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JAW MOVEMENTS DURING PRESCRIBED AND
VISUALLY DIRECTED TASKS IN ASYMPTOMATIC AND
TMD SUBJECTS

By

Dr. KRUPALINI

A thesis submitted as a partial fulfillment for the degree of
Master of Dental Science in Prosthodontics

Faculty of Dentistry
The University of Sydney

March, 2005

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STATEMENT OF AUTHORSHIP

I declare that all work presented in this thesis is my own, unless otherwise stated. The work of colleagues is recognized in the Acknowledgements and specifically within the body of the text, wherever appropriate.

[Signature]
23/1/05
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<tr>
<td>CED</td>
<td>Cambridge Electronic Design</td>
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<td>CPG</td>
<td>Central Pattern Generator</td>
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<td>EMG</td>
<td>Electromyography</td>
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<tr>
<td>ICP</td>
<td>Inter-Cuspal Position</td>
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<td>LEDs</td>
<td>Light Emitting Diodes</td>
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<td>MIPT</td>
<td>Mid- Incisor Point</td>
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<td>RDC</td>
<td>Research Diagnostic Criteria</td>
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<td>RMS</td>
<td>Root Mean Square</td>
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<td>TMD</td>
<td>Temporomandibular Disorders</td>
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<td>Visual Analogue Scale</td>
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ABSTRACT

Introduction

Muscle dysfunction is the most common problem observed in TMD patients, presenting with jaw muscle pain and abnormal and/or restricted jaw movements. Recording jaw movement and jaw muscle EMG are required to understand oro-motor function and as a possible aid in diagnosis and treatment of patients. However, the value of EMG and jaw tracking is controversial, and there is a need for carefully designed and controlled clinical studies.

Aim and hypothesis

The aim of this study was to determine whether there are differences firstly in the extent and reproducibility of jaw movements carried out at different speeds; and secondly in jaw muscle EMG activity in a group of symptomatic TMD patients compared with asymptomatic controls.

Methods and materials

Nine symptomatic TMD patients (8 females and one 1 male between the ages of 21 and 54 years) were recruited from the Oro-facial Pain Clinic of Westmead Center for Oral Health, and nine asymptomatic volunteers (6 females and 3 male between the ages of 26 and 38 years) were selected from students and staff from the University of Sydney. Bilateral surface electrodes were placed to record the EMG activity of masseter, temporalis and anterior digastric muscles, and jaw movements were recorded using JAWS-3D. Prescribed jaw movements of maximum open-close, protrusive-retrusive and right and left lateral excursive movements were carried out at slow and fast speeds
together with the EMG recordings. A VAS score obtained after each trial indicated pain intensity. Jaw movement data were analysed using quantitative and qualitative analysis for jaw displacement and coefficient of variance was used qualitatively to assess the difference in variability of the TMD group compared with controls. RMS (root mean square) of the EMG data was analysed using Mann-Whitney U test and Wilcoxon signed ranks test.

Results

Maximum jaw displacement for right lateral (controls of 10 ±1.9 mm, and 7.4 ± 3.7 mm in the TMD group); left lateral (controls of 11.3 ± 1.1 mm, and 8.6 ± 4.4 mm in the TMD group); protrusive (controls of 8.7 ± 2.2 mm, and 5.9 ± 1.8 mm in the TMD group); and open-close (controls of 40 ± 9.8 mm, and 33.5 ± 8.2 mm in the TMD group) movements, showed a reduced mean, larger standard deviation and greater range in the TMD group compared with the control group. Qualitative analysis of jaw movement data showed greater variation and reduced ability to reproduce jaw movements in the TMD group compared with controls. Also with the TMD group, variability in jaw movement was greater for the return phase compared with the out-going phase. Of the 40 tasks, mean EMG activity in the TMD group was reduced in 29 tasks of which 23 showed a statistically significant difference. Digastric and the masseter muscles showed a significant EMG activity in most of the tasks, and least activity in the anterior temporalis muscle. Digastric and masseter muscles showed a significantly reduced EMG activity in the TMD group compared with controls.
Discussion

The TMD group showed a greater range and standard deviation, reduced mean, greater variability and reduced ability in performing prescribed jaw movements compared with controls. Jaw muscle EMG was reduced significantly and showed a greater variability in the TMD group compared with controls. During opening, digastric (agonist) and masseter (antagonist) muscles showed reduced EMG activity. Hence the present study supports the hypothesis that pain has distinct effects on motor function and that increased motor activity exacerbates pain. However the results did not support the pain adaptation model.

Conclusion

TMD patients exhibited reduced and varied jaw movements compared with controls, and also showed a significantly reduced overall mean EMG activity. However the data for jaw opening movement did not support the pain adaptation model.
INTRODUCTION

Temporomandibular disorders (TMD) refers to a collection of general and oro-facial conditions affecting the physiology of temporomandibular joints (TMJ) and/or the jaw muscles, as well as the contiguous tissue components (NIH 1996). Functional disorders of the masticatory system are the most common reason for seeking treatment in an oro-facial pain clinic (Okeson 1996). There are good reasons to believe that jaw motor function and muscle pain are inter-related, since cardinal symptoms of TMD include pain and tenderness in the jaw muscles, and restriction and deviation in jaw movements (DeBoever and Carlsson 1994). Muscle hyperactivity, muscle tension, or muscle spasm caused by psychological, psychophysiological, neuromuscular or biomechanical factors, have been commonly thought responsible for pain and jaw motor dysfunction (Svensson and Graven-Nielsen 2001).

The diagnoses of TMD and management strategies are based on a comprehensive history and clinical examination (Cooper 1997). A lack of standardized diagnostic criteria has been an obstacle to diagnosis. Diagnostic protocols of known reliability and validity have not been routinely used for TMD, but there is an abundance of clinical literature describing signs and symptoms relevant to TMD. In general these data are not described using measurable (i.e. quantitative) criteria.

The aetiology of TMD is multifactorial and some of the pathophysiology cannot be assessed purely on physical symptoms and may be attributed to biobehavioral components. In view of this, Dworkin and LeResche (1992) developed the Research Diagnostic Criteria for Temporomandibular Disorders (RDC/ TMD), the most widely
used diagnostic protocol, which allows standardization and replication of clinical information of the most common forms of muscle and joint related TMD. The authors further state that RDC/TMD should not be perceived as a constraint or requirement which might limit clinical practice or even dictate research protocols, beyond the expectation that the use of these RDC/TMD criteria would enhance communication of findings among clinical researchers (Dworkin and LeResche 1992).

**Mandibular movements and Jaw tracking**

Jaw movements represent an interplay between temporomandibular neuromuscular function and temporomandibular morphology. It has been hypothesized that TMD arises from an imbalance in the relationship of the jaw and skull with the muscles that posture and move the mandible into dental occlusion (Cooper 1997). The jaw muscles are intricately involved in determining jaw position and movement. The activity of these muscles is continuously modified by proprioceptive feedback from the oro-facial region including the periodontium, TMJ and jaw muscles (Gibbs *et al* 1971, Hannam *et al* 1977). Subjects with jaw muscle pain represent a unique group because their movements often demonstrate abnormal patterns that could be related to abnormal muscle function due to pain, or from positional or degenerative changes in the TMJ. Hence it is not surprising that dysfunctional conditions of the masticatory system are reflected in associated changes in jaw movements (Nielsen *et al* 1990). Contrary to this, Svensson and Graven-Nielsen (2001) in their review of mechanisms and clinical manifestations of “craniofacial muscle pain”, suggest that changes in somatosensory and motor function may be a consequence of pain rather than the cause.
Professor Alfred Gysi (1910) was the first dental clinician to describe a graphical method to trace jaw movements. Subsequently more advanced techniques such as cinematography, cinefluorography and mechanical tracing devices were developed (Posselt 1958, Weinberg 1964, Gibbs et al 1969, Shields et al 1978).

