject was asked to report frequency over the past month, using responses of 'none of the time', 'a little of the time', 'some of the time', 'most of the time', and 'all of the time' (score range 0–4), yielding a maximal 'score' of 40 for the instrument. The L-OBC assessed, as confirmation, whether our recruitment strategy of obtaining a range of reported behaviors was successful. The behaviors 'touch', 'press', and 'hold' were of particular interest because they would potentially appear to represent linguistic variations of generally the same behavior in terms of force characteristics.

Electromyographic activity was measured from three jaw muscles (bilateral masseter, temporalis, and supra-hyoid group), in order to sample broadly the presumed vectors of force applied to the jaw during each behavior, as implied by the measured EMG activity. Each subject's skin was prepared using Nu-prep (a mild skin cleanser), followed by an alcohol wipe. Standard 1.0 cm^2 electrodes were placed overlying each muscle (22), with an inter-electrode distance of 1 cm. A ground electrode was attached to the ear lobe. The sample rate for the EMG acquisition was 2 KHz.

Procedure

Subjects completed the L-OBC questionnaire, and electrodes were affixed. The subjects lifted a series of weights with their dominant biceps, and these results were previously reported (19). The subject was asked to perform each oral behavior, in turn (e.g. 'please clench your teeth'); if the subject asked for clarification, the experimenter always responded, 'do whatever you think the word means to you'. Electromyographic activity during each oral behavior was collected using a 3-s baseline, 3-s task, and 6-s recovery period paradigm for each of two trials. The task period of 3 s was chosen in order to obtain focused EMG activity; a longer period was considered to be a risk for variability in performance. Data collection during the behavior was initiated as indicated by EMG monitoring on an oscilloscope. Some trials (< 1%) were repeated if the behavior was not continuous for the 3-s period. At the end of the recovery period following each task performance, if the subject had not reduced the EMG activity to < 25% of the maximum level of EMG exhibited during the requested behavior by visual confirmation, additional time was provided before proceeding to the next task.

Data analysis

Using a task-only design (23), the EMG data from the 3-s task period (6,000 samples) were reduced offline to root-mean-square (RMS) values and then were natural log-transformed because of positive skew. As reported previously (19), the EMG values from the right and left sides of each of the masseter and temporalis were reliable, and the EMG values for trial 1 and trial 2 of all muscles were reliable; consequently, the data were collapsed for each muscle by computing the mean for sides and trials in order to improve EMG reliability for the subsequent analyses. A two-way (behavioral tasks, groups) multivariate analysis of variance (MANOVA)-based profile analysis (24) permitted comparison of the EMG means of the three muscle groups in order to assess whether the resultant variate, jaw muscle activity, differed across tasks and between groups (controls, patients). The level of statistical significance for all analyses was set at an α-level of 0.05. Descriptive statistics were obtained using STATA (version 10.0; StataCorp LP, College Station, TX, USA), and the MANOVA was obtained using STATISTICA (version 6.0; StatSoft, Tulsa, OK, USA).

Results

Visual inspection of the differing patterns of mean EMG values among all subjects (Fig. 1) indicated the following: (i) 'clenching' was a very active behavior of the temporalis and masseter; (ii) tasks exhibited appropriate face validity (e.g. high suprahyoid activity with 'yawning', 'reading', and 'tongue pressing'); (iii) some tasks exhibited expected characteristics not previously identified (e.g. tensing the jaw requires noticeably more suprahyoid activity compared with that of temporalis and masseter); (iv) 'holding' the teeth together, characterized by equal contributions by each measured muscle group, appeared to be different from 'pressing' and 'touching', characterized by non-equal contributions; and (v) the total muscle activity for 'touch', 'hold', 'press', and 'clench' occurred, respectively, in an ascending order, which is consistent with our common-sense understanding of what the words imply behaviorally.

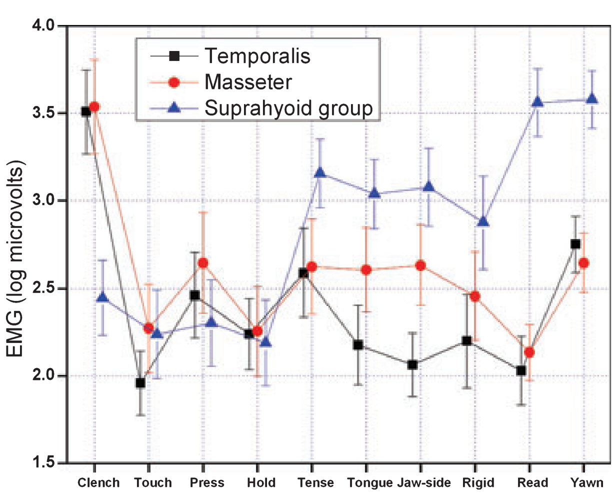

Fig. 1. Plot from profile analysis of log electromyographic (EMG) activity from each muscle by task, demonstrating significant differences across tasks based on a three-dimensional variate formed from measured EMG of masseter, temporalis, and suprahyoid muscle units (Wilks lambda = 0.07034, F(27, 20) = 9.7906, P = 0.00000). Experimental groups (patients, controls) are collapsed together. The y-axis refers to natural log-transformed values in microvolts; vertical bars denote 0.95 confidence intervals. See the text for a further description of each task.

