Chewing in Temporomandibular Disorder Patients: An Exploratory Study of an Association With Some Psychological Variables

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Aims: *To compare kinematic parameters (ie, amplitude, velocity, cycle frequency) of chewing and pain characteristics in a group of female myofascial temporomandibular disorder (TMD) patients with an age-matched control female group, and to study correlations between psychological variables and kinematic variables of chewing.* ***Methods:*** *Twenty-nine female participants were recruited. All participants were categorized according to the Research Diagnostic Criteria for TMD (RDC/TMD) into control (n = 14, mean age 28.9 years, SD 5.0 years) or TMD (n = 15, mean age 31.3 years, SD 10.7) groups. Jaw movements were recorded during free gum chewing and chewing standardized for timing. Patients completed the Depression, Anxiety, and Stress Scales (DASS-42), the Pain Catastrophizing Scale (PCS), the Fear of Pain Questionnaire-III (FPQ-III), and the Pain Self-Efficacy Questionnaire (PSEQ). Statistical analyses involved evaluation for group differences, and correlations between kinematic variables and psychological questionnaire scores (eg, depression, anxiety, stress) and pain intensity ratings.* ***Results:*** *Velocity and amplitude of standardized (but not free) chewing were significantly greater (*P < *.05) in the TMD group than the control group. There were significant (*P < *.05) positive correlations between pain intensity ratings and velocity and amplitude of standardized chewing but not free chewing. There were significant (*P < *.05) positive correlations between depression and jaw amplitude and stress and jaw velocity for standardized but not free chewing.* ***Conclusion:*** *This exploratory study has provided data suggesting that psychological factors, manifesting in depression and stress, play a role in influencing the association between pain and motor activity.* J OROFAC PAIN 2011;25:56–67

Key words: anxiety, clinical pain, depression, jaw movement, mastication, pain adaptation model, stress, temporomandibular disorders

Temporomandibular disorders (TMD) are the most common chronic pain condition in the orofacial area.[1–3] Although pain and limitation of jaw movement are well-established symptoms of TMD, the precise relationship between these symptoms is controversial. The Pain Adaptation Model is one explanation of this relationship, which, as applied to the jaw motor system, proposes that through brainstem-based mechanisms, nociceptive input alters jaw muscle activity to reduce the amplitude and velocity of jaw movement. These motor changes represent a functional, adaptive response to promote healing by protecting the jaw motor system from further injury.[4–6]

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In general, the findings from many human experimental and clinical muscle pain studies lend support to the Pain Adaptation Model.[4,5,7–13] However, some findings are not always consistent with the model.[6,14,15] There is growing evidence that the relation between pain and motor activity may be influenced by brain regions other than at the level of the brainstem where the Pain Adaptation Model and another model, the Vicious Cycle Theory, are proposed to operate. The primary motor cortex may be involved in this pain-motor interaction. In the anesthetized rat, intraoral noxious stimulation results in prolonged (> 4 hours) decreases in the excitability of the face primary motor cortex (face MI).[16] In the awake human, hypertonic saline injections into human facial skin or the masseter muscle evokes long-duration (> 6 minutes) decreases in face MI activity as shown on magnetic resonance imaging,[17] and capsaicin-evoked tongue mucosal pain interfers with MI neuroplasticity associated with novel tongue-task motor training.[18] These data suggest that pain inhibits voluntary motor drive through inhibition of MI. This inhibition may contribute to the reductions in amplitude and velocity of movement proposed by the Pain Adaptation Model to occur in pain.

Given this possible involvement of motor cortical regions in the pain-motor interaction, influences from other higher centers might then also play a role in the interaction between the experience of pain and motor activity. In particular, psychological factors (eg, beliefs, fear, mood, and learning processes) have been found to be important.[6,19–22] For example, there is evidence that depression, catastrophizing, and fear-avoidance beliefs correlate with subjective or objective measures of motor performance.[19–22] Self-report of depression also correlates significantly with self-report of disability and physical performance,[21] and individuals with high pain-related fear have smaller peak velocities and accelerations of the lumbar spine and hip joints in reaching trials.[20] In addition, given that people with depressive disorders have deficits in executive function, attention, short-term and working memory in verbal and visual tasks,[23] depression may have a possible effect on motor control through changes in cognitive processes influencing the ability to perform motor tasks. Flor and colleagues have demonstrated that operant learning processes can also moderate the experience of pain following noxious stimulation, and those changes are detectable on brain function studies.[24] The possible involvement of psychological factors in the interaction between pain and motor activity may help explain why some findings from experimental and clinical studies of pain-motor interactions are not always consistent with the proposals of the Pain Adaptation Model, if these factors have not been taken into account in these studies.[6,14] The current authors have recently proposed a revision to the Pain Adaptation Model which has been termed the *Integrated Pain Adaptation Model*.[6] This new model builds on the brainstem-based mechanisms of the Pain Adaptation Model by incorporating influences on the pain-motor interaction from higher centers, for example involving psychological factors.