During the last 30-40 years several researchers have described the use of electronic jaw tracking devices that allow both the recording of jaw movement and measurement of the velocity of movement without inter-cuspal interference, which could permit differential diagnosis of jaw movement patterns (Gillings 1967, Luschei and Goodwin 1969, Alhgren 1970, Jankelson et al 1975, Van Willigen 1979, Mongini and Tempia-Valenta 1984). A concern is whether certain patterns of abnormal jaw movement are diagnostic of specific pathological or dysfunctional conditions.

Several studies and reviews have described oro-motor function and underlying neurophysiology (Møller 1966, Luschei and Goldberg 1981, Klineberg and Sessle 1985, Lund et al 1991, Nakamura and Katakura 1995). It has been suggested that a good understanding of oro-motor function requires registration of jaw-muscle EMG activity combined with recording of jaw movements (Stohler 1986, Howell et al 1992, 1993). The accurate monitoring of these records may provide information of diagnostic and prognostic value (Howell et al 1993).

A kinematic analysis of jaw-movements most often includes measurement of maximum jaw displacement in three dimensions, in addition to duration and velocity of movements (Neil and Howell 1986, Throckmorton et al 1992, Plesh et al 1993). Howell et al (1992) and Cecere et al (1996) examined the reliability and reproducibility of these devices and in particular, the problem with non-linearity of a magnet-based jaw tracking system.
Studies by Monteiro and Clark (1985), and Cooper (1989) suggest that jaw tracking and EMG recordings are techniques that allow objective measurement of jaw function and associated muscle activity. Other studies by Feine et al (1988), Lund and Widmer (1989) and Mohl et al (1990) have criticized jaw tracking and EMG as being of no greater diagnostic value than standard clinical examination, and of not being well supported by scientific evidence. However opto-electronic jaw-tracking devices have increased accuracy and sensitivity compared with magnet-based devices (Airoldi, Gallo and Palla 1994). One such device, JAWS-3D (Metroploy AG, Zurich, Switzerland), records the movement of the whole mandible as a rigid body in 6 degrees of freedom, with reference to extra-orally placed landmarks. The small error of JAWS-3D (0.2mm) in recording jaw movements together with its low invasiveness justifies its use in the clinical research.

Clark and Lynn (1986) compared three parameters of jaw movement- magnitude, accuracy and velocity in the horizontal plane between TMD and non-patient controls. Twenty controls and 20 TMD patients from staff and students of the University of California, Los Angeles (UCLA) and patients of UCLA respectively, volunteered for the study. Both groups performed full excursive (right lateral, left lateral and protrusive) movements. Data were derived from measuring the maximum displacement and accuracy of each movement, which was obtained by dividing maximum length by the maximum width of the superimposed movements for each excursion and expressed as a ratio. These authors used the term “accuracy” to mean consistency of movements (the difference in the out-going movement to the return movement and ability of the jaw to return to the starting point). The second part of the study included measuring the maximum velocity of protrusive and retractive movements. A statistically significant difference for maximum opening (p< 0.001) was found (measured clinically with a
millimeter ruler) between control and TMD groups. No significant differences were found between the groups for right lateral, left lateral and protrusive movements on kinesiographic analysis. The controls were significantly different from the TMD group on right (p< 0.001) and left (p< 0.015) accuracy ratio, but not with protrusive. The controls had significantly higher retrusive velocity (p< 0.02) than the TMD group.

Similarly, Monteiro et al (1987) analysed the relationship between accuracy of jaw movement and masticatory dysfunction symptoms of TMD. Thirty control subjects and 20 TMD patients whose primary diagnosis was myalgia participated in the study. Lateral and protrusive jaw movements were recorded and analysed for accuracy, which was obtained by dividing maximum length by the maximum width of the superimposed movements for each excursion. The accuracy of jaw movements was then correlated with sub-categories in a questionnaire. Results showed that lateral jaw movement accuracy differentiated between patient and non-patient groups, but the accuracy of protrusive movements did not allow differentiation. The strength of correlation of accuracy, with the level of symptoms and TMD was not a good predictor of the severity of TMD. One interesting qualitative observation from this study was that many of the TMD patients were able to track the outward lateral excursive movement readily and reproducibly, but the inward movement varied.

Feine and colleagues (1988) used kinesiographic recordings of jaw movements during three different tasks in 10 asymptomatic subjects and 7 symptomatic patients with TMD, to evaluate the criteria used to diagnose jaw dysfunction. Jaw movement tasks involved jaw displacement, velocity, centric closure from “rest” position, and chewing. Although the kinesiographic recordings could not differentiate jaw movements between symptomatic and asymptomatic subjects, the authors did report that the average and
maximum jaw opening velocities were lower in patients with persistent jaw muscle pain than in matched controls. They were also unable to find differences in maximum displacement during empty open-close movements.

Nielsen et al (1990) analyzed functional and border movements in 24 controls and 26 TMD subjects with muscle pain. Both groups were studied with one of two tracking instruments- the Kinesiograph or the Sirognathograph, and detailed calibration curves were developed to determine the linearity of the two systems. Jaw movements were studied first in the sagittal plane when the subject moved the jaw from the inter-cuspal position (ICP) through maximum protrusion-retrusion and maximum open-close. Then in the frontal plane starting from ICP and moving laterally to right then left, followed by open-close movements, speech and mastication. The same three movements were repeated in the horizontal plane. Thirty-five parameters of jaw movement were measured in at least one of three planes.

The results indicated no significant differences in the length of protrusive movements, whilst deviation in protrusion was observed only in subjects with reciprocal click and joint degeneration. Significant difference between the length of the left and right laterotrusion, restrictions in the extent of movement, divergent paths of lateral movement, and restriction in the angle of lateral border movement were noted in patients with muscle pain only, compared with the arthromyalgic group. Maximum vertical opening did not differ significantly among subjects either with muscle pain only or with both muscle and joint pain between TMD and control groups. The speech envelope and the envelope of function were also similar to that of the controls. It was concluded that TMD subjects demonstrated greater variability in reproducing a predetermined jaw position and greater variability in locating a predetermined target position. Similar
results were reported by Ransjo and Thilander (1963) who found that the perception of jaw position was poorer in patients with a mixed (muscle-joint) disorder.

Tsolka et al (1994) analysed clinical, electromyographic (EMG) and kinesiographic assessment of women with TMD, compared with an age and gender-matched control group. The study was designed to examine the magnitude and pattern of opening and closing, velocity of jaw movement during normal and fast opening and closing, and the vertical, antero-posterior and lateral position of the jaw from “rest” or postural position to ICP. The results indicated no significant differences between the two groups with maximum vertical opening, maximum antero-posterior movements in the sagittal plane, and maximum deviation to left or right in the frontal plane. Different patterns of opening and closing did not show any differentiation between the groups, however maximum and average velocities during fast opening were significantly different. The vertical and antero-posterior movements of the jaw from postural position to ICP were also significantly different between the two groups.

