A Controlled Comparison of Emotional Reactivity and Physiological Response in Masticatory Muscle Pain Patients

John E. Schmidt, PhD
Assistant Professor
Department of Psychiatry and Psychology
and Department of Anesthesiology
Mayo Clinic
Rochester, Minnesota

Charles R. Carlson, PhD
Professor and Chair
Department of Psychology
University of Kentucky
Lexington, Kentucky

Correspondence to:
Dr John E. Schmidt
Department of Psychiatry and Psychology
Mayo Clinic
Rochester, MN 55905
Fax: 507-255-1877
Email: schmidt.john1@mayo.edu

Aims: *To investigate* (1) *differences in heart rate variability (HRV) indices between masticatory muscle pain (MMP) patients and pain-free controls at rest, during a stressor condition, and during a post-stressor recovery period, and* (2) *factors including psychological distress, social environment, and family-of-origin characteristics in the MMP sample compared to a pain-free matched control sample.* ***Methods:*** *Physiological activation and emotional reactivity were assessed in 22 MMP patients and 23 controls during baseline, stressor, and recovery periods. Physiological activity was assessed with frequency domain HRV indices. Emotional reactivity was assessed with the Emotional Assessment Scale. Analytic strategy began with overall 2 x 3 multivariate analyses of variance on physiological data followed by focused contrasts to test specific hypotheses regarding physiological and emotional status. Hypothesized differences between study groups on psychological and social-environmental variables were compared with univariate analyses of variance.* ***Results:*** *The MMP patients showed physiological activation during the baseline period and significantly more physiological activation during the recovery period compared to the controls. This pattern was also present in emotional reactivity between the groups. The emotional and physiological differences between the groups across study periods were more pronounced in pain patients reporting a traumatic stressor.* ***Conclusion:*** *These results provide further evidence of physiological activation and emotional responding in MMP patients that differentiates them from matched pain-free controls. The use of HRV indices to measure physiological functioning quantifies the degree of sympathetic and parasympathetic activation. Study results suggest the use of these HRV indices may improve understanding of the role of excitatory and inhibitory mechanisms in patients with MMP conditions.* J OROFAC PAIN 2009;23:230–242

Key words: emotional reactivity, heart rate variability, masticatory muscle pain, orofacial pain, self-regulation

Chronic masticatory muscle pain (MMP) is one of the more common orofacial pain conditions.[1] Generally, orofacial pain conditions are primarily present in young and middle-aged adults and are less common in children or the elderly. There is also a gender difference, with women twice as likely to report an orofacial pain problem.[2] The high prevalence of comorbid physiological conditions that often present in long-term orofacial pain patients (eg, interstitial cystitis, irritable bowel syndrome) suggests broad physiological dysfunction may be a significant factor in the maintenance of the pain condition.[3]

Compared to pain-free controls, chronic orofacial pain patients have reported lower pain tolerance and thresholds,[4] more emotional and cardiovascular reactivity,[5] more psychological distress,[6] more fatigue, and more sleep dysfunction.[6] Several studies have also demonstrated the comorbidity and increased incidence of anxiety[7,8] and depression[9] in subgroups of chronic orofacial pain patients. These findings may reflect a more fragile and reactive behavioral and emotional response system in these patients. In fact, chronic orofacial pain patients have demonstrated heightened emotional reactivity to stressors in previous studies.

In addition to the increased pain symptoms and psychological distress among these patients, there is a high incidence of comorbid traumatic life experiences. A recent study found 49.8% of over 1,200 orofacial pain patients reported traumatic life events.[10] The number of orofacial pain patients reporting clinically significant symptomatology of posttraumatic stress disorder (PTSD) is also high, ranging from 15% to 23%.[11–13]

The systemic and chronic level of activation present in chronic orofacial pain patients, which is often pronounced in patients reporting a traumatic stressor, does not appear to diminish over time. The characteristics commonly found in chronic orofacial pain patients—increased emotional reactivity, increased prevalence of psychopathology, and increased physiological reactivity—imply compromised autonomic regulation and suggest the need for a quantitative measure of autonomic system functioning. A physiological measure representative of autonomic balance would provide a better understanding of the associations among emotional and physiological responses to environmental challenges by providing an index of autonomic homeostasis and flexibility. Heart rate variability (HRV) is a physiological index that has demonstrated usefulness in providing a quantitative measure of sympathetic and parasympathetic activity, and an index of autonomic balance.[14]

HRV is derived from fluctuations in the time interval between normal heartbeats. Fluctuations in the inter-beat or NN interval are expressed as beat-to-beat alterations in heart rate and are a representation of the heart's ability to respond to normal regulatory impulses that affect heart rhythm.[15,16] Quantitatively, HRV is reported in either the time domain or frequency domain. Time domain indices are calculated by taking a section of electrocardiogram (ECG) data (5 minutes to 24 hours) and performing the appropriate transformation on the NN interval. These include the mean NN intervals; SDNN, the standard deviation of the NN intervals; or RMSSD, the root mean squared differences of successive NN intervals. All the time-domain HRV indices are estimates of high-frequency variation in heart rate, thus higher values suggest stronger vagal and less sympathetic control of heart rhythm.[14] More commonly, HRV indices are presented as a function of power at different frequency ranges of heart functioning by using a nonparametric Fast Fourier Transform (FFT) algorithm to calculate the power spectral density of the time-series data. The HRV power spectrum is parsed into four frequency ranges as follows: *(1)* ultra low frequency (ULF, ≤ 0.003 Hz), *(2)* very low frequency (VLF, 0.003 to 0.04 Hz), *(3)* low frequency (LF, 0.04 to 0.15 Hz), and *(4)* high frequency (HF, 0.15 to 0.4 Hz). Power in the ULF and VLF ranges are not pertinent to the present study. The LF range includes both sympathetic and parasympathetic influences.[17] Basic studies using atropine and similar drugs that dampen vagal activity by blocking the action of acetylcholine have resulted in strongly reduced LF power.[18,19] The HF range reflects vagal activity and is thus primarily parasympathetically modulated.[19] Increased HF power has been associated with higher parasympathetic activity in studies of paced breathing[20] and treatment for depression.[21] Total vagal blockade essentially eliminates the power in the HF range, and reduces power in the LF range. With gradual blockade of vagal input, the ratio of LF to HF power increases, demonstrating a shift in sympathovagal equilibrium to sympathetic dominance.[22]

