Longitudinal Multilevel Modeling of Facial Pain, Muscle Tension, and Stress

Journal of Dental Research
2016, Vol. 95(4) 416–422
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for Dental Research 2016
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sagepub.com/journalsPermissions.nav
DOI: 10.1177/0022034515625216
jdr.sagepub.com

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Abstract

The role of masticatory muscle activation on pain in temporomandibular muscle and joint disorders (TMJD) is controversial. This single-group, prospective panel study examined the relationships among masticatory muscle tension, emotional distress, and TMJD pain in a sample of 7,023 observations obtained from 171 individuals using longitudinal multilevel modeling. Three main hypotheses were tested. The first posited that emotional distress and muscle tension directly influenced pain (hypothesis 1a: Distress → TMJD Pain; hypothesis 1b: Muscle Tension → TMJD Pain). The second posited that emotional distress directly influenced muscle tension (Distress → Muscle Tension), and the third posited that the effect of emotional distress on pain was mediated by muscle tension (Distress → Muscle Tension → TMJD pain). We also examined the fit of the data to possible alternative models. All the data used in this study were collected via an experience sampling methodology. The fit of the preferred models was better than that of the alternative models, with the preferred models explaining large proportions of the data, especially for level 2 variance (hypothesis 1a = 41% variance; hypothesis 1b = 69% variance; hypothesis 2 = 48% variance). In the mediation model, the addition of muscle tension to the model reduced the impact of emotional distress. The findings support a causal role for masticatory muscle tension in TMJD pain. Clinically, the results suggest that addressing tension and other oral parafunctions in those diagnosed with TMJDs should be an important part of the conservative, noninvasive care of individuals diagnosed with the myofascial pain or arthralgia of TMJD.

Keywords: temporomandibular, experience sampling, parafunctions, distress, masticatory muscles, therapeutics

The role of masticatory muscle activation in temporomandibular muscle and joint disorder (TMJD) pain is controversial. Studies show that clenching is a significant risk factor for TMJD (Huang et al. 2002; Velly et al. 2003), and experimental studies show that deliberate low-level to maximal clenching can increase pain and may result in a diagnosis of TMJD myofascial pain and/or arthralgia (Glaros and Burton 2004; Dawson et al. 2013; Koutris et al. 2013). Reduction of these daytime oral parafunctions in those with the myofascial TMJD reduces pain (Townsend et al. 2001; Glaros et al. 2007). The mechanism by which these behaviors create pain is unknown but may involve multiple pathways (Muroi et al. 2007; Finestone et al. 2008; Castrillon et al. 2010; Koutris et al. 2013).

Individuals with TMJD pain also show greater psychological and emotional distress than those without pain. Patients with chronic TMJD pain typically report significantly higher levels of somatoform disorders and mood disorders (e.g., depression) than newly diagnosed patients. Individuals without TMJD pain (e.g., those with disc displacement only) often report lower levels of emotional distress (Manfredini et al. 2004).

The findings from these experimental, cross-sectional, and longitudinal studies suggest that affective distress “sets the stage” for TMJD pain and that oral parafunctional behaviors help trigger TMJD pain. This study examined the fit of data to this proposed model of TMJD using longitudinal multilevel modeling (MLM) with time-varying covariates and individually varying times of observation to test the hypothesis that masticatory muscle tension and affective distress directly influenced jaw pain (hypothesis 1). The study used the same approach to test the corresponding hypothesis that affective

distress affected masticatory muscle tension (hypothesis 2). We also examined the fit of the data to alternative models specifying the reverse causal sequence and compared it with the fit of the hypothesized models. Hypothesis 3 posited that muscle tension mediated the effect of affective distress on jaw pain. The data used in this study were collected via an experience sampling method (ESM). ESM is characterized by repeated measurement of behaviors and states in an individual’s natural environment. Because the time between observations and recording of behaviors and states is short in ESM, potential problems with retrospective bias were minimized.