In contrast with jaw tracking as a method to assess the difference in magnitude of jaw movement between symptomatic and asymptomatic subjects, several studies (Celic et al 2003, Hesse et al 1996, Tallents et al 1996, Miller et al 1999) have assessed differences through clinical examination using a millimeter ruler. These studies calculated jaw opening index as a gold standard for diagnosing TMD. The findings of these studies suggest that there is a statistically significant difference between TMD patients and healthy controls in maximum mouth opening (Celic et al 2003).
Conclusion

Reduced jaw movement is a strong indicator of TMD and helps to distinguish TMD patients from non-TMD controls (Reider 1978, Solberg et al 1979, Gross and Gale 1983, Dworkin and LeResche 1992). Studies using jaw tracking devices to measure jaw displacement did not show a clear differentiation between TMD patients and non-TMD controls. However clinical studies that measured the amount of jaw displacement using a millimeter ruler, showed a statistically significant difference. Clark et al (1986) measured vertical displacement by millimeter ruler showed a statistically significant difference between TMD patient and control groups. However, these results were not replicated in studies using jaw tracking. This lack of agreement between clinical and kinematic studies could be due to one or more factors associated with: the multifactorial nature of TMD; greater intra- and inter-subject variation; inconsistent study design of sample size, subject selection and short-comings in methods and analysis. Nielsen et al (1990) showed a significant difference in the amount of lateral displacement in a kinematic study, similar to the results showed in several clinical studies (Celic et al 2003, Hesse et al 1996, Tallents et al 1996, Miller et al 1999). However studies by Tsolka et al (1994) and Clark et al (1986) did not agree. Overall the studies do not provide a consensus on the diagnostic value of magnitude, accuracy and velocity of jaw movements.

Electromyographic activity

Electromyography (EMG) has been widely applied to estimate oro-facial muscle function or dysfunction (Dahlstrom 1989). Association between jaw muscle EMG with TMD signs and symptoms, as well as the biomechanical integrity of the TMJ, occlusion,
life stress, oral parafunctions, jaw movements, jaw posture, bite force and chewing efficiency, have been investigated to explore the pathophysiology of the jaw muscles in relation to the pathogenesis of TMD, and to search for definitive criteria for TMD diagnosis.

There are different methods of recording EMG activity (surface, hook or intramuscular fine wire electrodes), either to record total muscle activity or single motor unit activity. EMG activity can be determined in fast-opening, fast-closing, slow-opening and slow-closing phases and divided into phases with antagonist and agonist activity (Schwartz et al 1989). It would appear that evaluation of jaw muscle activity by surface EMG is a simple, non-invasive and potentially useful tool for diagnosing jaw dysfunction. However controversy about the usefulness of EMG for patients with TMD, concerns the reliability and validity of such assessment as a diagnostic and prognostic tool (Lund and Widmer 1989, Mohl et al 1990, Dworkin and LeResche 1992, Okeson 1996). EMG recordings with jaw movement recording are nevertheless accepted as a reliable research tool to study oro-motor function and underlying neurophysiology (Møller 1966, Luschei and Goldberg 1981, Lund et al 1989, Nakamura and Katakura 1995).

Variability in age, gender, overlying tissue thickness (with respect to surface EMG), occlusion, stress levels, intra- and inter-individual variation in jaw movements and lack of predictability of EMG recordings associated with jaw movement, electrode placement, and electronic equipment instability, cannot be overlooked. A standardized protocol that would take these variables into consideration could provide significant data, which may be of value in diagnosis and treatment of TMD. A review of the literature is necessary to understand the effects of experimental pain and clinical pain on jaw muscle EMG
activity, with the jaw at the clinically determined “rest” or postural position and during jaw movements.

It has been reported that experimental jaw muscle pain shares some clinical features of persistent clinical muscle pain, and may refer to the TMJ, jaw and teeth (Svensson and Graven-Nielsen 2001). Experimental pain studies are useful in evaluating the effects of pain, since the properties of pain are known, however this pain may not represent the actual nature of the pain experienced by TMD patients. Hence clinical studies evaluating jaw muscle activity in TMD subjects provides more realistic data to understand the pathophysiology of TMD.

**EMG activity during rest**

Several studies have recorded jaw muscle “resting” EMG activity. It is assumed that a “resting” muscle is characterized by the absence of EMG activity.

Møller (1966) suggested that with the jaw at rest, there is a low level EMG activity present in the jaw-closing muscles, in the range of 3 to 5 µV. Ashton-Miller et al (1990) studied experimental pain of the sternocleidomastoid muscle and found a significant increase in surface EMG activity. They attributed this increase in EMG to the mimetic response of the platysma muscle. Similar conclusions were made in a study by Stohler et al (1996), which looked at muscle activity when the intensity of pain was at least as great as that of chronic muscle pain patients. The results indicated a significant increase in “resting” muscle activity in jaw-closing muscles during pain. On the contrary Graven-Nielsen et al (1997) showed no increase in EMG activity at “rest”. Svensson et al (1998), in describing the effect of experimental muscle pain, found a transient increase in the
EMG activity 30-60s after the injection of hypertonic saline, with pain sensation lasting for 600s after the infusion. It was concluded that, there was a transient increase in “resting” EMG activity after infusion of hypertonic saline, but this increase did not correlate with intensity or duration of pain. This suggested that human experimental muscle pain per se is unable to evoke long-lasting muscle activity.

Some clinical studies evaluating “resting” muscle EMG indicate no significant differences between TMD and controls (Rough et al 1981, Sherman 1985, Floor et al 1991), whilst two studies by Intrieri et al (1994) and Paesani et al (1994) have even shown a slight decrease in “resting” EMG activity.

On the contrary, Kapel and co-workers (1989) compared “resting” EMG activity between age and gender-matched TMD patients and controls on bilateral frontalis, temporals and masseter muscles and found a significantly elevated baseline EMG activity for four of the six sites examined. Tsolka et al (1994) evaluated “resting” and maximum activity during clenching on bilateral masseter and temporals muscle with kinesiographic recordings. The results suggest that “resting” EMG activity of the TMD group was significantly greater for three of the four sites, than the controls. Similar results were reported by Brudette and Gale (1988), Liu et al (1999), suggesting hypertonic activity of jaw muscles in TMD patients.

A controlled study by Glaros et al (1997) found a statistically significant increase in “resting” EMG activity between the groups on three of six sites (right frontalis, left temporalis and left masseter). The other part of the study obtained a “cutoff” score, to accurately separate the two groups. The authors concluded that the application of a “cutoff” value resulted in misclassification of about one third of the TMD and non-pain
individuals, which does not support the use of “resting” EMG in distinguishing facial pain patients from non-pain controls.

**EMG activity during maximum clenching and active movement**

Measurement of maximum EMG activity during static and dynamic contraction of the jaw closing muscles has been widely used to examine motor function of the masticatory system. Experimental Studies by Svensson *et al* (1998) and Wang *et al* (2000) have shown jaw muscle pain induced by infusion of hypertonic saline to reduce the maximum voluntary occlusal forces and maximum EMG activity of the jaw closing muscles. Similar results were obtained by Ashton-Miller *et al* (1990) and Graven-Nielsen *et al* (1997), suggesting that experimental pain influences the recruitment pattern of motor units, which supports the hypothesis that pain inhibits the activity of the alpha-motor neuron pool.