The ability of HRV to provide a quantitative index of autonomic functioning is most apparent in studies of trauma survivors suffering from PTSD. A diagnosis of PTSD may result in reduced HF HRV, increased LF HRV, reduced emotional inhibition, and a lack of behavioral flexibility in stressful situations. Moreover, there is evidence to suggest one of the sources contributing to the behavioral inflexibility is early family context and ongoing social support networks.[23] To test these hypotheses, Cohen and colleagues conducted two studies comparing PTSD patients with controls on HRV indices while resting, when discussing a personally relevant stressor, and post-stressor recovery. The pattern of autonomic response in the PTSD participants showed no significant change across study periods, while the control group showed a decrease in HF and an increase in LF during the stressor period compared to the baseline and post periods.[24,25] The authors suggested that responses to recalling a distressing event by the control group appear to represent a typical autonomic reaction. In contrast, the response of the PTSD patients demonstrates a continuous state

of autonomic activation in either a restful or distressing state. This rigidity of autonomic activity may reflect the constant state of hyperactivation that is one of the hallmarks of PTSD symptomatology, and suggests diminished inhibitory control.

Engaging in inhibitory control of sympathetic activity after a stressor likely represents a healthy, balanced psychophysiological response system, while disinhibition of sympathetic activity suggests psychophysiological inflexibility. Thayer and Lane have developed a model of neurovisceral integration[26] that seeks to demonstrate how anxiety-related arousal represents a disinhibition of positive feedback circuits normally under tonic inhibitory control. This model considers the interactions of cognitive, affective, behavioral, and physiological states and dispositions across the spectrum of normal and pathological functioning. Disinhibition of sympathetic tone may result in a reduction in system flexibility. Instead of the negative feedback loop associated with increased parasympathetic functioning and subsequent inhibition of sympathetic activation after arousal, a positive feedback loop becomes dominant resulting in sustained vigilance to environmental stimuli.[26,27] The use of HRV to investigate autonomic activity in MMP patients may broaden the understanding of the dynamic relationships among emotional reactivity and negative life experiences. Further, the information provided by controlled analyses of HRV with MMP patients may provide a distinct quantitative index of autonomic regulation and demonstrate a consistent pattern of behavioral disinhibition in these patients.

The present study had two general aims: to investigate *(1)* differences in HRV indices between MMP patients and pain-free controls at rest, during a stressor condition, and during a post-stressor recovery period, and *(2)* factors including psychological distress, social-environment, and family of origin characteristics in the MMP sample compared to a pain-free matched control sample. The specific hypotheses were: *(1)* while quietly sitting during baseline assessment, MMP patients will have lower HF and higher LF HRV indices compared to pain-free controls[26,27]; *(2)* during the recovery period, MMP patients will have lower HF and higher LF HRV indices compared to pain-free controls[26,27]; *(3)* MMP patients reporting a traumatic stressor will show very little change in HRV indices between baseline, stressor, and recovery[24,25]; *(4)* MMP patients will report more emotional reactivity to the stressor condition as reported on the EAS compared to pain-free controls[4,5]; *(5)* MMP patients will report more psychological distress, sleep dysfunction, and fatigue than pain-free controls on self-report measures[6,7]; and *(6)* MMP patients will report less social support, more social constraints, and a family-of-origin environment characterized by conflict and aggression, compared to pain-free controls.[23]

Materials and Methods

Setting and Participants

This study was approved by the University of Kentucky Institutional Review Board and all participants provided written informed consent. Study participants were recruited from patients seeking care at the University of Kentucky Orofacial Pain Center. Controls were recruited by posting flyers describing the study throughout the University of Kentucky Medical Center. Controls were matched to patients on age, height, and weight. Study inclusion criteria for patients were as follows: *(1)* age 18 years or older; *(2)* female; *(3)* Research Diagnostic Criteria/Temporomandibular Disorders (RDC/TMD) Axis I TMD diagnosis[28] made by a faculty member or resident trained in orofacial pain examination and management; *(4)* diagnosis of pain duration of at least 2 months; *(5)* current pain level of at least 3 on a 0 to 10 visual analog scale (VAS, 0 = no pain and 10 = worst pain imaginable)—this ensured patients had a moderate level of pain based on the previous work of Collins et al[29]; *(6)* no past or current history of hypertension or heart disease; *(7)* no taking of any cardiovascular control medication (eg, beta-blockers); *(8)* no history of asthma or other chronic respiratory conditions; *(9)* no history of diabetes; *(10)* not pregnant at time of study participation; *(11)* resting blood pressure criteria: systolic blood pressure < 140 mmHg, diastolic blood pressure < 90 mmHg.[30] Controls met the same criteria with the exception of items 3, 4, and 5. In addition, controls had no current or past chronic pain condition. All participants received $40 compensation.