Methods

Participants

An initial set of 193 individuals recruited from the general population or selected from patients of the University of Missouri–Kansas City Facial Pain Center served as participants. Inclusion criteria for the study included age between 18 and 65 years,

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residence within the Kansas City metropolitan area, and a willingness to carry a pager and complete response cards as directed for a 1-wk period. Exclusion criteria included any history of major trauma to the head or neck, current use of an intraoral appliance, active orthodontic treatment, any other chronic pain condition, or current, daily use of any analgesic, antidepressant, or muscle relaxant medication. All participants were assessed using the Research Diagnostic Criteria for Temporomandibular Disorders (RDC/TMD) (Dworkin and LeResche 1992). Individuals who received a diagnosis of osteoarthritis or osteoarthrosis of the temporomandibular joint (TMJ) according to RDC/TMD criteria were excluded from participation.

Experience Sampling Method

To obtain more accurate measures of pain and other states, ESM was used (see Glaros et al. 2005 for additional details). Data collection began in 2001 and continued for 8 y. A customized program was used to place calls to pagers carried by participants. The mean time between calls was 120 min, with a 40-min window of variability within which a specific call could be placed. Variability in calling schedules reduced the possibility that participant behavior would be affected by the anticipation of a call at a fixed point in time.

Participants were instructed to fill out a preprinted 3×5 -in. card each time they were paged, unless doing so would jeopardize their safety. Participants reported on facial pain ("When you were paged, how much tension were you experiencing in the jaw, face, and/or head?" ["TMJDPain"]), sensations of muscle tightness ("When . . . , how much tension was in your jaw, face, and/or head?" ["MTension"]), and stress ("When . . . , how much stress were you experiencing?" ["Distress"]). All measures were recorded on an 11-point (0–10) numerical rating scale. The anchors for TMJDPain, MTension, and Distress were "no pain to severe pain," "completely relaxed to extremely tense," and "no stress to extremely high stress," respectively.

Procedure

After obtaining informed consent, a research assistant who was blind to the participant's diagnosis instructed the participant on the use of the pager, following a written script. Participants were asked when they became fully alert and capable of responding to a page after awakening, and they were also asked when they typically retired for the evening. This allowed for individual flexibility in generating call schedules appropriate for each participant. The first day of paging varied randomly from Monday through Sunday and continued for 1 wk. Values requested by participants for start- and end-of-day times were randomized by up to 15 min on either side of the requested time prior to being entered into the dialer program. Participants were not contacted during their normal sleep hours; 95% of pages occurred between 7 a.m. and 10 p.m.

Data Analysis Strategy

We used longitudinal MLM to estimate baseline and periodic change in observed outcomes for each participant over a 1-wk

period (Duckworth et al. 2010). To examine whether within-individual changes in MTension and Distress predicted changes in TMJDPain (hypothesis 1) and whether changes in Distress predicted changes in MTension (hypothesis 2), we included baseline and time-varying predictor variables to examine the potential causal relationships among the 3 variables. We analyzed and compared 2 sets of models, those corresponding to our hypotheses and those reversing the predictors and outcomes. Because the models were nonhierarchical, we compared them with the Akaike information criterion (AIC), a parsimony-adjusted relative measure of the information lost when using a model to represent whatever is producing the data. AIC values have no inherent meaning, but lower values indicate better fit (Burnham and Anderson 2004).

Time-varying covariates were measured at the paging occasion immediately prior to the outcome and were centered on each participant's mean, making the individual mean the baseline measure. We examined how a change in Distress (or MTension) relative to baseline affected the change in MTension (or TMJDPain) a short time later. We centered Time at the first paging occasion of the third day so the baseline measures of Distress, MTension, and TMJDPain were free from any error associated with unfamiliarity with the paging and reporting system of ESM. To control for individual differences in age and sex in each model, we included grand mean-centered age and sex as level 2 covariates. SAS PROC MIXED (version 9.3; SAS Institute, Cary, NC, USA) was used to assess the models.