Studies on static maximum muscle activity have described reduced maximum EMG activity (Sheikholeslam *et al* 1980, Clark *et al* 1984, Shi 1989, Kroon and Naeiji 1992, Visser *et al* 1995, Van der glas *et al* 1996, Liu *et al* 1999), reduced maximum voluntary occlusal force (Molin 1972, Shi 1989, Buchner *et al* 1992), and a shorter endurance time at sub-maximum contraction levels. These data support the pain adaptation model *i.e.*, the muscle pain through central nervous system influences, inhibits the maximum voluntary output of the contracting muscles (agonist muscle) whilst increasing the output to the opposing muscles (antagonist muscles).
Few studies have examined the EMG activity during movement. Lund et al (1991) studied motor function during empty open-close jaw movements and showed that the injection of hypertonic saline into the human masseter muscle has several effects:

- reduction of the agonist burst during empty open-close jaw movements;
- reduced velocity and amplitude of repetitive opening movements;
- some motor units, which were silent during jaw opening in the control period (before hypertonic saline was injected), showed an increased firing rate.

However, the presence of activity of masseter during empty open-close movement is still debatable.

Svensson et al (1996) described the effect of a single bolus injection into the unilateral masseter in 10 healthy subjects as reduced maximum jaw displacement in lateral and vertical axes and reduced maximum velocities during jaw opening and closing. In another study Svensson et al (1997) on bilateral injection of hypertonic saline into the masseter muscle reported a significant increase in antagonist EMG and a significant decrease in agonist EMG during mastication. These studies described the effect of hypertonic saline injection into the masseter muscle to have consistently shown

- a decrease in agonist EMG activity in the range of 10% to 15%;
- a small increase in antagonist EMG activity;
- significantly reduced mean opening and closing velocity.

Among the clinical studies comparing jaw muscle activity during active movement, Mongini et al (1989) assessed habitual mastication and its influence on jaw movement and masseter EMG activity in a group of 86 TMD patients, compared with the 12 control subjects. The results suggested that:
- symmetrical chewing cycles were lost, symptomatic TMD patients had a preferential side of chewing compared to controls and the excursive movements were restricted.
- reduced number of chewing cycles, and movements were often repetitive and markedly deviated towards the affected side.
- increased EMG activity of the masseter during opening, and an irregular distribution of the pattern of muscle activity during closing.

However the criteria for the regular pattern of jaw movement were not necessarily defined and as a result the differences with TMD patients were not clear.

Feine et al (1988) described the average and maximum jaw opening velocity to be lower in patients with persistent jaw muscle pain. There was no difference in the magnitude of empty open-close jaw movements.


Nielsen and colleagues (1990) examined muscle function in an attempt to identify any alteration in muscle recruitment in TMD subjects. The study involved 43 patients with clinically determined pain in temporalis, masseter and supra-hyoid muscles and 17 asymptomatic controls. Surface EMG recordings were made while subjects performed 16 tasks including rapid jaw closing, retrusion, ipsilateral laterotrusion and natural as well as contralateral mastication, whilst incisor movement was simultaneously monitored. Unfortunately, this study and the study by Møller et al (1984) had methodological inconsistencies where the control and patient groups were not matched. However the
study by Nielsen et al (1990), found that subjects with muscle pain used their jaw-closing muscles with lower frequency and amplitude than asymptomatic subjects.

Hellstrand and Hellsing (1995) conducted a pilot study of activation patterns and motor unit analysis of jaw muscles in TMD patients compared with an asymptomatic group. Ten TMD patients were divided into two groups:

- Group I was of five female patients (age range of 23 to 67 years) where twenty individual motor units in masseter, temporalis and digastric muscles bilaterally were studied. One patient showed clear signs of myopathy in the right temporal muscle.

- Group II consisted of 5 age and gender matched patients compared with a group of five asymptomatic controls. Surface EMG was recorded from superficial masseter, temporal and the anterior digastric muscles during jaw opening to maximum and jaw closure with maximum voluntary contraction. The patterns of jaw muscle activity of TMD patients was different from those of asymptomatic individuals and data were in agreement with Stohler et al (1985), Yemm (1985), Stohler and Ashton-Miller (1988) and Lund et al (1991), where increased activity was observed during jaw opening and jaw closing.

These studies support the Pain Adaptation Model described by Lund et al (1991), which proposes that the relative pattern of agonist and antagonist muscles are modified during pain. Cyclical motor activities such as breathing and mastication are generated by the brainstem central pattern generator (CPG). The model proposes that peripheral nociceptive inputs from skin, muscles and joints alter the motor command from the CPG. Although there is a direct excitatory pathway to alpha-motoneurones of agonist muscles, there is increased inhibition of the excitatory interneurones and increased
excitation of inhibitory interneurones to agonist alpha-motoneurones. The net effect results in decreased activity of agonist muscles. At the same time, an increased excitation of the excitatory interneurones and a decreased inhibition of inhibitory interneurones to antagonist muscle alpha-motoneurones, results in their increased activity. Thus with pain, the increased antagonist activity and decreased agonist activity would lead to a reduction in range and velocity of jaw movement to protect the injured part, to avoid further damage and promote healing.

Tsolka *et al* (1994) evaluated signs and symptoms of TMD in women in a controlled trial using specific clinical observations, EMG and kinesiographic recordings. The average and maximum opening velocities were less in patients than in controls and no significant differences existed between TMD patients and the control group in either maximum or average values of elevator muscle activity during clenching.

Pinho *et al* (2000) evaluated EMG activity of 40 TMD patients and compared the data with a similar study conducted on a comparable group of asymptomatic subjects by Rilo *et al* (1997). EMG activity during rest, clenching, lateral excursions and maximum unaided opening were recorded from the anterior temporalis, superficial masseter and anterior digastric muscles. Pinho *et al* reported the following:

- mean “resting” activity of the TMD group (2.52± 1.25 μV) was higher than the control group (1.92± 1.20μV)
- reduced mean clenching activity compared with controls (66.77 μV in TMD and 110.3 μV in control)
- significant differences in the left and right side mean activity (p<0.05) were observed in the superficial masseter, deep masseter and the anterior
digastric muscles, although not in the anterior temporalis.

Conclusion

There is no indisputable evidence in favour of increased EMG activity of jaw-closing muscles in clinical or experimental studies with craniofacial muscle pain. A small difference in "resting" EMG activity of 3 to 10 µV between TMD and control groups is inconclusive, and the clinical relevance of this increase has yet to be determined. There is good evidence that maximum EMG activity and occlusal force levels are reduced in TMD patients compared with controls (Svensson and Graven-Nielsen 2001). Experimental and clinical studies indicate that EMG activity of the agonist muscles is decreased and antagonist muscles increased during pain with jaw movements. Average and maximum velocity of jaw movements are reduced in the TMD group compared with controls.

Although most recent studies point towards the pain adaptation model (Lund et al 1991) and have analysed EMG data in terms of agonist and antagonist activity, because of the complexity of oro-motor function and the complex structure of jaw muscles, there is still uncertainty in defining muscle activity purely as antagonist or agonist. In addition, lack of a standardized technique is a further limiting factor in understanding the effect of jaw muscle pain on jaw motor activity.