To test if psychological factors could play a role in the pain-motor interaction, this exploratory pilot study of chewing movements was conducted in a group of female TMD patients and a group of female controls. The study first sought to determine whether the chewing movements of TMD patients were smaller and slower than control participants as would be predicted by the Pain Adaptation Model and, secondly, to determine whether there was evidence supporting a role for psychological factors in the pain-motor interaction in the jaw motor system. On the basis of previous studies showing that orofacial pain is associated with smaller and slower jaw movements,[6] the first hypothesis was that amplitude, velocity, and cycle frequency of chewing should be smaller in the TMD group than the control group. On the basis of the negative correlation between some psychological measures and movement parameters identified in the spinal system (see above), the second hypothesis was that psychological variables (eg, depression, anxiety, stress, and pain intensity ratings) will correlate negatively with kinematic variables of jaw motor activity during chewing. Therefore, the aims of this pilot study were to compare kinematic parameters (ie, amplitude, velocity, cycle frequency) of chewing and pain characteristics in a group of female myofascial TMD patients with an age-matched control female group and to study correlations between psychological variables and kinematic variables of chewing.

Materials and Methods

Twenty-nine female participants, 14 controls and 15 with TMD, were recruited for this study (mean age [± SD] of control group, 28.9 ± 5.0 years; mean age of TMD group, 31.3 ± 10.7 years). All participants gave informed consent. Experimental procedures were approved by the Sydney West Area Health Service Human Ethics Committee of Westmead Hospital and the Human Ethics Committee of the University of Sydney.

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Participants

All participants were examined by one clinician (CCP) who is experienced and calibrated with the Research Diagnostic Criteria for TMD (RDC/TMD)[25] to confirm the presence or absence of a TMD diagnosis before the experimental recording. Participants were classified into a myofascial TMD pain group or into a control group without TMD. Participants with TMD were patients and health-professional staff and students from the Orofacial Pain Clinic of Westmead Hospital. The controls were staff and students at Westmead Hospital. Participants were excluded if they had any history of major trauma to the neck or head, were currently using an intraoral appliance, were undergoing active orthodontic treatment, had a history of any chronic pain condition other than myofascial TMD (eg, extracranial pain, headache, trigeminal neuropathic pain, temporomandibular arthralgia, osteoarthritis, ostheoarthrosis, or disc displacement), or regularly took analgesics or central nervous system medications (eg, antidepressants, anxiolytics, sedatives, anticonvulsants). Although patients with fibromyalgia and chronic fatigue were excluded, some patients reported pain in the back (n = 4) or arms, hands, legs, or feet (n = 6). Some of the procedures have been previously described in detail.[14,26–28]

Jaw Movement Recording and Visual Feedback

An optoelectronic jaw tracking system (JAWS3D, Metropoly) was used to record the movement of the mandible in six degrees-of-freedom (sampling rate: 67 samples/second). The movement of the mid-incisor point, ie, the point between the incisal edges of the lower central incisor teeth, was displayed as a dot on a video screen in front of the participant. This dot provided visual feedback for the participant to track, in real time, a computer-controlled target that consisted of a linear bank of light-emitting diodes (LEDs) that were illuminated in sequence to generate a target. This LED bank was placed to the side of the trajectory of mid-incisor point movement that was produced when participants moved their jaws. Custom-made metal/acrylic clutches, temporarily attached to two to three upper and lower anterior teeth on the right side with cyanoacrylate cement, supported the target frames of the tracking system.

Jaw Tasks

Participants sat upright with the Frankfort horizontal plane approximately parallel to the floor and without head restraint. All participants initially softened chewing gum (0.14 g) for 30 seconds by chewing on the left side. Recordings of jaw movement were then made during unilateral chewing of the gum only on the right side and as naturally as possible (termed "nonstandardized chewing" or "free chewing") or during right-sided chewing and after being instructed to follow as closely as possible the timing of the computer-controlled target ("standardized chewing"). Standardized chewing required the participants to follow the time and speed of the target LED bank, which was adjusted to oscillate at 900 ms/chewing cycle (ie, standardized for timing but not amplitude[29]). Two trials of nonstandardized chewing and two trials of standardized chewing were performed. The total duration for each chewing trial was approximately 15 seconds.

Measures

All participants in the TMD and control groups completed the following measures immediately prior to the experimental tasks: *(1)* Depression, Anxiety, and Stress Scales (DASS-42)[30]; *(2)* Pain Catastrophizing Scale (PCS)[31]; *(3)* Fear of Pain Questionnaire-III (FPQ-III)[32]; and *(4)* Pain Self-Efficacy Questionnaire (PSEQ).[33] The DASS-42[30] is a reliable and well-validated tool measuring the cognitive and affective dimensions of psychological distress. It has three scales (depression, anxiety, and stress) and 42 items. Symptoms in the past week are rated from 0 ("not at all") to 3 ("most of the time"). The total scores for each scale consist of the sum of the items.