To test hypothesis 3 (Distress $\rightarrow$ MTension $\rightarrow$ TMJDPain), we aligned our data chronologically to model the effect of Distress at a given measurement occasion on MTension at the next occasion, the effect of both on TMJDPain at the third occasion, and so on. In step 1 (Bauer et al. 2006), we modeled Distress as a predictor of TMJDPain. In step 2, we modeled Distress as a predictor of MTension, and in step 3, we modeled MTension as a predictor of TMJDPain. In step 4, we modeled both Distress and MTension as predictors of TMJDPain. In the final step, we "stacked" the predictor and mediator variables for each measurement occasion within each person to create a new outcome variable that allowed the fitting of a "multivariate" model with a univariate equation. Indicator variables were used within the revised data set to distinguish the predictor and mediator, as well as to allow proper estimation of the standard errors to be used in testing the mediation effects.

Results

Data Screening and Preparation

Four participants provided invalid responses during ESM data collection, and ESM data were missing for 6 other participants; these cases were deleted. Of the remaining 183, 84 were diagnosed with no TMJD and 93 with TMJD (diagnosis data were missing for 6 individuals). Of these 93, 65 were diagnosed with myofascial pain (with or without limited opening) and/or arthralgia, 27 with disc displacement, and 5 with arthralgia only (the total is greater than 93 due to multiple diagnoses). The mean (SD) age of the participants was 36.1 (12.2) years; 80% were women, and 80% were white.

Table 1. Parameter Estimates for 2-Level Linear Growth Models of TMJD Pain and Distress, Hypothesis 1a.

Distress → TMJD Pain			TMJD Pain → Distress		
Parameter	Estimate (SE)	P	Parameter	Estimate (SE)	P
Fixed effects					
Intercept (γ_{00})	1.43 (0.09)	<0.01	Intercept (γ_{00})	2.34 (0.09)	<0.01
Time (γ_{10})	0.03 (0.01)	0.02	Time (γ_{10})	0.00 (0.02)	0.88
PC stress (γ_{20})	0.08 (0.01)	<0.01	PC jaw pain (γ_{20})	0.06 (0.02)	<0.01
PM stress (γ_{01})	0.68 (0.07)	<0.01	PM jaw pain (γ_{01})	0.54 (0.06)	<0.01
GM age (γ_{02})	0.00 (0.01)	0.65	GM age (γ_{02})	0.02 (0.01)	<0.05
GM sex (γ_{03})	0.57 (0.19)	<0.01	GM sex (γ_{03})	-0.21 (0.22)	0.34
Variance estimate					
Level 1 (σ^2)	1.45 (0.03)	<0.01	Level 1 (σ^2)	2.67 (0.05)	<0.01
Intercept (τ_0^2)	1.49 (0.17)	<0.01	Intercept (τ_0^2)	1.17 (0.14)	<0.01
Time (τ_1^2)	0.02 (0.00)	<0.01	Time (τ_1^2)	0.04 (0.01)	<0.01
PC stress (τ_2^2)	0.01 (0.00)	<0.01	PC jaw pain (τ_2^2)	0.01 (0.00)	0.03
Intercept, time (τ_{01})	-0.01 (0.02)	0.43	Intercept, time (τ_{01})	-0.03 (0.02)	0.11
Intercept, PC stress (τ_{02})	0.04 (0.01)	0.01	Intercept, PC jaw pain (τ_{02})	0.01 (0.02)	0.68
Time, PC stress (τ_{12})	0.00 (0.00)	0.38	Time, PC jaw pain (τ_{12})	0.00 (0.00)	0.50
Fit Indices			Fit Indices		
	Deviance	AIC		Deviance	AIC
	23,500.6	23,526.6		27,567.4	27,593.4
					27,634.2

Time is scaled in days and is centered on the beginning of day 3. Estimates based on 171 people and 7,023 observations. Sex was coded as 0 = male and 1 = female. AIC, Akaike information criterion; BIC, Bayes information criterion; GM, grand mean centered; PC, person centered; PM, grand mean-centered person mean; TMJD, temporomandibular muscle and joint disorder.