The participants in this study were 22 female chronic orofacial pain patients diagnosed specifically with MMP according to RDC/TMD criteria.[28] Patients had a mean (± SD) age of 41.0 years (12.6), a mean weight of 151.5 pounds (29.3), and a mean height of 64.5 inches (1.8). Patients were matched to 23 pain-free controls on age (± 5 years), weight (± 5 pounds), and height parameters (± 2 inches). Pain duration for the patients was a mean of 81.23 months (101.1) with only one patient reporting pain of a duration less than 3 months.

Design

The study design compared MMP patients to matched pain-free controls on a standard set of psychometric measures and on physiological responses before, during, and after the laboratory challenge (see below). Dental faculty and residents experienced in the diagnosis and treatment of TMD identified potential study participants during the initial diagnostic appointment. All study participants received an initial evaluation by a resident, followed by a diagnostic reliability check by the attending faculty member. The laboratory challenge for all participants was administered by the principal investigator.

Dependent Measures

Prior to the initial evaluation, all patients completed an orofacial pain questionnaire gathering demographic data, pain history, and medical history. Patients then completed a battery of psychological questionnaires as follows:

- **Symptom Check List–90 (SCL–90),**[31] a 90-item multi-dimensional self-report measure of psychological functioning scored on a five-point scale of distress. The specific dimensions include somatization, obsessive-compulsive behavior, interpersonal sensitivity, depression, anxiety, hostility, phobic anxiety, paranoid ideation, psychoticism, and a global severity index.
- **Pittsburgh Sleep Quality Index (PSQI),**[32] a 19-item measure of sleep quality. The PSQI gathers information regarding the amount of hours the patient sleeps each night, the amount of hours in bed each night, how often the patient is woken up.
- **Posttraumatic Stress Disorder Check List–Civilian version (PCL–C),**[33] a self-report measure used to assess PTSD symptomatology.
- **Multi-dimensional Fatigue Symptom Inventory (MFSI),**[34] a 30-item measure designed to identify five facets of fatigue: *(1)* global experience of fatigue; *(2)* somatic symptoms of fatigue; *(3)* cognitive symptoms of fatigue; *(4)* affective symptoms of fatigue; and *(5)* behavioral symptoms of fatigue. Patients are asked to rate each statement according to how true it has been over the past 7 days.
- **Emotion Assessment Scale (EAS),**[35] a 24-item scale designed to measure eight fundamental dimensions of emotional responses (surprise, fear, disgust, anger, guilt, anxiety, sadness, happiness) on a 100-mm VAS anchored at one end with "Least possible" and at the other end with "Most possible."
- **Family-of-Origin Scale (FOS),**[36] a 40-item measure of the perceived tone of social-emotional relationships in the family-of-origin, focusing on warmth and acceptance. The 15-item short form was used in this study.
- **Social Constraints Scale (SCS),**[37] a 15-item self-report measure of the extent to which the participant's social environment inhibits expression of distressing thoughts and feelings.
- **Duke–UNC Functional Social Support Questionnaire (DUKE–SSQ),**[38] an eight-item social support questionnaire.

Current Stage of Menstrual Cycle

Day of menstrual cycle was recorded for participants by recording the first day of their previous period. The menstrual cycle is divided into four phases: menstruation (days 1 to 5), proliferative phase (days 6 to 13), ovulation (day 14), and luteal or secretory phase (days 15 to 28). Research has demonstrated that autonomic regulation fluctuates during the menstrual cycle with lower HRV in the luteal phase[39,40] and that sympathetic nervous system activity may be dominant during the luteal phase.

Physiological Measures

The physiological measures were recorded using the MP150 Biopac data acquisition system (Biopac Systems). Cardiovascular activity was recorded using three Ag/AgCl electrodes with shielded leads connected to an ECG100C amplifier module. Sampling rate was set to 1,000 samples/second and the Lead I configuration was used and sensors attached in accordance with standard laboratory protocol.[41] To calculate the HRV frequency domain indices, the ECG signal was first filtered and transformed by the Biopac Aquire system software into R-R intervals. These data were then saved as a text file for frequency domain analyses. Frequency domain analyses were completed using HRV Analysis Software version 1.1 SP1 by the Biomedical Signal Analysis Group, Department of Applied Physics, University of Kuopio. For this study, Fast Fourier Transform nonparametric HRV values in normalized units are reported. Breathing rate in breaths per minute was recorded by placing a nasal cannula under the participant's nose and using the CO2100C respiration amplifier module.