The PCS[31] assesses negative cognitive and affective strategies for coping with pain. Three subscales (magnification, rumination, and helplessness) capture a person's orientation towards noxious stimuli and/or previous memories of pain. Each of the 13 questions is rated on a five-point Likert scale ranging from 0 (not at all) to 4 (all the time). Range: 0 to 52.

The FPQ-III[32] is a 30-item self-report measure, with three subscales (Severe Pain, Minor Pain, and Medical Pain). A person's tendency to be fearful in general (trait fear) is tapped by rating a range of pain events, such as receiving a paper cut on the finger, falling down a flight of concrete steps, or receiving an injection in the arm. Items are rated on a five-point Likert scale ranging from 1 (not at all) to 5 (extreme). Ratings for 10 situations in each group are summed into a total score, with a possible range of 30 to 150.

The PSEQ[33] consists of 10 questions about current situations, evaluating how individuals perform activities despite their pain. In this study, partici-

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Table 1 Baseline Pain Characteristics of Participants

	Control			TMD			
Characteristic	n	Mean (SD)	Frequency	n	Mean (SD)	Frequency	*P* value
Age and number of participants	14	28.9 (5.0)	–	15	31.3 (10.8)	–	.445 (age)
Limitation in chewing†	0	–	–	9	–	–	.001*
Limitation in eating hard food†	0	–	–	9	–	–	.001*
Presence of pain just before start of chewing							
Free	0	–	–	8	–	–	.002*
Standardized	0	–	–	9	–	–	.001*
Characteristic Pain intensity ratings†	–	0	–	–	45.1 (24.8)	–	≤ .001*
Graded Chronic Pain Scale[34]†							
0	–	–	14	–	–	0	≤ .001*
1	–	–	0	–	–	9	–
2	–	–	0	–	–	3	–
3	–	–	0	–	–	1	–
4	–	–	0	–	–	2	–

* = statistically significant ($P < .05$) differences between the two groups. †Questions taken from the RDC/TMD.

pants were instructed to "think about times you have experienced pain" and rate *general versus present* confidence to do things, despite the pain. Each item is rated from 0 ("not at all confident") to 6 ("completely confident"), resulting in a total range of 0 to 60. Higher scores reflect stronger self-efficacy beliefs (eg, I can enjoy things, despite the pain).

Before chewing, participants used a numerical rating scale (NRS-11) to indicate present facial pain intensity ratings ("How strong is your pain now?") and expectancy of pain during the next chewing movement ("How painful do you expect this next task sequence to be?"). After chewing, participants were asked to indicate the pain level just experienced during the movement ("How strong was your pain during the movement?"), to indicate how bothersome the pain was during the movement ("How much does the pain of this trial bother you?"), and to indicate pain intensity after the movement ("How strong is the pain now during rest?").

Data Analysis

For each chewing task in each participant, the mid-incisor point vertical trajectories (ie, in the z-axis [superior-inferior]) were plotted as time/displacement plots. The first and the last strokes of each chewing sequence were rejected. A customized computer program identified, for the outgoing (ie, opening) phase of each chewing cycle, the onset of mid-incisor point movement as the time at which the mid-incisor point had displaced 0.5 mm from maximum closure at the end of the previous cycle. The offset of mid-incisor point movement was defined as the last 0.5 mm of opening movement before jaw closing commenced. The onset of the return (ie, closing) phase of each chewing cycle was the time at which the mid-incisor point had displaced 0.5 mm from maximum opening at the end of jaw opening, and the offset was the time at which displacement was within 0.5 mm of maximum closure. The period between each onset of jaw opening within a chewing sequence was defined as a masticatory cycle, and the number of cycles over a continuous 10-second period of chewing was counted. The amplitude of mid-incisor point jaw movement on the outgoing phase was the maximum displacement along the z-axis (superior-inferior) from the onset of jaw movement. The amplitude on the return phase was the maximum displacement of the jaw from maximum displacement to the offset of jaw movement on the return phase. The outgoing (and return) velocities were then calculated by dividing the amplitude by the duration of that outgoing (and return) phase.

The data were analyzed with statistical software (SPSS, version 16.0, IBM) with the alpha value for statistical significance set at 0.05. The analysis of group differences between TMD and control participants was performed with the chi-square test or Fisher's exact test for categorical variables, and independent *t* tests were used for continuous variables. The nonparametric correlation (Spearman's rank correlation coefficient) was used to refer to a linear relationship between two quanti-

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Table 2 Scores for Psychological Measures

	Control		TMD		
Psychological measure	Mean	SD	Mean	SD	*P* value
Depression	2.21	2.25	9.46	8.71	.007*
Anxiety	1.42	1.91	10.86	10.9	.005*
Stress	6.42	5.28	17.13	10.1	.002*
PCS	11	8.36	12.73	10.64	.631
FPQ-III	79.286	23.15	77.867	24.9	.875
PSEQ	42.85	18.74	45.0	13.82	.727

* = statistically significant ($P < .05$) differences between the two groups.