The number of valid responses to pages varied from 10 to 71, with mean (SD) = 41.0 (11.0), median (quartile 1 [Q_1], quartile 3 [Q_3]) = 42.0 (35.0, 49.0), and mode = 46.0. MLM can handle missing data at level 1, but higher levels cannot have missing predictors. Therefore, listwise deletion was used for level 2 variables, resulting in a final sample of 171 participants and 7,023 observations.

Measurements of TMJDPain, MTension, and Distress all ranged from 0 to 10 and had modes equal to 0. The means (SDs) of TMJD pain, MTension, and Distress were 1.5 (1.6), 2.4 (2.3), and 2.0 (2.2), and the medians (Q_1 , Q_3) were 0.9 (0.1, 2.2), 2.0 (0.0, 4.0), and 2.0 (0.0, 4.0), respectively. Because the distributions of the 3 variables were positively skewed, maximum likelihood estimation with sandwich estimators for standard errors was used.

All models had significant slope variances for Time and the person-centered predictor; the associations between these variables and the outcomes varied between occasions. Interactions between person-centered predictors and Time were nonsignificant for each model; the associations between person-centered predictors and outcome variables remained constant over time.

Hypothesis 1a: Changes in Distress Predict TMJD Pain Better Than Changes in TMJD Pain Predict Distress

The preferred model (Distress → TMJDPain) had a significant positive covariance between the slope of person-centered Distress and the intercept; in an individual with a higher initial level of TMJDPain, the level of Distress relative to that individual's baseline had a stronger association with TMJDPain

(Table 1). Both models had significant fixed effects for person-centered and grand mean-centered person mean predictors even after controlling for age and sex. The preferred model also had significant fixed effects for Time and sex, explaining about 29% of the level 1 variance and 41% of the level 2 variance in TMJDPain. Females had greater TMJDPain on average, and TMJDPain increased over time. The alternative model (TMJDPain → Distress) had a small, significant fixed effect for age but not for Time or sex. Older participants tended to have slightly greater Distress. The alternative model explained 21% of the level 1 variance in Distress and 39% of the Level 2 variance, both less than the preferred model. According to the AIC, model fit was much better for the preferred model than the alternative.

Hypothesis 1b: Changes in Tension Predict TMJD Pain Better Than Changes in TMJD Pain Predict Tension

For the preferred model (MTension → TMJDPain), the covariance between the slope of person-centered MTension and the intercept was positive; for a higher initial level of TMJDPain, the level of MTension relative to baseline had a stronger association with TMJDPain (Table 2). For the alternative model (TMJDPain → MTension), the covariance between the slope of person-centered TMJDPain and the intercept was negative; for higher initial levels of MTension, the level of TMJDPain relative to baseline had a weaker association with MTension. Both models had significant fixed effects for Time, the person-centered predictor, and the grand mean-centered person mean predictor. The preferred model's significant fixed effect for sex

Table 2. Parameter Estimates for 2-Level Linear Growth Models of TMJD Pain and Muscle Tension, Hypothesis 1b.