Inspection of Fig. 1 indicates that the variances appear very similar overall; the Box M test for homogeneity of variance was performed, using TMD vs. non-TMD as a grouping variable for purposes of running the analyses. For each task, the Box M value was non-significant for the variances of the three muscle groups (all $P > 0.05$).

The task means for each of the three muscle groups were then assessed statistically using the MANOVA. The profile plots did not differ significantly between the two study groups (Multivariate $F = 0.25$, $P = 0.86$) and the interaction term (task × group) was also not significant (Multivariate $F = 1.28$, $P = 0.29$). These two statistical results collectively indicate that the mean EMG magnitudes for each muscle within a given behavioral task did not differ between study groups.

The two groups (TMD and non-TMD) were then collapsed into a single sample in order to increase power given the number of within-subject levels for task, and the MANOVA was repeated using the EMG amplitudes from the masseter, temporalis, and suprahyoid as three dependent variables and with the 10 tasks as the within-subject factor. The resultant profile analysis using MANOVA indicated that the tasks did differ in how the three muscles were recruited [Wilks lambda = 0.07034, $F(27, 20) = 9.7906$, $P < 0.001$]. A planned multiple-comparison test (Newman–Keuls) was performed (Table 1). Note that most (24 of 25) cells without shading (indicating $P < 0.05$) exhibit probability levels substantially below the 0.05 level, whereas most (17 of 20) cells with shading (indicating $P > 0.05$) exhibit probability levels substantially above the 0.05 level. Of the four pairwise correlations that bracket the 0.05 probability level, all occur in relation to the behavior 'press', which then had the most ambiguous EMG patterning. Otherwise, each tested behavior was distinct from at least three other behaviors.

Of particular interest were the relationships among 'touch', 'press', and 'hold', and between 'tense' and 'rigid'. While the words within each group appear to be quite similar in meaning, 'touch' is different from 'press' but not 'hold', and 'press' is marginally not different ($P = 0.062$) from 'hold'. 'Tensing' the jaw vs. holding the jaw 'rigid' represent different behaviors ($P = 0.005$). Based on inspection of the resultant profile plot (Fig. 1), a *post hoc* hypothesis also emerged regarding whether

Table 1

Post-hoc comparisons

Task	1 Clench	2 Touch	3 Press	4 Hold	5 Tense	6 Tongue	7 Jaw side	8 Rigid	9 Read	10 Yawn
1		< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
2	< 0.001		< 0.001	**0.162**	< 0.001	**0.249**	**0.644**	**0.243**	**0.540**	< 0.001
3	< 0.001	< 0.001		**0.062**	**0.274**	**0.077**	0.007	**0.071**	0.004	0.036
4	< 0.001	**0.162**	**0.062**		0.009	**0.856**	**0.444**	**0.738**	**0.390**	< 0.001
5	< 0.001	< 0.001	**0.274**	0.009		0.004	< 0.001	0.005	< 0.001	**0.169**
6	< 0.001	**0.249**	**0.077**	**0.856**	0.004		**0.338**	**0.845**	**0.429**	< 0.001
7	< 0.001	**0.644**	0.007	**0.444**	< 0.001	**0.338**		**0.481**	**0.778**	< 0.001
8	< 0.001	**0.243**	**0.071**	**0.738**	0.005	**0.845**	**0.481**		**0.477**	< 0.001
9	< 0.001	**0.540**	0.004	**0.390**	< 0.001	**0.429**	**0.778**	**0.477**		< 0.001
10	< 0.001	< 0.001	0.036	< 0.001	**0.169**	< 0.001	< 0.001	< 0.001	< 0.001	

The probabilities associated with each pairwise comparison, based on Newman–Keuls testing of all possible pairs using the multivariate composite variable from all three muscles as the dependent variable, are shown. This set of pairwise comparisons is illustrated in a full 10×10 matrix. Error within mean squares = 0.32631 with 414 degrees of freedom (d.f.). Bold text exhibits a probability of > 0.05.

muscle vectors associated with 'pressing the tongue' vs. 'holding the jaw to the side or forward' were different, and they were not ($P = 0.34$).