Table 3 Pain Intensity Ratings and Chewing Cycle Variables

	Control		TMD		
Chewing Type	Mean	SD	Mean	SD	*P* value
Free chewing					
Pain expectancy	0	0	26	30	.005*
Pain intensity ratings					
Start of movement	0	0	27	28	.002*
During the movement	0	0	23	30	.01*
After the movement	0	0	27	31	.005*
Outgoing velocity (mm/s)	26.7	8.8	28.2	10.5	.681
Return velocity (mm/s)	27.6	7.5	29.8	10.5	.525
Amplitude (mm)	12.1	3.9	12.5	2.9	.752
Frequency (n in 10 s)	11.7	2.1	10.8	2.2	.267
Standardized chewing					
Pain expectancy	0	0	22	29	.012*
Pain intensity ratings					
Start of movement	0	0	25	27	.003*
During the movement	0	0	22	27	.007*
After the movement	0	0	22	29	.011*
Outgoing velocity (mm/s)	24.9	9.4	32.6	9.7	.038*
Return velocity (mm/s)	28.0	10.4	34.9	10.7	.092
Amplitude (mm)	11.5	4.2	14.9	4.4	.037*
Frequency (n in 10 s)	11.1	0.9	10.9	1.1	.647

* = statistically significant ($P < .05$) differences between the two groups.

ties. For correlations with psychological variables, participants from both control and TMD groups were grouped into either a "no depression" or a "depression" group; the "depression" group was all participants who gave depression scores in the "mild," "moderate," "severe," or "extremely severe" categories on the DASS-42. Participants were also divided into a "no stress" or "stress" cohort, and a "no anxiety" and an "anxiety" group. For some of the analyses, data from the cases and controls were combined to cover the full range of variation in pain intensity and to achieve greater statistical power with these exploratory data.

Results

Baseline characteristics of control and TMD groups are listed in Table 1. In comparison with the control group, most TMD patients exhibited limitations in eating hard foods, and/or in chewing, and/or were in pain on the day of the experiment immediately prior to free or standardized chewing (Table 1).

The TMD patients exhibited significantly higher depression, anxiety, and stress scores than the control group (Table 2). There was no significant difference between groups for catastrophizing, fear, and pain self-efficacy (Table 2). In contrast to the control

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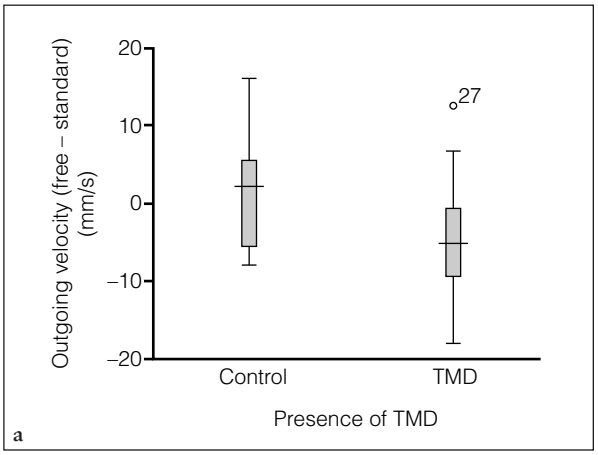
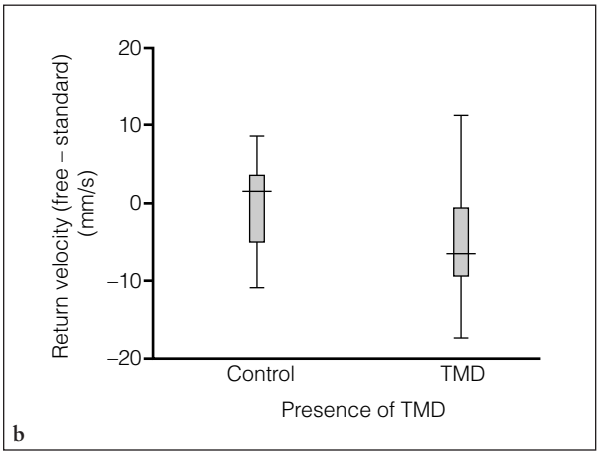
Table 4 Difference Between Free Chewing and Standardized Chewing

	Control			TMD			
	Mean	SD	*P* value within group	Mean	SD	*P* value within group	*P* value between groups
Difference in outgoing velocity	1.80	7.08	.359	–4.47	8.31	.056	.038*
Difference in return velocity	–0.42	6.26	.805	–5.06	7.85	.026*	.091
Difference in amplitude	0.65	4.7	.610	–2.4	3.58	.021*	.057
Difference in frequency	0.59	1.81	.244	–0.13	1.89	.798	.302

* = statistically significant (*P* < .05) differences for comparisons within and between the two groups.