Muscle Tension → TMJD Pain			TMJD Pain → Muscle Tension		
Parameter	Estimate (SE)	P	Parameter	Estimate (SE)	P
Fixed effects					
Intercept (γ_{00})	1.46 (0.07)	<0.01	Intercept (γ_{00})	2.35 (0.07)	<0.01
Time (γ_{10})	0.03 (0.01)	0.04	Time (γ_{10})	0.03 (0.01)	0.03
PC muscle tension (γ_{20})	0.15 (0.02)	<0.01	PC jaw pain (γ_{20})	0.17 (0.02)	<0.01
PM muscle tension (γ_{01})	0.76 (0.05)	<0.01	PM jaw pain (γ_{01})	0.88 (0.04)	<0.01
GM age (γ_{02})	0.00 (0.01)	0.69	GM age (γ_{02})	0.00 (0.01)	0.69
GM sex (γ_{03})	0.29 (0.14)	0.03	GM sex (γ_{03})	0.29 (0.14)	0.03
Variance estimate					
Level 1 (σ^2)	1.42 (0.02)	<0.01	Level 1 (σ^2)	2.01 (0.03)	<0.01
Intercept (τ_{00}^2)	0.76 (0.09)	<0.01	Intercept (τ_{00}^2)	0.81 (0.10)	<0.01
Time (τ_{10}^2)	0.02 (0.00)	<0.01	Time (τ_{10}^2)	0.02 (0.00)	<0.01
PC muscle tension (τ_{20}^2)	0.02 (0.00)	<0.01	PC jaw pain (τ_{20}^2)	0.02 (0.01)	<0.01
Intercept, time (τ_{01})	-0.01 (0.01)	0.40	Intercept, time (τ_{01})	0.02 (0.01)	0.16
Intercept, PC muscle tension (τ_{02})	0.06 (0.01)	<0.01	Intercept, PC jaw pain (τ_{02})	-0.04 (0.02)	0.02
Time, PC muscle tension (τ_{12})	0.00 (0.00)	0.27	Time, PC jaw pain (τ_{12})	0.00 (0.00)	0.23
Fit Indices			Fit Indices		
	Deviance	AIC		Deviance	AIC
	23,202.9	23,228.9		25,560.0	25,586.0
		BIC			BIC
		23,269.7			25,626.8

Time is scaled in days and is centered on the beginning of day 3. Estimates based on 171 people and 7,023 observations. Sex was coded as 0 = male and 1 = female. AIC, Akaike information criterion; BIC, Bayes information criterion; GM, grand mean centered; PC, person centered; PM, grand mean-centered person mean; TMJD, temporomandibular muscle and joint disorder.

indicated that females reported greater TMJD Pain than males. The preferred model accounted for 47% of the level 1 variance in TMJD Pain and 69% for level 2. The alternative model explained similar amounts of variance in MTension, 45% for level 1 and 71% for level 2. The preferred model had much better AIC fit than the alternative.

Hypothesis 2: Changes in Distress Predict Tension Better Than Changes in Tension Predict Distress

Both models had significant fixed effects for the person-centered predictor and the grand mean-centered person mean predictor (Table 3). The preferred model (Distress → MTension) also had a significant effect for Time, indicating MTension increased over time. The preferred model explained 31% of the level 1 variance in MTension and 48% for level 2. In contrast, the alternative model (MTension → Distress) explained 25% of the level 1 variance in Distress, less than the preferred model, and 48% for level 2. The preferred model had much better AIC fit than the alternative.

Hypothesis 3: Tension Mediates the Effect of Distress on TMJD Pain

With Distress as the predictor with a random slope and TMJD Pain and MTension as the outcomes (steps 1 and 2, respectively; Bauer et al. 2006), the fixed effect of Distress was significant in both models (Table 4). With MTension as the predictor and TMJD Pain as the outcome, the fixed effect of

MTension was significant (step 3). For step 4, we fit a model with TMJD Pain as the outcome and Distress and MTension as the predictors with random slopes for both. The fixed effect for Distress became smaller by 0.024 units but was still significant, and MTension became smaller by a much lesser amount of 0.007 units and was still significant. This pattern of results indicates partial mediation.

We calculated the indirect effect of Distress → TMJD Pain → MTension to be 0.03 (SE = 0.004, $z = 6.47$, $P < 0.0001$). The total effect of Distress on TMJD Pain, which includes both Distress → MTension and Distress → TMJD Pain → MTension, was estimated to be 0.05 (SE = 0.012, $z = 4.32$, $P < 0.0001$). For every 1-point increase in self-reported Distress at a particular measurement occasion, there was a corresponding increase in self-reported TMJD Pain of about .05 points 2 occasions later, of which .03 points (54%) were through MTension reported 1 occasion earlier. The model explained 36% of the variance in TMJD Pain at level 1 and 11% of the variance in MTension.