Procedure

Prior to the laboratory evaluation, participants completed an informed consent and were interviewed to ensure they met all screening criteria. Height and weight were recorded and the participant then completed study psychometric measures in a quiet room free from distractions. Once the study measures were completed, the participant was seated in a comfortable chair and the physiological recording leads were attached and tested in accordance with standard laboratory procedures. After a 5-minute adaptation period, the participant was instructed to sit quietly and was alone in the laboratory for a 10-minute baseline recording period. The first EAS was administered after the baseline. This was followed by the laboratory challenge (recall period). The laboratory challenge consisted of having the participant describe one past significant stressful negative life event for 10 minutes. Participants were encouraged not to "relive" negative life experiences, only to describe them. Prior to beginning the laboratory challenge, the PCL-C was reviewed and if a traumatic event was reported, the participant was asked to describe the event marked as most distressing. If no traumatic event was reported on the PCL-C, the participant was asked to describe the most significant stressful life event experienced. All narratives were videotaped. The videotapes from this study will be analyzed and coded for a future paper. Prior to describing the significant life event, a 2-minute narrative trial was completed to acclimate the participant to the stimulus condition. The participant was instructed to describe the day's activities for 2 minutes while facing the video camera. During the 2-minute acclimation and the 10-minute narrative, the participant was alone in the laboratory. This stimulus procedure has been used to investigate HRV differences among normal controls and with individuals diagnosed with PTSD and panic anxiety.[24,25] This type of procedure has also been successfully used in the study of emotional expression with normals,[42] cancer patients,[43] and with TMD patients.[44] The laboratory challenge was followed by a 10-minute post-stressor recording (recovery period). This was followed by completion of another EAS. Participants were then debriefed and excused from the study.

Analytic Strategy

Overall 2 (MMP patients vs matched pain-free controls) × 3 (baseline, stressor, and recovery) repeated measures MANOVAS were performed on the physiological data. Specific hypotheses for physiological and emotional status variables were tested with focused contrasts. Hypothesized differences between the two groups on general psychological and social-environment variables were compared with univariate ANOVAs. In addition, when testing for recall and recovery period differences, analyses of covariance were performed using baseline physiological variables as the covariate in order to control for baseline between group differences. All statistical analyses were completed with the Statistical Package for the Social Sciences, Release 11.5.0.0 (SPSS Inc). The criterion for statistical significance was set at $P < .05$. To control for type 1 error associated with multiple comparisons, Bonferroni corrections were used for self-report measures with multiple scales (SCL-90-R and MFSI). Effect sizes for hypothesized analyses are reported using Cohen's d. Pre-study power analyses assuming a power of .80, large anticipated effect size, and $P = .05$ suggested at least 20 participants in each group would be necessary.

Results

Pain Assessment

Pain evaluations were completed prior to beginning the laboratory challenge to ensure the MMP patients were indeed experiencing ongoing muscle pain at the time of the study. The MMP group reported a mean (± SD) present pain intensity over the previous week of 5.4 (2.6) on the pain VAS. The control group reported no chronic pain condition or present pain complaint at the time of study participation.

Current Stage of Menstrual Cycle

Menstrual stage distribution for the study sample was as follows: menstruation (n = 6), proliferative phase (n = 6), ovulation (n = 0), and luteal or secretory phase (n = 9). The remaining participants (n = 24) were either taking oral contraceptives, had a hysterectomy, or were postmenopausal. Prior to completing the physiological analyses, the two groups were compared on phase of menstrual cycle during time of study participation. This comparison was done to ensure there was an equal distribution of participants in the luteal phase between the groups. A χ^2 comparison was completed and showed no significant difference in the number of participants in the luteal phase (MMP = 6 vs control = 3; χ^2 [1] = 1.42, $P < .30$).

Table 1 Characteristics of HRV Indices

	MMP group (n = 22) mean (SD)	Control group (n = 23) mean (SD)	F (1,44)	*P*	Cohen's d
Baseline					
LF (nu)	60.11 (17.92)	51.18 (11.89)	3.86	.056	.59
HF (nu)	39.89 (17.92)	48.82 (11.89)	3.86	.056	.59
Recall					
LF (nu)	74.65 (14.80)	73.83 (12.36)	.04	.843	.06
HF (nu)	24.44 (12.27)	26.17 (12.36)	.22	.646	.14
Recovery					
LF (nu)	63.87 (16.61)	54.69 (12.66)	4.30	.044	.62
HF (nu)	36.13 (16.61)	46.49 (10.82)	6.11	.018	.74

LF (nu) = low frequency (normalized units), HF (nu) = high frequency (normalized units). Cohen's d notes effect sizes.

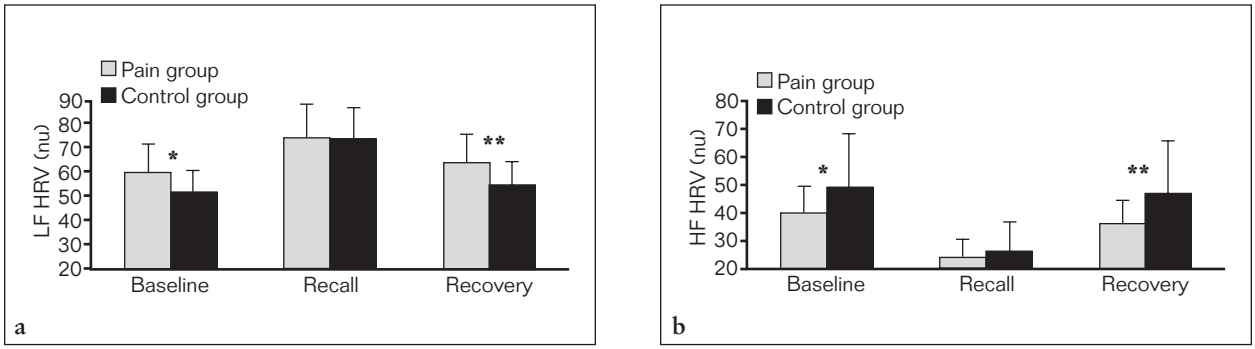

Fig 1 *(a)* LF and *(b)* HF HRV characteristics between groups across study periods. **P* < .06 and ***P* < .05 between group differences at baseline and recovery periods as noted.