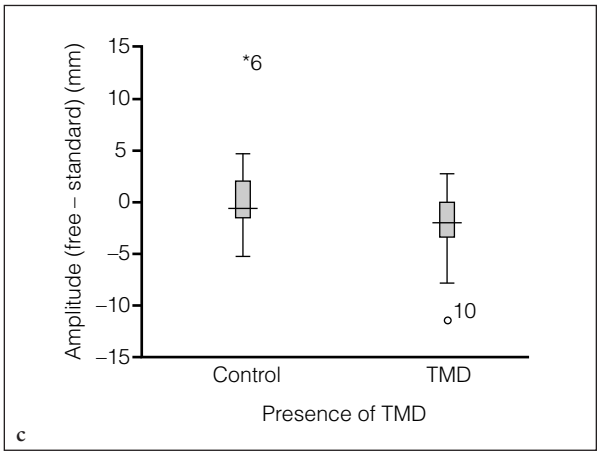


Fig 1 Box plots showing medians (middle horizontal lines), interquartile ranges (filled rectangles), and maxima and minima (horizontal hairlines) for differences between free chewing and standardized chewing for outgoing velocity *(a)*, return velocity *(b)*, and amplitude *(c)*. In each plot, all participants have been divided into a control and TMD group. The three numbered data points represent outliers.

group, the TMD group exhibited pain at the start, during, and after free and standardized chewing (Table 3). Although there was no significant difference (*P* > .05) between the TMD and control groups for outgoing and return velocity and amplitude and frequency of free chewing, the outgoing velocity and amplitude of standardized chewing were significantly greater (*P* < .05) in the TMD group than in the control group (Table 3).

In the control group, there were no significant differences between free chewing and standardized chewing for outgoing velocity, return velocity, amplitude, or frequency (Table 4). Box plots of these control data are illustrated on the left side of each plot in Fig 1. In the TMD group by contrast, the return velocity and amplitude were significantly greater during standardized chewing than free chewing (Table 4; Fig 1). There was a significantly greater difference (*P* = .038) in outgoing velocity between free and standardized chewing in the TMD group than in the control group (Table 4). There was a significant positive correlation between anxiety and the difference in amplitude between free and standardized chewing (*P* = .043), but there were no other

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Table 5 Associations Between Intensity of Pain and Chewing Cycle Variables‡

Chewing cycle	Characteristic pain intensity ratings† rank correlation (*P* value)	Pain intensity ratings at the start of movement rank correlation (*P* value)	Pain intensity after movement rank correlation (*P* value)
Free			
Outgoing velocity	0.075 (.689)	0.213 (.267)	0.308 (.104)
Return velocity	0.160 (.407)	0.277 (.146)	0.325 (.086)
Amplitude	0.101 (.602)	0.217 (.258)	0.263 (.168)
Frequency	–0.1 (.607)	0.072 (.709)	0.160 (.406)
Standard			
Outgoing velocity	0.402 (.031)*	0.372 (.047)*	0.296 (.119)
Return velocity	0.389 (.037)*	0.468 (.010)*	0.397 (.033)*
Amplitude	0.397 (.033)*	0.425 (.022)*	0.349 (.063)
Frequency	–0.081 (.677)	0.098 (.612)	0.019 (.923)

* = statistically significant (*P* < .05) results; † = question taken from the RDC/TMD; ‡ = data from TMD group combined with data from control group. There was no correlation between any variable and pain expectancy.

Table 6 Correlations Between Psychological Measures and Kinematic Variables for Free and Standardized Chewing Cycles†

Chewing cycle	Depression rank correlation (*P* value)	Anxiety rank correlation (*P* value)	Stress rank correlation (*P* value)
Free			
Outgoing velocity	0.387 (.038)*	0.080 (.679)	0.263 (.168)
Return velocity	0.277 (.146)	0.089 (.646)	0.314 (.097)
Amplitude	0.323 (.087)	0.890 (.890)	0.204 (.288)
Frequency	0.125 (.517)	0.890 (.890)	0.111 (.566)
Standard			
Outgoing velocity	0.489 (.006)*	0.285 (.134)	0.323 (.088)
Return velocity	0.392 (.035)*	0.281 (.140)	0.412 (.026)*
Amplitude	0.443 (.016)*	0.290 (.128)	0.323 (.088)
Frequency	0.091 (.640)	–0.106 (.584)	0.220 (.252)

* = statistically significant (*P* < .05) results; † = data from TMD group combined with data from control group.

significant correlations between any psychological variable and the differences between free and standardized chewing velocity, amplitude, or frequency ($P > .05$).