Discussion

Hypothesis 1 posited that Distress and MTension independently influenced TMJD Pain. The results showed much better fit for these models than the alternatives and, in the case of Distress → TMJD Pain, greater explanatory power. Similarly, the preferred model for hypothesis 2, Distress → MTension, also showed much better fit and greater explanatory power than for the alternative. These findings provide strong evidence that stress and muscle tension are triggers for the myofascial pain and arthralgia of TMJD pain.

Table 3. Parameter Estimates for Two-Level Linear Growth Models of Muscle Tension and Distress, Hypothesis 2.

Distress → Muscle Tension			Muscle Tension → Distress		
Parameter	Estimate (SE)	P	Parameter	Estimate (SE)	P
Fixed effects					
Intercept (γ_{00})	2.32 (0.10)	<0.01	Intercept (γ_{00})	2.35 (0.08)	<0.01
Time (γ_{10})	0.04 (0.01)	<0.01	Time (γ_{10})	0.00 (0.02)	0.87
PC stress (γ_{20})	0.10 (0.01)	<0.01	PC muscle tension (γ_{20})	0.11 (0.02)	<0.01
PM stress (γ_{01})	0.81 (0.07)	<0.01	PM muscle tension (γ_{01})	0.56 (0.05)	<0.01
GM age (γ_{02})	0.00 (0.01)	0.52	GM age (γ_{02})	0.01 (0.01)	0.08
GM sex (γ_{03})	0.35 (0.14)	0.15	GM sex (γ_{03})	-0.12 (0.21)	0.56
Variance estimate					
Level I (σ^2)	2.02 (0.04)	<0.01	Level I (σ^2)	2.63 (0.05)	<0.01
Intercept (τ_0^2)	1.49 (0.17)	<0.01	Intercept (τ_0^2)	1.00 (0.12)	<0.01
Time (τ_1^2)	0.02 (0.00)	<0.01	Time (τ_1^2)	0.04 (0.01)	<0.01
PC stress (τ_2^2)	0.01 (0.00)	<0.01	PC muscle tension (τ_2^2)	0.01 (0.00)	<0.01
Intercept, time (τ_{01})	0.00 (0.02)	0.97	Intercept, time (τ_{01})	-0.03 (0.02)	0.11
Intercept, PC stress (τ_{02})	0.02 (0.02)	0.34	Intercept, PC muscle tension (τ_{02})	0.02 (0.02)	0.20
Time, PC stress (τ_{12})	0.00 (0.00)	0.77	Time, PC muscle tension (τ_{12})	0.00 (0.00)	0.31
Fit Indices			Fit Indices		
	Deviance	AIC		Deviance	AIC
	25,715.6	25,741.6		27,474.9	27,500.9
		BIC			BIC
		25,782.4			27,541.8

Time is scaled in days and is centered on the beginning of day 3. Estimates based on 171 people and 7,023 observations. Sex was coded as 0 = male and 1 = female. AIC, Akaike information criterion; BIC, Bayes information criterion; GM, grand mean centered; PC, person centered; PM, grand mean-centered person mean.

Table 4. Parameter Estimates for the Mediation Analysis of MTension → Distress → TMJDPain, Hypothesis 3.