Physiological Variables

The overall MANOVA for HRV indices indicated no significant main effect for group differences between the MMP group and control group (Wilks' Lambda [3,41] = .86, *P* < .10). Results showed a significant main effect for time (Wilks' Lambda [6,38] = .38, *P* < .001). Pairwise comparisons among the HRV indices across the three study time periods showed significant differences between the baseline and recall periods (LF baseline = 55.45, recall = 74.23, *P* < .001; HF baseline = 44.55, recall = 25.34, *P* < .001) and the recall and recovery periods (LF recall = 74.23, recovery = 59.07, *P* < .001; HF recall = 25.34, recovery = 41.55, *P* < .001). These data confirm the effectiveness of the stress recall procedure used in this study. There was no effect for the interaction of time x group (Wilks' Lambda [6,38] = .87, *P* < .10).

The overall MANOVA was followed by focused contrasts to evaluate the a priori hypothesis that the MMP group would have higher LF HRV and lower HF indices at baseline compared to the control group (Table 1, Fig 1). Focused contrasts showed marginally significant differences in the LF and HF baseline HRV values with the MMP group higher on LF HRV (F [1,44] = 3.86, *P* < .06) and lower on HF HRV (F [1,44] = 3.86, *P* < .06) compared to the control group. To evaluate the a priori hypothesis that the MMP group will have higher LF and lower HF HRV indices at recovery compared to the control group, focused contrasts between the experimental groups were completed on these HRV indices (Table 1, Fig 1). Results showed the MMP group to be significantly higher on LF (F [1,44] = 4.30, *P* < .05) and significantly lower on HF (F [1,44] = 6.11, *P* < .05) compared to the control group. There was no significant difference between the two groups on the HRV indices during the recall period.

To determine if the baseline and recovery period differences were due to marginal initial baseline differences between the groups, analyses of covariance (ANCOVA) using the initial baseline values as the

Table 2 ANCOVA Results for HRV Indices

	MMP group (n = 22) mean (SD)	Control group (n = 23) mean (SD)	F (1,44)	*P*
Recall				
LF (nu)	74.65 (14.80)	73.83 (12.36)	.07	.793
HF (nu)	24.44 (12.27)	26.17 (12.36)	.00	.985
Recovery				
LF (nu)	63.87 (16.61)	54.69 (12.66)	1.02	.318
HF (nu)	36.13 (16.61)	46.49 (10.82)	2.26	.140

Baseline values for HRV indices were used as covariates for these data.

covariate were completed for the recall and recovery period HRV indices. No significant differences were found between the two groups on recall or recovery period HRV indices when baseline values were used as covariates (Table 2).

Prevalence and Severity of Traumatic Stressors

The two groups were compared on number of participants who reported a traumatic stressor and met criteria for clinically significant PTSD symptomatology according to the cut-off score established by Blanchard et al.[45] A χ^2 comparison between the two groups was completed and showed no significant difference in the number of participants reporting a significant stressor on the PCL-C (MMP = 14 vs control = 11; χ^2 [1] = 1.13, $P < .30$). These two subgroups were compared on the PCL-sum score to determine if there was a significant difference in reported PTSD symptom intensity. Results showed no significant difference between the two sub-groups on PCL-sum score (MMP = 35.14 vs control = 31.18; F [1,24] = .79, $P < .40$). The number of participants that met the score for clinically significant PTSD symptomatology was n = 5 (23%) for the MMP group and n = 1 (4%) for the control group.

A 1 (traumatic stressor) × 3 (baseline, stressor, and recovery) repeated measures ANOVA was used to evaluate the hypothesis that MMP participants reporting a traumatic stressor will show very little change in HRV indices between the three recording periods. Of the 22 MMP participants in this study, 14 (64%) reported a traumatic stressor. The overall MANOVA for the HRV indices indicated no significant main effect for time (Wilks' Lambda [2,12] = .52, $P < .20$). Repeated measures univariate analyses were significant for LF HRV (F [2,12] = 6.40, $P < .05$) and for HF HRV (F [2,12] = 6.40, $P < .01$) across the three study periods. Within-subject focused contrasts showed a significant difference between the baseline and recall periods for all HRV indices, and a significant difference between the recall and recovery periods on the HRV indices.

A similar set of analyses was completed with the control participants reporting a traumatic experience (n = 11). The pattern of HF and LF HRV change across study periods for the controls with traumatic experiences were similar to the MMP patients with a notable exception (Fig 2). While both groups showed a significant change in HF and LF HRV between the recall and the recovery periods, there was a significant difference between these two sub-groups on HF HRV in the recovery period even after controlling for baseline differences (MMP = 35.63 vs control = 46.80, F [1,23] = 4.66, $P < .05$, Cohen's d = .74). The difference in LF HRV was marginally significant after controlling for baseline differences (MMP = 64.37 vs control = 55.65, F [1,23] = 2.03, $P < .15$, Cohen's d = .53). For both HRV indices, the MMP patients showed less change from recall to recovery compared to the controls.

Breathing rates in breaths-per-minute were also recorded for each period. Focused contrasts for the baseline (MMP = 18.8 vs control = 16.4, F [1,44] = 2.57, $P < .200$) and recovery periods (MMP = 18.2 vs control = 15.6, F [1,44] = 3.33, $P < .10$) showed no significant difference in breathing rates between the two groups.