There is a varied understanding of the magnitude, accuracy and velocity of jaw movement and EMG activity during these movements. Lack of controlled clinical studies, the multifactorial nature of TMD, lack of standardization of recording devices and varying methodologies account for the varied results. Few studies have executed
standardizing jaw movements and evaluating differences in magnitude on maximum excursion and the ability to carry out prescribed movements.

In view with this, a pilot study was designed to minimize methodological error. Each subject was assessed by the RDC/TMD protocol, jaw movements were monitored with the JAWS-3D (a validated research tool for jaw kinematic studies) which records movement of the jaw as a rigid body in 6 degrees of freedom. Jaw movements were to maximum excursions and EMG recordings of superficial jaw muscles were made during these movements.
AIM

The aim of this study was to determine whether there were differences in a group of symptomatic TMD patients (TMD group) compared with a group of asymptomatic subjects (control group) in jaw muscle EMG, and in the extent and reproducibility of prescribed jaw movements (following a visual cue) carried out at different speeds (slow and fast).
HYPOTHESES

1. There will be a difference in the extent of mandibular movements and the ability of the jaw to reproducibly follow prescribed slow and fast movements, between TMD and control groups. The TMD group will show:
   - greater restriction of opening, laterotrusive and protrusive movements
   - decreased ability to move the jaw in a defined direction
   - greater variability with jaw movement to maximum excursion during slow and fast movement.

2. Compared with the control group, EMG recordings from superficial jaw muscles in the TMD group will show:
   - a reduced EMG activity during the out-going phase of open-close, laterotrusive and protrusive movements
   - reduced EMG activity of the digastric muscle and increased EMG activity in the masseter muscle during the out-going phase of open-close jaw movements.
METHODOLOGY

Subjects

Nine symptomatic TMD patients, 8 females and one 1 male between the ages of 21 and 54 years comprised the TMD group. Nine asymptomatic volunteers, 6 females and 3 male between the ages of 26 and 38 years comprised the control group. Symptomatic subjects were recruited from patients attending the Oro-facial Pain Clinic of Westmead Center for Oral Health and asymptomatic subjects were selected from students and staff from the University of Sydney.

The data for 2 of the TMD patients and 4 of the control subjects were obtained from the discontinued study of previous MDSc (Prosthodontics) student Dr. Anil Kontham. The Western Sydney Area Health Service Ethics Committee and the Human Ethics Committee of the University of Sydney approved the research.

Inclusion and exclusion criteria

Inclusion criteria

- Subjects who were willing to participate in the study (each subject was given an overview of the research before their acceptance)

- Subjects were assessed as asymptomatic or symptomatic using clinical examination and analyzing Axis I and II RDC/TMD (Research Diagnostic Criteria / Temporomandibular Disorders) questionnaires (Dworkin and LeResche 1992). The RDC/TMD protocol incorporates a clinical examination and self-reporting of symptoms and associated psychosocial features
- Age range of subjects was 20 to 55 years - the most common age range for TMD patients (Solberg 1986, Laskin and Block 1986, Howard, 1991)
- Subjects were selected with fluent English (reading, writing and listening)
- Subjects were required to have discontinued any treatment (active and passive stretch exercise; use of splint etc.) that may influence recordings.

Exclusion criteria

- Subjects with signs or symptoms of TMD that were sufficiently severe to prevent them from performing the required jaw movements
- Subjects taking medication that had an effect on neuromuscular function (analgesics, anti-inflammatory, anti-psychotics)
- Subjects with health problems that would contraindicate their participation in the study - such as severe heart or respiratory problems, hypertension, rheumatic fever, diabetes, infectious diseases, bleeding disorders.

Materials

Metal clutches

Metal clutches (see figure 2,3) were constructed in three parts:

- titanium facing with an extension rod - the facing was directly attached to the maxillary and mandibular arches;
- rigid aluminium tube attached to the extension rod from the titanium facings;
- brass wire that was attached to the free-end of the aluminium tube.

The clutch assembly allowed attachment of the target frames of the opto-electronic recording device to selected anterior teeth of both jaws. The facings were with
acrylic resin to allow close approximation of the labial surfaces of the specified maxillary and mandibular teeth.

**Target frames**

Target frames were constructed of lightweight plastic shaped as a triangle with three light-emitting diodes (LEDs) positioned at the three corners of the triangle. One target frame was attached to each dental arch.

**Jaw tracking**

The optoelectronic jaw tracking system (JAWS-3D) used in this study was developed by Metropolis AG (Zurich, Switzerland) with a sampling rate of 67 samples per second. Three optical cameras positioned laterally from the subject recorded jaw displacement in six degree of freedom. The position of a predetermined point was displayed on a computer screen in the horizontal plane as a dot that moved in real time as the subject moved their jaw. Jaw movement data was digitized and stored for off-line analysis.

**Surface Electrodes**

Silver to silver chloride disc electrodes (Duotrode), manufactured by Myotronics (Seattle, USA) were used to record surface EMG activity of the

![Surface Electrode Image](image)

**Figure 1**- Picture of surface electrode
selected jaw muscles (see figure 1). A conductive gel was placed between each electrode and the prepared skin surface as is customary to enhance skin surface electrode contact.

**Adhesive tape**

Adhesive tape (Johnson and Johnson) was used to secure the wire extensions from each electrode.

**Acrylic resin**

Pattern resin (Duralay, USA) was used to link components of the clutches and to modify their contour to the specific labial shape of the selected anterior teeth of individual subjects.

**Adhesive liquid**

Superglue (Magic Superglue, Victoria, Australia) was used to attach the facings of the clutches modified by the incremental placement of acrylic resin to the teeth.

**Pre-preparation**

**First visit**

After obtaining informed consent from each subject, impressions of maxillary and mandibular arches were made with alginate impression material. Study casts were prepared and articulated at ICP on a semi-adjustable articulator (Denar Mark II, Denar Corp. USA).
Laboratory Preparation

Metal facings were modified to conform to the dental arch of each subject and to match the labial and/or buccal surface of two or three anterior teeth on the right. Duralay resin was used either directly in the mouth or in the laboratory on the articulated casts. The metal facings were made free of occlusal contact and with a 20mm length and 1mm diameter extension attached in the center (see figure 2).

![Figure 2- Metal clutches customized with Duralay](image)

An aluminium tube of approximately 80mm in length, 2mm in external diameter and 1mm internal diameter was attached to the sprue of the metal facings with Duralay resin. The free end of the rigid tube was connected to a brass wire of 1mm diameter and 25 mm length. The tube was further split in the middle and joined with Duralay resin to allow electrical isolation (see figure 3). The aluminium tube may be carefully adjusted to align the target frames parallel to the sagittal plane and Frankfort horizontal plane. The target frames carrying light emitting diodes were attached to the brass wire end of the aluminium tubes (Murray et al 1999).
**Figure 3**- Metal clutches showing, metal facings modified with Duralay (A), aluminium tube (B) attached to the metal facing and brass wire (C).

**Second visit**

During recordings, subjects were placed in a standardized calm environment. They were asked to arrive 30 minutes before recordings and during this time were made aware of all aspects of the procedure and were assessed using the RDC/TMD protocol. Each subject completed the following forms:

- Standardized consent forms used in the Research Unit and Westmead Center for Oral Health
- Visual Analog Scale (VAS) was completed after each trial during recordings. A VAS represented the subject’s pain on a 10 cm scale (0 represents no pain and 10 represents the worst pain imaginable).

These assessments were carried out away from the recording site.