Discussion

Our data indicated that the patterning created by motor recruitment of the temporalis, masseter, and suprahyoid muscles was specific, with few exceptions, for each of the behavioral terms with respect to at least three other behaviors. Overall, among the 10 tested behaviors, more differences than similarities were exhibited in terms of contraction-level patterning of the three muscles. A truism in psychometric research is that 'reliability constrains validity', which means that a validity coefficient can be only as large as the reliability coefficient. Our previous study demonstrated high reliability; for example, masseter muscle test–retest reliability coefficients were greater than 0.8 for seven of the behaviors (19). The present study demonstrates that the 10 tested behavioral terms point largely to specific behaviors, which is a form of validity. The only terms of significant interest without unique EMG profiling were the pair of pressing tongue vs. holding the jaw forward or the side. These would clearly be different behaviors when observed, and so they are clearly distinct terms, but just not distinct with respect to measured EMG.

Our previous reliability data (19) indicated that individuals have a clear understanding of each behavioral term. The reliability of oral task performance was generally as good as the reliability associated with the simple task of lifting a weight with the hand (19). As noted in the Introduction, a limitation in the study of Moss *et al.*(16) was examining these types of behaviors only in healthy controls; it was unclear whether rehearsal and familiarity with the associated behavior (as would be true in individuals who perform the behavior often) would affect how a task might be performed. The profile plots for controls vs. TMD were visually and statistically indistinguishable. Consequently, practice effects or familiarity did not alter performance.

The present study has three implications: the first concerns support for a possible causal relationship between the wide range of potential oral behavioral patterns and functional disorders of the jaw (25, 26), usually based on concurrent association with 'clenching' (27). Among the various behaviors tested in this study as well as those identified elsewhere (28), clenching is probably the easiest for individuals to self-identify, and it is probably the most severe in terms of magnitude of muscle contraction. But clenching is not the only waking oral parafunction, and the possible causal potential for the other behaviors has been explored in a parallel manner in the area of back pain. Bracing behaviors are common factors for back pain persistence (29), and the fear-avoidance model inherently includes, as mediating between fear of pain and avoidance behavior *per se*, some type of specific behavior comprising the individual's response (30). The oral behaviors, with measurable muscle activation resulting in static jaw positioning, may have such a role.

The second implication is that the differing underlying muscle activities associated with each behavior may have different impacts on symptoms, function, or both, depending on the relative frequency of occurrence of the behaviors. Recent work on the central nervous system (CNS) organization of muscle forces upon the TMJ (31) links directly into actual behavioral patterning, such that 'tensing' of the jaw may result in a wide range of possible vectors of force distribution, some of which may well be detrimental to TMJ integrity. It is relatively easy to consider how clenching could exhibit forces sufficiently strong to cause problems (32–34). However, the present data indicate that the magnitudes of effort involved with the different behaviors may be far from extreme, consistent with the data reported by Glaros *et al.* (35). Our data also indicate that the individuals who perform these behaviors infrequently (i.e. our 'controls') and the individuals who perform them frequently (i.e. our 'patients') do the same thing – at least, within the limits of the multivariate model – suggesting that any pathogenesis associated with the behaviors is related to frequency of occurrence as well as to the lifetime course (36). The prevalence of the different behaviors must also be considered as we begin to test possible causal relationships (37).

The third implication relates to the validity of self-report measures in general. Traditional test theory relies upon item covariation as evidence for an underlying latent variable (or construct) (38), but shared variation of two or more items, however, also reflects the possibility of overlap in what the items are measuring (18). For most self-report items, there is seldom any criterion measure available for judging the specificity of a given item relative to its latent variable. This is not a trivial issue given the increasing importance being placed on patient-reported outcomes; we would like to be certain that such self-reports have validity at least equal to objective clinical outcomes. The present data, given the objective criterion (EMG amplitudes) for mental concepts (e.g. 'clench'), provide a window on the validity of behavioral concepts.

In addressing the first two implications together, our data, as previously reported (19), indicate that the patients reported significantly higher frequencies over the previous month of almost all of the behaviors assessed via the L-OBC, as compared with controls. If the data regarding frequency of occurrence were to be combined with the magnitude data reported here, then a daily 'density' for each identified behavior might provide a useful perspective regarding how oral parafunctional behaviors lead to clinical problems (25).

The ability to elicit superior motor control lies in the capacity to recruit the necessary and sufficient motor units for a given load. There is generally high variability in 'resting baseline' EMG of the masticatory elevator muscles (39, 40) (and which also occurred in our study). Our baseline command of 'please relax your whole body' was, not surprisingly, often followed by anything but relaxation, and subjects displayed highly variable EMG patterns, suggesting random behaviors in response to the directive. The ongoing motor unit activation that underlies these random behaviors represents a stream of multiple ongoing processes of the CNS (41). By contrast, muscle activity was predictable when the subjects performed directed behaviors. Both magnitude of muscle activity, in response to load, and organization of muscle patterning, with respect to the external force vector, are significant aspects of motor unit recruitment (42). Therefore, behaviors that asked for a more unambiguous activation of the musculature would be expected to show a higher degree of muscle control, as evidenced by our reliability data (19) and permit the demonstration of the distinctions between tasks. Subjects interpret 'rest' in highly idiosyncratic ways, in contrast to a 'clench' being, in fact, a clench.