Step 1: Distress → TMJDPain			Step 2: Distress → MTension		
Parameter	Estimate (SE)	P	Parameter	Estimate (SE)	P
Fixed effects					
Intercept (γ_{00})	1.32 (0.11)	<0.01	Intercept (γ_{00})	2.08 (0.12)	<0.01
Distress (γ_{20})	0.05 (0.01)	<0.01	Distress (γ_{20})	0.13 (0.01)	<0.01
Variance estimates					
Level I (σ^2)	1.54 (0.03)	<0.01	Level I (σ^2)	2.12 (0.04)	<0.01
Intercept (τ_0^2)	2.11 (0.24)	<0.01	Intercept (τ_0^2)	2.40 (0.27)	<0.01
Distress (τ_1^2)	0.01 (0.00)	<0.01	Distress (τ_1^2)	0.01 (0.00)	<0.01
Intercept, distress (τ_{01})	0.03 (0.02)	0.14	Intercept, distress (τ_{01})	0.00 (0.02)	0.96
Fit indices			Fit indices		
Deviance	AIC	BIC	Deviance	AIC	BIC
24,730.5	24,742.5	24,761.5	27,708.4	27,720.4	27,739.6
Step 3: MTension → TMJDPain			Step 4: MTension, Distress → TMJDPain		
Parameter	Estimate (SE)	P	Parameter	Estimate (SE)	P
Fixed effects					
Intercept (γ_{00})	0.98 (0.09)	<0.01	Intercept (γ_{00})	0.91 (0.09)	<0.01
Muscle tension (γ_{20})	0.18 (0.02)	<0.01	Muscle tension (γ_{20})	0.17 (0.02)	<0.01
			Distress (γ_{30})	0.03 (0.01)	<0.01
Variance estimates					
Level I (σ^2)	1.46 (0.02)	<0.01	Level I (σ^2)	1.43 (0.02)	<0.01
Intercept (τ_0^2)	1.34 (0.18)	<0.01	Intercept (τ_0^2)	1.19 (0.17)	<0.01
MTension (τ_1^2)	0.03 (0.00)	<0.01	MTension (τ_1^2)	0.02 (0.00)	<0.01
			Distress (τ_2^2)	0.01 (0.00)	<0.01
Intercept, MTension (τ_{01})	0.03 (0.02)	0.11	Intercept, MTension (τ_{01})	0.03 (0.02)	0.12
			Intercept, distress (τ_{02})	0.01 (0.01)	0.45
			MTension, distress (τ_{12})	0.00 (0.00)	0.76
Fit indices			Fit indices		
Deviance	AIC	BIC	Deviance	AIC	BIC
24,327.8	24,339.8	24,359.0	24,276.8	24,296.8	24,328.9

Estimates based on 171 people and 7,023 observations. AIC, Akaike information criterion; BIC, Bayes information criterion; MTension, muscle tension; TMJD, temporomandibular muscle and joint disorder.

The amount of variance explained by the models varied. Very strong effects, at a level not typically found in studies involving humans, appeared for MTension $\rightarrow$ TMJDPain. Although TMJDPain $\rightarrow$ MTension had nearly equal explanatory power, MTension $\rightarrow$ TMJDPain had substantially better fit. In addition, higher initial levels of TMJDPain were associated with stronger associations between TMJDPain and MTension, a phenomenon supportive of MTension as a causal agent. TMJDPain $\rightarrow$ MTension, on the other hand, indicated that higher initial levels of MTension were associated with weaker association between the 2 variables, which would seem to argue against TMJDPain as a cause of MTension. These findings, consistent with experimental evidence noted earlier, indicate that the presence of muscle tension is strongly associated with later TMJD pain. The other models explained smaller but still meaningful percentages of the variance in patterns that supported the preferred models over the alternatives.

For all models, the level 2 fixed-effect variables explained much more variance than Time or other level 1 variables. For example, the average level of Distress reported by an individual over the course of the study explained much more variance in any given instance of reported TMJDPain than the reported level of Distress on the occasion immediately prior. That is, contiguous Distress was associated with TMJDPain, but an individual's overall average Distress, relative to other people in the sample, had an even greater impact (cf. Slade et al. 2015). The same interpretation can be made of the other 2 models, Distress $\rightarrow$ MTension and MTension $\rightarrow$ TMJDPain. Further reduction in the size of the level 1 fixed effects likely came from controlling for the level 2 fixed effects of age and sex, but controlling for these individual differences strengthened the internal validity of the findings.