**Procedure**

**Attachment of the clutches and surface electrodes**

Subjects were escorted to the clinical recording area and allowed to sit comfortably in a dental chair.
Surface electrodes placement

Bilateral masseter and anterior temporalis; and unilateral digastric muscle sites were located using anatomical landmarks and digital palpation. The skin overlying the muscle sites was prepared by wiping with a 70% isopropyl alcohol swab (Medi-swab, Smith and Nephew, Australia) to remove surface oil and to provide a more effective electrode contact. Surface disc electrodes were placed along the long-axis of each of the muscle and a conductive gel was injected under the disc. The electrodes were secured with celloidin adhesive tape (see figure 4).

![Surface electrode placement frontal and lateral views](image)

Figure 4- Surface electrode placement frontal and lateral views

Attachment of clutches

The prefabricated customized clutches were placed in position to check the emergence angle and parallelism of the target frames to the sagital plane. Clutches were attached to
three of the right maxillary and mandibular anterior teeth with adhesive (Magic Superglue). A line representing the Frankfort horizontal plane was drawn on the right side of the face, with the superior border of the tragus of the ear and the infra-orbital notch as landmarks. The target frames were aligned parallel to the Frankfort’s horizontal plane (see figure 5).

**Figure 5.** Metal clutches and LED’s attached (frontal and lateral view)

Subjects were moved from the dental chair to a recording chair and were required to sit upright without head support in a comfortable position facing the monitor screen. Subjects were asked to remain in this position during the recordings. All recordings were performed with the teeth slightly apart beginning in and finishing at postural jaw position.

**Recording of Jaw movements and EMG**

**Jaw movement recording**

Two lightweight target frames were attached by screws to the free ends (brass wire) of the maxillary and mandibular clutches. Target frames were adjusted to be parallel to the sagittal and Frankfort horizontal planes. The target frames were connected to the optical cameras. Before recording, two reference points were determined using a portable LED namely:

- **primary reference point** - the mid-incisor point of the mandibular teeth (MIPT), as the point on the target frames in line with the mid-incisor less the actual distance from the mid-incisor

- **Secondary reference point** - the approximate central point of the condylar head (25 mm medial to the skin surface, along the approximate transverse axis)

The MIPT was displayed as a dot (MIPT dot) on the monitor screen enabling the subject to follow on-line the movement of LEDs as they appear on the monitor screen along the line of LEDs.

Since jaw movement was recorded in relation to the maxilla, any associated head movement did not influence jaw movement measurements. Subjects were required to swallow and relax their jaw with their lips lightly touching to achieve postural jaw position. Jaw movements were standardized by having subjects move the MIPT dot on the monitor to follow a computer-controlled target. The target in these standardized movements was an LED as part of a linear group of 15 LEDs positioned on a monitor screen and to the side of the trajectory of the MIPT dot. Only one LED was illuminated at any one time. Illumination of successive LED's was controlled by a script written in Spike
2 software (Cambridge Electronic Design, Cambridge, UK) and run on the CED system (see figure 6).

![Figure 6- Jaw-movement demonstration](image)

Before recordings, subjects were familiarized with the required jaw movement sequence by asking them to perform the jaw movements. This also allowed the LEDs to be aligned along the direction of movement in the horizontal plane. During each recording, each movement was repeated a minimum of 5 times and carried out at two rates of movement - slow (1.3 mm/s of jaw displacement) and fast (6.5 mm/s of jaw displacement). The rate of jaw movement was adjusted to slow and fast by changing the time-off duration between each LED and the time-on duration of each LED. The perception of pain on jaw movement was measured using a VAS at the completion of each movement. Symptomatic subjects were asked to perform open and close movements in two steps, first until they felt pain, and second to move to maximum excursion even though they felt pain (5 movements each of slow and fast were completed).

Jaw movements

Prescribed jaw movements of maximum open-close, protrusive-retrusive and right and left lateral excursive movements were carried out.
jaw movements were set to the maximum displacement in each direction

jaw movements were repeated a minimum of 5 times at slow and fast rates

each trial began with a holding period of 2s in postural jaw position followed by sequential illumination of LED’s the time of which is set different for slow and fast jaw movements

subjects were asked to hold the MIPT dot within the boundaries of the illuminated LED for the holding period of each step in the displacement sequence

this sequencing was followed until each subject reached maximum jaw displacement. On reaching the last LED, the jaw was held for 5s, and then returned in the same sequence to postural jaw position

This complete sequence was termed a trial. A minimum of 5 trials were completed, each with at least a 1 minute rest period between successive trials.

**EMG recording**

Bipolar surface electrodes were connected to the CED data acquisition equipment through an amplifier (SA Instruments, San Diego, USA) that allowed high and low pass filtering as well as individual channel gain changes. The data acquisition equipment was the Micro 1401 manufactured by Cambridge Electronic Design (CED, Cambridge, UK). The sampling rate was set to a minimum of 5000 samples/s.

Analysis of the EMG data was performed off-line.
Data Analyses

Jaw movements

The files created by JAWS-3D were converted to data files and the trajectories of the primary points were plotted along the anterior-posterior (x), medial-lateral (y) and superior-inferior (z) axes for visual inspection. Each data file consisted of the amount of displacement for each of x, y and z-axes and the timing of each of these values.

Quantitative and qualitative analyses were undertaken to determine the amount of jaw displacement and the subject's ability to track a target during jaw movements. The data was obtained by averaging 5-6 trials of the same movement at two different rates of movement, slow and fast, within the two groups, TMD and control.

Axis of interest (x, y or z-axis depending on the movement) was extracted from this average data file and plotted. The TMD and control subject's plotted data was overlayed separately to provide a graphical display of the group's performance in each task at each speed of movement.

The movement data from JAWS-3D was analysed to compare accuracy of mandibular movement between TMD and control groups by calculating the coefficient of variance. First, every 50th point of the data was obtained for every trial of each movement, and then the coefficient of variance was calculated in the x, y and z-axes by dividing the standard deviation of 5 same movement trials (for example, slow protrusion) by their mean and multiplying by 100. The coefficient of variance values for each movement was then plotted to qualitatively determine the difference in variance between the TMD and control groups.
EMG

The raw EMG activity recorded from each muscle was rectified and smoothed with a digital filter (Butterworth filter; cut off: 2 Hz). Only the out-going phase of the data was selected for analysis. The start and end times of each out-going phase of the data were extracted from the JAWS-3D data and the root mean square (RMS) values were calculated for each muscle for each movement. The mean and standard deviation of each movement were obtained for both TMD and control groups. RMS values for each movement were tested for normality of distribution and the data was not found normally distributed. As a result, a non-parametric Mann-Whitney U test was used to test the statistical significance of the EMG activity between TMD and control groups. A p value of <0.05 was considered to be statistically significant. Group variance was calculated using the RMS values of each task trial for all subjects within the group for each muscle in each movement to determine the intra-subject variability.

VAS Score

VAS scores, to determine the intensity of the pain were completed after each trial of the recordings, and plotted against time for each subject.
RESULTS

RDC/TMD

The control group of nine asymptomatic subjects contained 6 female and 3 male subjects with a mean age of 32 ± 4 years. Control group subjects were assessed by the RDC/TMD protocol as free of TMD signs or symptoms.