Similarly, GALLO *et al.* (7) demonstrated, via waveform analysis, specificity of single-muscle patterning of the raw EMG across the assessed behaviors (chewing soft food, chewing hard food, swallowing, laughing, speaking, and tooth grinding and clenching, as well as no activity); their data provide strong evidence regarding how differences in central motor control of the behaviors are organized. Going beyond the neural control of a single muscle to the control of a muscle system, it is equally likely that the central control patterns for each of the behaviors observed here are also different, which would not be surprising given the different developmental trajectories and biological roles for the different behaviors. The behaviors themselves have a relatively distinct linkage to the underlying semantics. Of a more speculative nature is whether this semantic linkage has an associated predictable network of central activation that extends beyond the motor cortex. If that is true, then the somatic engagement associated with each of the observed behaviors may reflect differing states of the individual. Those states might be represented broadly by, for example, habitual (postural) stance, pain avoidance, or emotional reactivity, in which case each behavior is associated with different meanings. That behavior has meaning is accepted (43), but whether the differences in these various oral behaviors also reflect differences in meaning is speculative.

This speculation is but an extension of the classic response-specificity theory in general psychophysiology (26, 44–46), which addresses differential patterning across systems (e.g. muscular, autonomic to the heart, autonomic to the skin, etc.). With an organ as rich as the oral region in terms of functional development beginning from birth – starting with suckling, and then progressively ingestion and mastication – it is not unreasonable to suspect that differential patterning of behaviors, all requiring muscle activation, might exist, and that they may have different linkages emotionally and cognitively. Or, perhaps these behaviors are just crude manifestations of a simple activation pathway, such as has been conceptualized as general arousal (47–50). We suspect that at a clinical level both hypotheses are true, with different proportions of applicability in different individuals, and that this complexity underlies part of the poor predictability of treatment outcomes in TMD.

There are three limitations of this study. The first is that no direct observation was possible for most of the tested behaviors. While this would appear to be a critical limitation given the goal of the study, three factors mitigate its potential impact: (i) equality of variances from the dominant muscle of observable tasks (e.g. yawn, read) vs. non-observable tasks (e.g. press tongue); (ii) labeled tasks accounting for a substantial amount of variance (per MANOVA main-effect); and (iii) consistency of performance across trials, as previously reported.(19). While it would be ideal to observe the behavior directly, there is no real method that permits this without the intrusiveness affecting the validity of the measurement itself. The actual behavior that an individual performed reliably in response to the directive 'please clench', for example, may well have varied across individuals, but MANOVA main effects clearly suggest greater homogeneity within labeled tasks than between tasks. The extent of applicability of findings to the exact behavior performed by an individual remains to be confirmed.

The second limitation is that two other muscle groups – lateral and medial pterygoids – were not measured. The technical difficulty of such measurement is secondary to its invasiveness as a potential contaminant of valid behavioral enactments, a requirement of this study. We do not believe that the absence of pterygoid data detracts from the present results, in that it is quite unlikely that the inclusion of additional vectors in the model would undermine the present statistical results, but their inclusion would certainly provide a complete representation of all vectors acting on the jaw during each task.

The third limitation is that because we operationalized behavioral performance in terms of EMG activity, we conclude with the curious paradox of stating that two behaviors not different in terms of EMG activity are nevertheless different because visual assessment would easily confirm that they are in fact different behaviors. Perhaps with additional data from the missing muscles, those two behaviors would then be different in terms of EMG activity. Our purpose in using EMG activity was to assess that which is otherwise not observable. However, EMG activity does have its limitations as a measurement tool.

In sum, this study extended the findings from our related paper on reliability of performance of the measured oral behaviors by demonstrating that not only is the performance reliable for each task, but the labeled tasks also exhibit validity in that each task can be distinguished from many similar tasks, as assessed via multivariate modeling of EMG. This study provides data useful towards the criterion-oriented validity of the self-report instrument, the Oral Behaviors Checklist. If subjects report that they perform a listed behavior, it appears that the term references a commonly understood behavior that all observers would agree upon as representing that particular task. The frequency with which one performs the task does not appear to affect its behavioral meaning. Not only does it appear that the range of distinct oral parafunctional behaviors is quite extensive but the range of the underlying force dynamics of the associated muscles is varied across the behaviors.

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