For standardized but not free chewing, there were significant ($P < .05$) positive correlations between characteristic pain intensity ratings and pain intensity ratings at the start of movement, and velocity (outgoing, return) and amplitude, and between pain intensity after movement and return velocity (control and TMD groups combined; Table 5). There were significant ($P < .05$) positive correlations between depression and outgoing and return velocity and amplitude of jaw movement during standardized chewing (control and TMD groups combined; Table 6). Depression was also significantly positively correlated with outgoing velocity during free chewing, and stress was significantly positively correlated with return velocity during standardized chewing. The data are presented as box plots in Figs 2 and 3 to show median, interquartile ranges, maxima, and minima for outgoing velocity, return velocity, and amplitude during free chewing and standardized chewing where significant differences were identified in Table 6.

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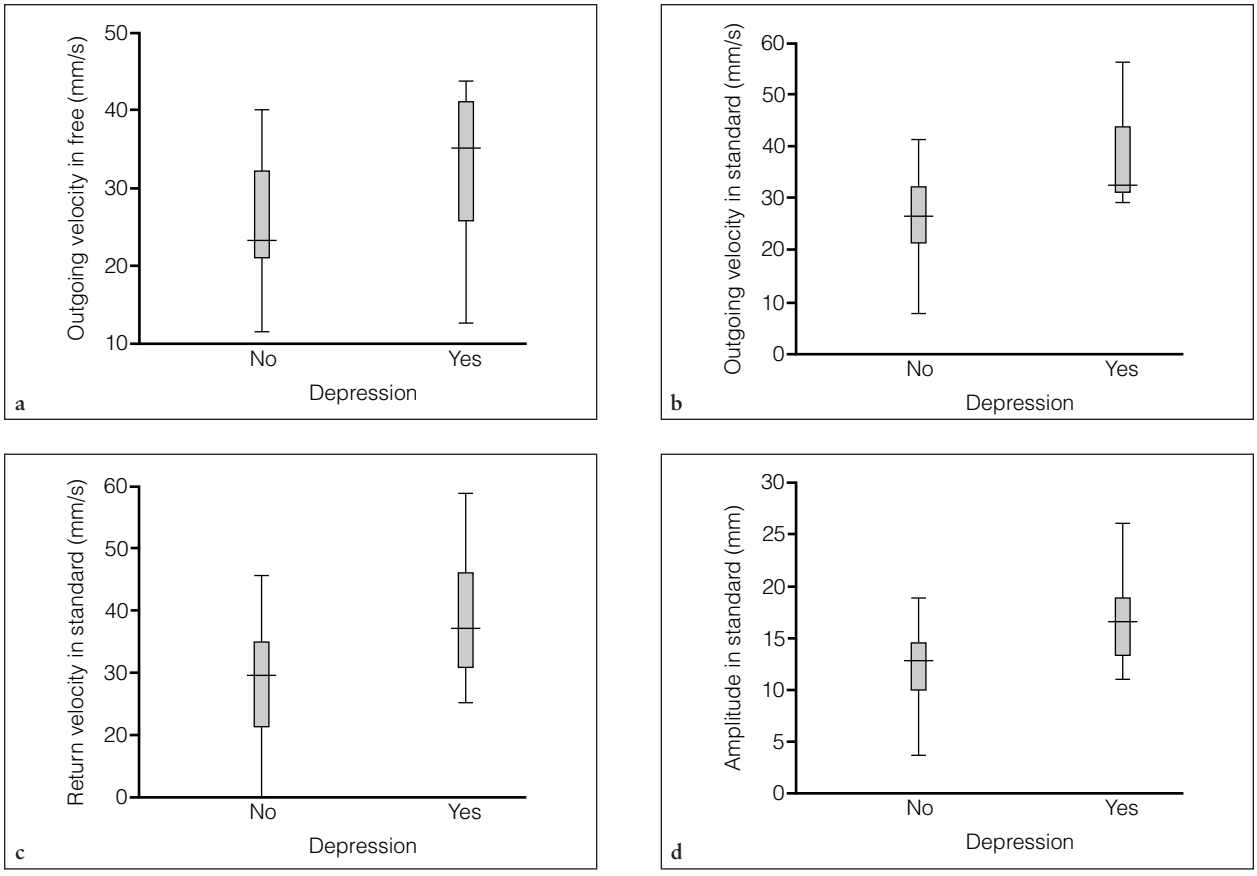

Fig 2 Box plots showing medians (middle horizontal lines), interquartile ranges (filled rectangles), and maxima and minima (horizontal hairlines) for outgoing velocity *(a and b)*, return velocity *(c)* and amplitude *(d)* during free chewing (upper left plot) and standardized chewing. In each plot, all participants were divided into a no depression cohort (from the DASS-42 scale) and a depression cohort ("mild," "moderate," "severe," and "extremely severe" categories from the DASS-42 scale).