The symptomatic TMD group comprised 8 female and 1 male with a mean age of 37 ± 11 years. Specific features of the TMD group:

- Subject A, E, F, G, H and I presented with bilateral symptoms.
- Four of these 6 subjects (F, G, H and I) had myofascial pain with limited jaw opening and right and left joint arthralgia- with right and left joint tenderness, painful excursive movements, restricted jaw movements (subject F and H) and at least 3 muscle sites tender to palpation.
- Subject A and E presented with myofascial pain with limited jaw opening and right joint disc displacement with reduction. These 2 subject had more severe symptoms and a marked restriction in jaw displacement.
- Subject B was diagnosed with right side myofascial pain.
- Subjects C and D were diagnosed with myofascial pain with limited jaw opening on the left and left arthralgia.

A greater range in the age and standard deviation was noted within the TMD group compared with the control group. One common feature with TMD group was, all the subjects were symptomatic on active movement and most of the subject had limited jaw displacement.
**Jaw movements**

Qualitative analysis of jaw movement was performed for each task. Graphical representation of the average of all trials in each task for each subject were layered one upon the other for both TMD and control groups.

**Right lateral**

**Slow movement**

On slow right lateral movement, the control group showed a precise separation of task as rest, out-going, middle hold and return phases, which was less evident in the jaw movements of the TMD group. The controls showed consistent out-going and inconsistency in the return phase of jaw movements and 2 subjects showed some variability in the out-going phase (see figure 7b). TMD subjects showed greater inconsistency in the ability to move the jaw in a specified direction.

![Graphical representation of the y-axis (mediolateral) during slow right lateral movements for TMD (a) and control (b) groups (x-axis and y-axis represents time and displacement respectively).](image)

**Figure 7**. Graphical representation of the y-axis (mediolateral) during slow right lateral movements for TMD (a) and control (b) groups (x-axis and y-axis represents time and displacement respectively).
Four subjects showed a marked restriction in movement from 2 to 6mm (see figure 7a). TMD subjects had maximum right lateral movement in the range of 2 to 13 mm (7.4 ± 3.7 mm) and controls of 7 to 14 mm (9.8 ± 1.9mm).

Fast movement

Fast right lateral movement, the control group showed distinct phases of jaw movement (rest, out-going, hold and return phase), but this was less pronounced in the TMD group (see figure 8b). Four of 9 TMD subjects were unable to stabilize the jaw during the hold phase and a limited range of movements compared with controls (see figure 8a). The range of movement for the control group was 7.5 to 13 mm (10 ± 1.8 mm) and for the TMD group was 1.5 to 14 mm (7 ± 3.3 mm).

Figure 8a. Graphical representation of the y-axis (mediolateral) during fast right lateral movements for TMD (a) and control (b) groups (x-axis and y-axis represents time and displacement respectively).
Left lateral

Slow movement

The TMD group showed greater difficulty on slow left lateral movements compared with the controls. Of the controls, 3 subjects showed inconsistency in the out-going, hold and return phases similar to TMD subjects (see figure 9b), however showed a normal range of movement. Four of the TMD subjects showed greater restriction in jaw movement (see figure 9a). Controls showed a range of movement of 9 to 13 mm (11.3 ± 1.1 mm) and the TMD group of 2 to 14 mm (8 ± 4 mm). The TMD group showed greater variation in the return than the out-going phases within the TMD group and compared with controls.

![Graphical representation of y-axis (mediolateral) during slow left lateral movements of TMD (a) and control (b) groups (x-axis and y-axis represents time and displacement respectively).](image)

**Figure 9.**

Fast movement

Eight of 9 control subjects showed reproducible rest, and for out-going, hold and return phases. One subject showed difficulty in maintaining the hold phase (see figure
The range of fast movements for the controls was 9 to 13 mm (11.3 ± 1.1 mm). Most TMD subjects showed a similar pattern as the control group. Four of 9 TMD subjects had difficulty in maintaining the hold phase, and 1 subject showed greater variability in jaw movements throughout this task. The TMD group showed greater variation in the return phase compared with controls. Three out of 9 TMD subjects showed limitation in the jaw movement (see figure 10a). Jaw movement for the TMD group ranged from 2 to 14 mm (8.6 ± 4.4 mm).

![Graphical representation of the y-axis (mediolateral) during fast left lateral movements of TMD (a) and control (b) groups](image)

**Figure 10** - Graphical representation of the y-axis (mediolateral) during fast left lateral movements of TMD (a) and control (b) groups (x-axis and y-axis represents time and displacement respectively).

**Protrusion**

**Slow movement**

The control group showed smooth movement compared with the TMD group, with exception of 3 subjects who were not able to stabilize the jaw during the middle hold period (see figure 11b). Protrusive movements for the control group were 6 to 12 mm (8.5 ± 1.9 mm). The TMD group showed greater difficulty in slow protrusion and
restricted movement of 3 to 8 mm (5.8 ± 1.7 mm). The ability to track the target for the TMD group showed considerable variation, except for 1 subject where movement was similar to the control group (see figure 11a).

![Graphical representation of the x-axis (anteroposterior) during slow protrusive movements for TMD (a) and control (b) groups](image)

(a)  
(b)

**Figure 11.** Graphical representation of the x-axis (anteroposterior) during slow protrusive movements for TMD (a) and control (b) groups (x-axis and y-axis represents time and displacement respectively).

**Fast movement**

TMD and control groups showed similar variation in fast protrusion. Six TMD subjects performed the fast movement accurately, with the exception of 3 subjects. Of these, one showed a variable movement through the task, the second showed lack of a stable hold period, and the third showed variable return phase movement (see figure 12a). The TMD group showed restricted movement compared with controls, with a range of 3 to 8 mm (5.9 ± 1.8 mm); compared with 5 to 11 mm (8.7 ± 2.2 mm) for controls (see figure 12b).
Figure 12.- Graphical representation of the x-axis (anteroposterior) during fast protrusive movements for TMD (a) and control (b) groups (x-axis and y-axis represents time and displacement respectively).

Maximum open-close

Slow movement

During slow maximum open-close movement, both TMD and control groups showed greater variability; in addition the TMD group showed greater difficulty in performing maximum open-close. TMD and control groups did not have a distinct rest, out-going, hold or return phase. Of 9 TMD subjects, data could (only) be obtained for 8 because of equipment error. Six of the 8 TMD showed variable jaw movements, and 2 did not return to postural position because the sampling period of the recording system was exceeded (see figure 13 a and b). However the control group showed smooth movements throughout all tasks. The TMD group movement was 17 to 47 mm (30.8 ± 8.2 mm) and for the controls 17 to 49mm (37.4 ± 9.7mm).
Figure 13. Graphical representation of the z-axis (vertical) during slow maximum open-close movements for TMD (a) and control (b) groups (x-axis and y-axis represents time and displacement respectively).

Fast movement

The TMD group showed greater variation in movement compared with the controls (see figure 14 a and b). Most TMD subjects were unable to hold the jaw between outgoing and return phases; however for those who were able to do so, the hold phase was not consistent in stabilizing the jaw.

Figure 14. Graphical representation of the z-axis (vertical) during fast maximum open-close movements for TMD (a) and control (b) group (x-axis and y-axis represents time and displacement respectively).
Only 7 of the TMD patient data could be analysed due to equipment error. The TMD group movement was 24 to 50 mm (33.5 ± 7.6 mm), and controls 32 to 52 mm (40 ± 7.2 mm).