Emotional Reactivity

Emotional status was assessed immediately following the baseline period and again after the recovery period. To evaluate the hypothesis that the MMP group would report more emotional reactivity to the stressor period compared to the control group, focused contrasts were completed on the emotional

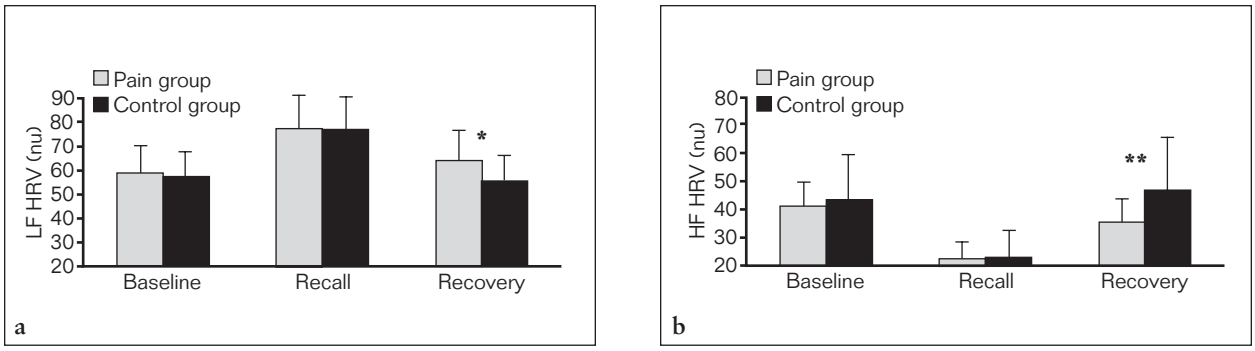

Fig 2 *(a)* LF and *(b)* HF HRV characteristics between groups for trauma survivors. *$P < .15$ and **$P < .05$ between group differences at recovery periods as noted.

Table 3 SCL-90-R Symptom Dimension, Fatigue, and Sleep Quality Data

	MMP group (n = 22) mean (SD)	Control group (n = 23) mean (SD)	F (1,44)	*P*	Cohen's d
GSI	64.55 (6.89)	54.26 (9.69)	16.69	.001	1.22
Somatization	67.95 (7.56)	50.48 (9.78)	44.71	.001	2.00
Obsessive-compulsive	63.23 (10.56)	54.39 (11.24)	7.74	.009	.81
Interpersonal sensitivity	58.73 (9.07)	56.78 (11.55)	.39	.534	.19
Depression	63.36 (5.67)	56.04 (9.32)	10.03	.003	.95
Anxiety	59.14 (11.13)	50.48 (10.02)	7.54	.009	.82
Hostility	55.91 (10.46)	50.91 (7.12)	3.54	.067	.56
Phobic anxiety	56.09 (11.75)	50.87 (8.77)	2.87	.097	.80
Paranoid ideation	57.41 (11.48)	50.43 (11.79)	4.03	.051	.60
Psychoticism	59.09 (11.45)	55.74 (11.56)	.95	.334	.29
MFSI					
General fatigue	16.77 (8.96)	6.68 (7.52)	13.56	.001	1.22
Emotional fatigue	9.91 (5.99)	6.96 (4.90)	3.27	.077	.54
Physical fatigue	11.95 (3.22)	6.73 (2.76)	32.99	.001	1.74
Mental fatigue	8.59 (5.37)	3.65 (3.76)	12.87	.001	1.01
Vigor	8.91 (4.45)	12.91 (3.34)	11.72	.001	1.02
PSQI	11.36 (3.54)	4.70 (2.29)	56.88	.001	2.00

SCL-90-R = Symptom Check List-90-Revised, GSI = Global Severity Index, MFSI = Multidimensional Fatigue Symptom Inventory, PSQI = Pittsburgh Sleep Quality Index. Cohen's d notes effect sizes.

status variables. The MMP group reported more "anxiety" prior to the stressor (MMP = 25.0 vs control = 11.0, F [1,43] = 4.35, $P < .05$, Cohen's d = .62) and more "anger" after the recovery period (MMP = 11.18 vs control = 2.74, F [1,43] = 5.87, $P < .05$, Cohen's d = .72) compared to the control group. In contrast, the control group reported more "happiness" prior to the stressor (MMP = 25.6 vs control = 42.8, F [1,43] = 4.09, $P < .05$, Cohen's d = .60) than did the MMP group.

Psychological, Physical, and Social Variables

To evaluate the hypothesis that the MMP group would report more psychological distress compared to the control group, a univariate comparison was completed on the Global Severity Index (GSI) of the SCL-90-R. The MMP group scored significantly higher on the GSI (F [1,44] = 16.69, $P < .001$, Cohen's d = 1.22) compared to the control group (Table 3). This analysis was followed by post-hoc comparisons on the individual SCL-90-R subscales by using Bonferroni corrections to control for Type 1 error (corrected significance level of $P = .006$).