Discussion

The principal findings of the present exploratory study were that there were no significant differences in kinematic parameters between the TMD and control groups for free chewing, but that outgoing (ie, opening) velocity and amplitude of standardized chewing (standardized for chewing frequency) were significantly larger in the TMD group than the control group. Significant positive correlations were observed between some of the kinematic variables of the chewing movement and pain intensity ratings, depression, anxiety, and stress, but no significant relationships were found for catastrophizing, self-efficacy beliefs, and specific fears.

Limitations of Data

This is an exploratory study with a small sample size that limits the generalizability of the conclusions

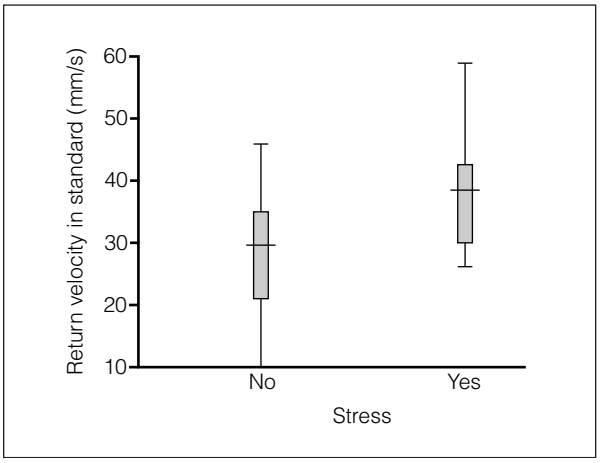

Fig 3 Box plot showing medians (middle horizontal lines), interquartile ranges (filled rectangles), and maxima and minima (horizontal hairlines) for return velocity during standardized chewing. In each plot, all participants were divided into a "no stress" cohort and a "stress" cohort.

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concerning the interaction of jaw movements and psychological factors. The chances of a type I error are increased by the number of analyses performed in proportion to the size of the sample. Despite these limitations, the study provides a guide for future investigations into how pain in muscles moderate muscle function and relate to symptoms of psychological distress that frequently coexist with chronic pain. The TMD group had mild depressive symptoms. Repeating the investigation with a stratified sample of depressed chronic pain patients (eg, grade III/IV on the graded chronic pain scale[34]) could systematically explore the effects of more severe psychological distress on jaw motor performance. It is also possible that other unmeasured factors could have accounted for the findings, for example, social factors or possible gender differences.[35–38] The cross-sectional study design does not allow an assessment of the direction of influence between motor activity and depression, anxiety, and stress.

Findings in Relation to Hypotheses

Within the limitations of this investigation, the first hypothesis, that amplitude, velocity, and cycle frequency of chewing should be smaller in the chronic pain group than the control group, was not confirmed. The second hypothesis, that psychological variables (eg, depression, anxiety, stress, and pain intensity ratings) will correlate negatively with kinematic variables of jaw motor activity during chewing, was also not confirmed. Instead, there was a positive correlation for the distress scales (depression, anxiety, and stress) but not for the more cognitive variables (catastrophizing, self-efficacy) and only for some kinematic parameters of chewing. Possible reasons for this lack of consistency with the hypotheses are outlined below.

TMD Pain and Chewing Cycle Parameters

The Pain Adaptation Model proposes that pain leads to decreased movement so as to protect the system from further injury and promote healing,[4–6] and some previous data are consistent with this model.[4,8–10,12,39] However, and consistent with other previous findings,[14] no reductions were observed in amplitude or velocity of movement during free or standardized chewing in the TMD group in comparison to the control group. There are a number of possible explanations for these differences between studies. First, it is possible that participants in the present study were already carrying out smaller jaw movements than they would normally, given the experimental set up, and the Pain Adaptation Model may not be readily demonstrable for small movements. Although the vertical displacement of the mid-incisor point during control free or standardized chewing (12.1 ± 3.9 mm, 11.5 ± 4.2 mm, respectively) tended to be lower than that in previous reports (~18 mm[8,40], ~19 mm[41]), these studies employed harder bolus consistencies and/or male participants. Harder foods and male gender are associated with larger amplitude jaw movements,[42] which may explain why the present study recorded smaller amplitude jaw movements from the female participants chewing gum. Further, the present findings are comparable to other previous studies that employed gum alone but which included both male and female participants (13.7 ± 2.4 mm;[29] 10.9 ± 2.5 mm [free chewing], 14.4 ± 4.1 mm [standardized chewing][14]).

Second, the patients may have been motivated to exert effort and to use their jaws in a manner inconsistent with the promotion of healing, as proposed by the Pain Adaptation Model. The TMD group were knowledgeable about contemporary pain management, as they were health professional staff, students, and patients from Westmead Hospital. Although the clinical population was RDC/TMD-defined, PSEQ and FPQ-III scores were equivalent to controls (see also[43]). They were as confident as pain-free individuals in performing normal daily activities despite the pain and were no less fearful than controls that an activity would aggravate the pain. They appear to have adopted a strategy to complete the chewing tasks with kinematic parameters no smaller than controls. Future studies could perform analogous longitudinal studies in TMD patients at the commencement of their pain-management program.