Hypothesis 3 posited that MTension would mediate the effect of Distress on TMJDPain. The results indicated a partial mediation effect; the addition of MTension reduced the fixed effect of Distress on TMJDPain, and the indirect effect through MTension accounted for a majority of the total effect on TMJDPain. However, both the indirect and total effects were small. In this model, the independent, mediator, and dependent variables were all at level 1. Given that the previous models showed smaller effects for level 1 predictors, the small indirect effect in the mediation model was not unexpected. In addition, the mediation model was able to explain a large amount of variance in TMJDPain and a moderate amount in MTension. Strong relationships among a person's average level of Distress, MTension, and TMJDPain have been observed in other studies (Glaros et al. 2005) examining contemporaneous events with EMS-derived data.

The observed variables in this study were all gathered using ESM. Accordingly, the possibility that various recall biases affected the results is reduced, compared with data collected via one-time self-report questionnaires. The error of measurement for each of the observed variables is also likely to be reduced, compared with one-time measurement via questionnaires. The differences in method used to collect data may account for the different conclusions reached by other investigators about the role of oral parafunctions in the pain reported by those with TMJD (Davis et al. 2010). The results are also

strengthened by the number of measurement occasions and the longitudinal nature of the data, through which we were able to predict responses to a particular prompt with responses to other prompts on prior occasions. Our use of MLM also addressed 2 potential difficulties in the ESM data: varying times between measurements and data missing at random.

The findings reported here are consistent with existing knowledge of myofascial and arthralgic TMJD pain. Individuals with TMJD may show hyperexcitability of the central nociceptive system and dysregulation of autonomic activity (Sarhani et al. 2004; Balasubramaniam et al. 2007; Chen et al. 2013). Temporal summation may be a mechanism for understanding how oral parafunctions produce pain and why women are over-represented in populations of TMJD patients (Sarhani and Greenspan 2005; Sarhani et al. 2007; Raphael 2009). The biomechanics of the masticatory system may also contribute to TMJD (Iwasaki et al. 2010). The degree to which genetic factors (Nackley and Diatchenko 2010; Michelotti et al. 2014) add to the variance explained by muscle tension/tooth contact and stress in an individual's pain is yet to be determined.

We chose muscle tension as a major variable because our previous clinical work suggested that muscle tension could occur in both the presence and absence of tooth contact. Oral parafunctional behaviors such as tooth contact and muscle tension occur at high rates in those without TMJD and at significantly higher levels in those with painful TMJD (Glaros et al. 2005). Thus, TMJD may result more from excessive, low-level normal behaviors than from uncommon or intense behaviors (e.g., nocturnal tooth grinding, clenching) (Sato et al. 2006; Chen et al. 2007; Raphael et al. 2012; Funato et al. 2014). Whether other parafunctional behaviors would generate equally strong results is unclear.

Our findings provide compelling evidence that stress and muscle tension are triggers for TMJD pain. From a clinical perspective, the results suggest that providers carefully assess the role of oral parafunctional behaviors, including chronic low-level parafunctions, in patients complaining of TMJD-related myofascial pain and arthralgia. Patients may not be aware of these behaviors (Glaros 1996). However, providers can encourage their patients to be mindful of any oral parafunctional behavior, to redefine such contact as a form of unnecessary muscle tension that can lead to pain, and to employ self-management strategies to reduce masticatory muscle tension.

Author Contributions

A.G. Glaros, contributed to conception, design, data acquisition, analysis, and interpretation, drafted and critically revised the manuscript; J.M. Marszalek, contributed to data analysis and interpretation, drafted and critically revised the manuscript; K. Williams, contributed to data acquisition, analysis, and interpretation, drafted and critically revised the manuscript. All authors gave final approval and agree to be accountable for all aspects of the work.

Acknowledgments

Portions of this work were supported by a grant from the National Institute of Dental and Craniofacial Research (DE13563), the University of Missouri–Kansas City, and Kansas City University

of Medicine and Biosciences. Preparation of this manuscript followed STROBE guidelines. The authors declare no potential conflicts of interest with respect to the authorship and/or publication of this article.

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