The MMP group reported greater somatization (F [1,44] = 44.71, $P < .001$, Cohen's d = 2.0) and depression (F [1,44] = 10.03, $P < .01$, Cohen's d = .95) on the SCL-90-R subscales as compared to the control group (Table 3). To evaluate the hypothesis that the MMP group would report more fatigue compared to the control group, univariate comparisons were made on the subscales of the MFSI by using Bonferroni corrections to control for Type 1 error (corrected significance level of $P = .01$). The MMP group reported significantly more general fatigue (F [1,44] = 13.56, $P < .001$, Cohen's d = 1.22), physical fatigue (F [1,44] = 32.99, $P < .001$, Cohen's d = 1.74), and mental fatigue (F [1,44] = 12.87, $P < .001$, Cohen's d = 1.01), and significantly less vigor (F [1,44] = 11.72, $P < .001$, Cohen's d = 1.02) compared to the control group (Table 3). As hypothesized, the MMP group also reported more sleep dysfunction (F [1,44] = 56.88, $P < .001$, Cohen's d = 2.0).

To evaluate the hypothesis that the MMP group would report more social constraints, less social support, and a family-of-origin environment characterized by conflict and aggression when compared to the control group, univariate comparisons were completed on these three variables. A significant difference was found on perceived social constraints (SCS: F [1,44] = 7.40, $P < .01$, Cohen's d = .78), with the MMP group reporting a more constraining social environment compared to the control group. In contrast, no difference was noted on perceived social support (DUKE-SSQ: F [1,44] = .08, $P < .80$). The MMP group also reported a more dysfunctional family-of-origin (FOS: F [1,44] = 4.46, $P < .05$, Cohen's d = .65) compared to the control group.

A post-hoc comparison on social environment measures was then completed among the participants in the MMP group who reported a traumatic stressor. Results showed that the MMP group participants reporting clinically significant PTSD symptomatology reported significantly higher perceived social constraints (MMP [PTSD-positive] = 43.0 vs MMP [PTSD-negative] = 29.6; F [1,13] = 6.33, $P < .05$, Cohen's d = 1.5) and lower perceived social support (MMP [PTSD-positive] = 23.2 vs MMP [PTSD-negative] = 33.1; F [1,13] = 8.78, $P < .05$, Cohen's d = 1.8) compared to the MMP group participants who reported a traumatic stressor but did not meet the cut-off for clinically significant PTSD symptomatology. There were no differences on the FOS measure between these two sub-groups of patients (MMP [PTSD-positive] = 41.7 vs MMP [PTSD-negative] = 38.0; F [1,13] = .25, $P < .700$).

Discussion

One of the noteworthy findings from this study was that MMP patients showed higher LF and lower HF HRV (but not significant [$P < .06$]) indices during the resting baseline and significantly higher LF and lower HF HRV during recovery from a personally relevant stressor compared to the controls. During the stressor period, the HRV values were nearly the same for both study groups. The physiological differences shown by the HRV indices between the MMP patients and controls during the baseline and recovery periods help us understand previous findings of heightened physiological activation with these patients. MMP patients have shown more cardiovascular and emotional reactivity to a standard stressor[5,6] and lower pain threshold and tolerance when compared to pain-free controls.[4,6,46] While pain-sensitivity differences are likely due to a complex integration of central nervous system changes, these differences also could be linked to chronic physiological activation that does not respond to inhibitory controls. The HRV differences between MMP patients and controls in the present study suggest potential use of HRV indices as a means to study the relative contributions of sympathetic and parasympathetic activity. Furthermore, the marginally significant increased sympathetic activity and decreased parasympathetic activity noted in the MMP patients at rest in this study as compared to the controls raises the possibility that these patients may be experiencing compromised inhibitory control of sympathetic activity.

HRV as an index of autonomically mediated inhibitory control is central to Thayer's model of neurovisceral integration.[26] Thayer's model posits that a reduction in overall system flexibility results from disinhibition of sympathetic nervous system activity. The data presented here provide preliminary evidence of such sympathetic disinhibition in MMP patients particularly following the presentation of a significant stressor. Higher LF and lower HF index values in the MPP patients during the recovery period compared to controls suggest diminished inhibitory control after a stressor. This similar pattern of physiological activation indexed by HRV measures has been associated with not only other chronic pain conditions, but other negative life experiences as well.[47]

Surprisingly, and in contrast to our hypothesis, the patients reporting a traumatic stressor did not maintain the elevated state of arousal attained during the recall period into the recovery period. While there appeared to be a difference between the

patients reporting a trauma and the nontrauma patients on the HRV indices during recovery, these differences were not significant. However, when compared to the controls reporting a trauma, the patients showed a significant difference on the HF and marginally significant difference on the LF HRV indices during the recovery period even after the baseline differences were accounted for. These data suggest that the MMP patients reporting a traumatic stressor may have had restricted ability to inhibit sympathetic activation during the recovery period, when compared to controls also reporting a traumatic stressor. Further, the sustained high LF and low HF HRV index values in this group of MMP patients shown in the recovery period were not accounted for by baseline values and suggest restricted ability to inhibit sympathetic activity. Previous studies by Cohen et al[24,25] exploring hyperarousal in PTSD patients have demonstrated a basal state of activation characterized by pronounced sympathetic activity, followed by no significant inhibitory activity of sympathetic tone after recounting traumatic events or after discussion of the traumatic experience linked to the onset of PTSD. Although the MMP patients reporting a traumatic experience in the present study did respond to discussing the event with an increase in LF and a decrease in HF HRV indices, these patients sustained more physiological activation between the stressor and recovery periods compared to the trauma-reporting controls. The differences between the results found by Cohen and the present study may be due mainly to patient characteristics. The patient volunteers in the Cohen studies were all diagnostically classified with PTSD and were being treated on an outpatient basis for this disorder. In contrast, only 23% of the patients reporting a traumatic event in the present study met the cut-off criteria for clinically significant PTSD symptomatology. Thus it is not surprising that physiological activation in the MMP patients was not as pronounced as in those with a PTSD diagnosis.