It is possible that the association between pain and motor activity may not be just a hard-wired brainstem level response but may be influenced by psychological factors, particularly in chronic pain states. Under more natural situations where orofacial pain patients need to perform a demanding task, eg, clearly articulated speech in demanding work situations, and chewing unexpectedly hard foods in particular social situations, it may be that the patient may be able to override the normal response as proposed by the Pain Adaptation Model, particularly if the patient has been involved in a pain-management program. Individuals in pain can indeed chew more quickly if necessary.[10,14] This ability to override the normal response, as proposed by the Pain Adaptation Model, may be the explanation as to why the TMD patients in the present study were able to perform the chewing tasks

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no smaller or slower than controls but nonetheless many reported limitations in chewing and eating hard food in their daily lives. Alternatively, it is possible that TMD patients' perceptions of chewing limitations may not match objective measures of limitations.

The Possible Role of Higher Motor Centers in the Pain-motor Interaction

The presence of a significant difference between the TMD and control groups for some kinematic parameters in standardized chewing but not free chewing is attributed to a greater influence from higher motor centers (eg, motor cortex) in standardized chewing in comparison with free chewing. The standardized chewing task imposes time constraints because participants are required to keep their jaw moving in time with an oscillating visual target. These constraints will demand a greater involvement of voluntary motor areas of the cerebral cortex (eg, masticatory cortex[44]) in modulating the brainstem-based central pattern generator[45] to produce the standardized chewing movements than in the generation of free chewing. As participants are instructed to chew in a normal fashion in free chewing and without regard to timing of chewing, it can be argued that there will be less cortical involvement and a greater relative involvement of the brainstem central pattern generator during free chewing than standardized chewing.[45] Recently, evidence has been provided for decreases in motor cortical excitability following noxious stimulation of orofacial tissues[16–18] or following noxious stimulation of the limb.[46–49] As the face MI has been implicated in the fine control of jaw movements,[50] it is possible that the face MI region of the TMD pain patients was impaired so that the fine control of jaw muscle activity required during the standardized chewing movements became affected. This loss of fine control may have manifested as an increase in chewing cycle amplitude, which then necessitated an increase in velocity in an attempt to keep in time with the target.

Role of Psychological Variables in the Relation Between Pain and Motor Activity

The control group reported lower than average distress scores compared to the general population,[30,51] but the psychological distress scores for the TMD group in this study are generally comparable to those recently described in a larger sample of 364 patients with persistent head, face, and mouth pain, assessed at a nearby teaching hospital (Royal North Shore Hospital, RNSH) from 1994 to 2004.[43] Although the sample size is small, the mean TMD DASS-42 anxiety (10.86 ± 10.9) and stress (17.13 ± 10.1) scores indicate significantly higher levels of psychological distress than the control group and are comparable to those of the female head pain patients from this larger RNSH group (anxiety, 7.2 ± 8.3; stress, 14.7 ± 11.3).[43] The mean TMD depression ratings (DASS-42; 9.46 ± 8.71) are also consistent with but slightly lower than those of the larger group (12.78 ± 11.03).[43] The mean Characteristic Pain Intensity Ratings for the TMD group in this study (45.1/100 ± 24.8/100) are approximately comparable to the mean pain intensity ratings over the past week from the larger sample (6.03/10 ± 2.41/10).[43]

The finding that the more depressed individuals chewed faster and with greater amplitudes might seem counterintuitive given that depression is associated with greater pain-related disability.[52–54] One possibility is that the more depressed individuals may have wanted to complete the task more quickly, but it may also relate to the nature of the sample, which comprised subjects who were mostly working or studying despite their TMD. It is possible that a purely patient sample (which was not employed in the present study) may have yielded different findings.

The relation between stress and motor control is controversial.[55–58] Muscle pain[59] has been reported to impair the fidelity of muscle spindle afferent transmission. There may have been a loss of fine motor control in the TMD patients such that they found it more difficult to control the timing of jaw movement in the standardized chewing. Pain can also impair cognitive abilities or attention to the standardized task.[60] The complexity of potential interactions between function, types of pain, psychological symptoms, and pain perception is an avenue for further study.[52]

Conclusions

The data from this exploratory investigation suggest that psychological factors, manifesting in depression and stress, play a role in influencing the association between pain and motor activity. Further, the manifestation of the Pain Adaptation Model may be influenced by psychological variables. If indeed one or more psychological variables are playing a role in influencing the relation between pain and motor activity, then the variability of these psychological measures between individuals[61–65] may help explain the variability within and between studies as to the effect of pain on motor activity.[6,66] Despite the limitations (see above), this study is the first to investigate in a detailed manner the

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possible interaction of psychological factors and jaw movement. The findings suggest that the topic merits future investigation with a larger sample size. Future studies could address an intervention procedure to build our understanding of the direction of these relationships within a model of psychological mechanisms, movement, and pain.

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