The HRV characteristics of the MMP patients across study periods suggest the problem is not in reaction to a stressor per se, but more likely a problem of prolonged sympathetic activation stemming from inhibitory failure at some level. Since the MMP patients also reported more anxiety after the baseline period and more anger after the recovery period compared to the pain-free controls, it may be that emotional reactivity is contributing to the elevated level of physiological functioning in these patients. The presence in them of more emotional reactivity also suggests that emotion regulation may be a factor. These results are in contrast to Carlson et al,[6] who did not report any differences on emotional reactivity between MMP patients and matched controls at baseline or after a standard stressor. On the other hand, use of a personally relevant stressor, in this case discussing a distressing or traumatic life experience, may account for this difference. While the change in HRV indices between the baseline and recall periods for both the MMP patients and the controls indicate the emotional stressor did in fact significantly influence autonomic system functioning through emotional arousal, the patients reported more emotional reactivity both prior to and after the stressor. In Thayer's model,[26] the inability to inhibit sympathetic activity has been associated with a defensive attentional style characteristic of anxiety, hyperarousal, and poor emotion regulation capabilities. These characteristics may also be present to some degree in MMP patients and have contributed to the prolonged physiological activation observed in the present study.

Consistent with previous literature focused on psychological distress in MMP patients, the SCL–90 results also suggest a problem with persistent emotional turmoil and poor emotional processing. The psychological distress in these patients may be the result of an emotion regulation deficiency, premorbid psychopathology, a long-term problem due to an antagonistic and unloving family-of-origin environment, the ongoing pain experience, or a combination thereof. Regardless of the source, problems in the social environment, as shown by the presence of social constraints in the MMP patients, suggest insufficient opportunities for cognitive processing of distress-related information. This is consistent with social-cognitive processing theory,[48,49] which posits that trauma-related distress may remain elevated if the individual fails to engage in discussion of thoughts and feelings regarding the traumatic experience. Such failure may occur because of a lack of ability to express trauma-related thoughts and feelings (eg, alexithymia). A failure to discuss trauma-related thoughts and feelings may also be due to a constraining social environment, where the individual's attempts at discussion are met with unexpected or negative responses from others. Discussion and processing of trauma-related thoughts and feelings in a nonconstraining social environment, on the other hand, provides opportunities for the individual to confront and reevaluate thoughts and feelings so this information can be integrated into preexisting cognitive schemas.

There is conflicting evidence in the literature about the etiology and mechanisms involved in

maintenance of muscle pain conditions. For example, some evidence suggests alterations in central processing structures maintain these conditions.[4,46,50] This central nervous system change may be due to alterations in baroreceptor effects, which in turn are influenced by arterial blood pressure changes.[46] There is also evidence to support the pain-adaptation model,[51] which proposes that chronic pain arises from increases in muscle activity in antagonist musculature structures that are likely a functional adaptation of muscle coordination to limit muscle activity at the site of pain.[52] In general, however, the evidence that overactivation of muscle structures as a driving mechanism for chronic muscle pain is not consistent.[53] The pres-ent study suggests that a failure of inhibitory control of sympathetic activation may be influencing central processing as well as physiological changes in peripheral structures. However, the differences found in this study between MMP patients and controls could also be due to the pain condition itself, and the possible drain in self-regulatory strength or tone that comes as the result of the ongoing pain experience.

The data presented here suggest that the use of HRV frequency analyses can be helpful in identifying autonomic characteristics in MMP patients. The HRV indices are consistent and stable biomarkers for sympathetic activation and inhibitory failure.[54] More importantly, HRV frequency indices demonstrate the potential ability to differentiate among MMP patients with traumatic experiences and those without such experiences. There is also the potential application of these quantitative markers for evaluating the effects of the treatment of MMP patients. Techniques that conceivably strengthen sympathetic inhibitory control through increasing vagal tone may lead to increased parasympathetic tone, improved sympathetic inhibition, and possible changes in psychophysiological response to environmental challenge. Carlson and colleagues have developed a Physical Self-Regulation Training protocol for orofacial pain patients that includes components tailored to reduce physiological activation through the use of diaphragmatic breathing training, gentle stretching exercises, and proprioceptive awareness training.[55] While the effects of these interventions on HRV indices have yet to be evaluated, the physiological activation differences between the MMP patients and controls in the present study suggest such self-regulatory skills training may improve inhibitory control of sympathetic activity. Indeed, recent work has shown that biofeedback training using HRV has resulted in increased vagal tone, parasympathetic activation, and an increase in baroreflex gain.[56]

While the results of this study are potentially important, several limitations must be noted. Although the experimental design provides the essential foundation for determining between-group differences, nearly significant baseline group differences on the HRV indices make it difficult to establish definitively the problem of recovery after the stressor. Recovery from events that provoke sympathetic activity in pain patients remains an open question that requires further study. The length of the recovery period may also be a problem here, as the present study limited post-stressor recording to 10 minutes. In future research, it is suggested that longer recovery times be considered to determine stressor-recovery rate of change in both pain patients and pain-free controls. Additionally, the sample size in this study included only a small group of MMP patients. These limitations suggest the need for replication and evaluation of HRV characteristics in a broader range of orofacial pain patients.

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