A qualitative comparison of slow and fast open until pain and maximum open-close jaw movements for the TMD group showed differences with greater variability for slow open until pain and maximum open-close in tracking a target (see figure 15 a and b). In the TMD group, fast open until pain showed a similar pattern to maximum open-close of the control group. Most TMD subjects in the fast maximum open-close movement did not show a hold period (see figure 16 a and b). Slow open until pain were inconsistent and showed a similar variability to the slow maximum open-close trials.

![Graphical representation of the z-axis (vertical) during slow maximum open-close (a) and slow open until pain (b) movements in the TMD group (x-axis and y-axis represents time and displacement respectively).](image)

**Figure 15-.** Graphical representation of the z-axis (vertical) during slow maximum open-close (a) and slow open until pain (b) movements in the TMD group (x-axis and y-axis represents time and displacement respectively).
Figure 16. Graphical representation of the z-axis (vertical) during fast maximum open-close (a) and fast open until pain (b) movements in the TMD group (x-axis and y-axis represents time and displacement respectively).

Conclusion

In summary, TMD subjects on right lateral jaw movement showed reduced ability to accurately track, compared with controls and this difference was more pronounced with slow jaw movements. Both the groups showed greater variability during the return phase compared with the out-going phase. During left lateral movement, the TMD group showed greater difficulty during slow compared with fast movements. The TMD group showed greater variation on the return phase compared with the out-going phase. With protrusion, the TMD group showed greater difficulty with slow movement compared with controls. However, fast protrusion did not show any differences between the groups except in the amount of displacement. During open-close, the TMD group showed greater variance in ability to track the target compared with controls. On slow and fast maximum open-close movement, the TMD group was not able to perform or stabilize the jaw during the hold phase.

The overall mean, standard deviation and range of mandibular movements for both the TMD and control groups are shown in Table-1. The mean and standard deviation was
derived from the mean trials of each subjects in each group. In general, the TMD group showed a reduced mean, greater range and standard deviation for jaw displacement compared with controls. However these differences were noted greater for the right and left lateral movements in the TMD group compared to protrusive and open-close movements.

<table>
<thead>
<tr>
<th>Movements</th>
<th>Control range (mean ± SD)</th>
<th>TMD range (mean ±SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Right lateral movement</strong></td>
<td>Slow 7-14 mm (9.8± 1.9 mm)</td>
<td>2-13mm (7.4±3.7 mm)</td>
</tr>
<tr>
<td></td>
<td>Fast 7.5-13 mm (10 ± 1.8mm)</td>
<td>1.5-14 mm (7 ± 3.3 mm)</td>
</tr>
<tr>
<td><strong>Left lateral movement</strong></td>
<td>Slow 9-13 mm (11.3 ± 1.1 mm)</td>
<td>2-14 mm (8 ± 4 mm)</td>
</tr>
<tr>
<td></td>
<td>Fast 10-13 mm (11.3 ± 1.1 mm)</td>
<td>2-14 mm (8.6 ± 4.4 mm)</td>
</tr>
<tr>
<td><strong>Protrusion</strong></td>
<td>Slow 6-12 mm (8.5 ± 1.9 mm)</td>
<td>3-8 mm (5.8 ± 1.7 mm)</td>
</tr>
<tr>
<td></td>
<td>Fast 5-11 mm (8.7 ± 2.2 mm)</td>
<td>3-8 mm (5.9 ± 1.8 mm)</td>
</tr>
<tr>
<td><strong>Open – close movement</strong></td>
<td>Slow 17-49mm(37.4 ± 9.8 mm)</td>
<td>17-47 mm (30.8 ± 8.2 .mm)</td>
</tr>
<tr>
<td></td>
<td>Fast 32-52mm(40±7.2 mm)</td>
<td>24-50mm (33.5 ± 7.6 mm)</td>
</tr>
</tbody>
</table>

**Table 1** Range, mean and standard deviation (SD) showing the amount of displacement in the TMD and control groups.

**Coefficient of variance**

The coefficient of variance calculated from the average of all trials for each task for TMD and control groups were plotted separately and compared to determine the variability between the groups to track a moving target. The x-axis represents data points expressed as numbers (1,2, 3...) and the y-axis the coefficient of variance values. The y axis has been standardized for ease of comparison. The x axis is dependent on time and may differ between groups.
Right lateral

Slow movement

The TMD group showed greater variability in both out-going and the return phases. Subjects A and E showed restricted displacement and greater variability in the jaw movement (see figure 17a).

![Graph](image)

**Figure 17**- The coefficient of variance of TMD (a) and control (b) groups during slow right lateral movements (x-axis and y-axis represents 50th point / time and coefficient of variance respectively).

The variability in the return phase for the control group (subject L, M, O and Q) was greater than the TMD group. The consistency of jaw movement during the hold phase only varied slightly between the TMD and control groups.
Fast movement

The TMD group showed greater variation in the return phase (7 out of 9 TMD subjects) and a slightly greater variation in the hold phase.

![Graphs showing data for TMD and control groups.]

**Figure 18**- The coefficient of variance of TMD (a) and control (b) groups during fast right lateral movements (x-axis and y-axis represents 50th point / time and coefficient of variance respectively).

Four of 9 control subjects (K, L, M and R) showed greater variation during the outgoing and return phases (see figure 18 a and b).
Left lateral

Slow movement

The TMD group showed greater variation during the entire task compared with the controls. There was greater variation in slow left lateral movement compared with the right lateral for the TMD group.

![Graph of TMD group](image)

**Figure 19** - The coefficient of variance of TMD (a) and control (b) groups during slow left lateral movements (x-axis and y-axis represents 50th point/time and coefficient of variance respectively).

However in the control group only the return phase showed variance which was noted less than the return phase of the TMD group (see figure 19 a and b).
Fast movement

Left lateral fast movements showed greater variability during hold and return phases for the TMD compared with the controls. Most TMD subjects showed a variable hold period and greater variation on the return phase.

Figure 20- The coefficient of variance of TMD (a) and control (b) groups during fast left lateral movements (x-axis and y-axis represents 50th point / time and coefficient of variance respectively).

Four of the control subjects (K, N, Q and R) showed a variability in the jaw movements during the out-going and return phase, however showed a consistent hold phase (see figure 20 a and b).
Protrusion

Slow movement

Both TMD and control groups showed variation throughout the tasks. In TMD group 4 (B, C, E and G) of 9 subjects showed greater variability in the jaw movements, where as in control group 5 (J, K, L, Q and R) of 9 subjects showed greater variability (see figure 21 a and b).

Figure 21- The coefficient of variance of TMD (a) and control (b) groups during slow protrusive movements (x-axis and y-axis represents 50th point / time and coefficient of variance respectively) .
Fast movement

The TMD group showed greater variability in the return phase compared with controls, while the controls showed greater variation in the outgoing phase. The variability of both groups was higher during fast compared with the slow protrusion (see figure 22 a and b).

![TMD group graph](image1)

![Control group graph](image2)

**Figure 22** - The coefficient of variance of TMD (a) and control (b) groups during fast protrusive movements (x-axis and y-axis represent 50th point / time and coefficient of variance respectively) .
Maximum open-close

Slow movement

The TMD group showed greater variation in movement compared with the controls. The variability was greater for the return phase in the TMD group (see figure 23a). The controls were more consistent in the outgoing and hold phases and showed a slight variation in the return phase (see figure 23b). Similar results were seen with the

![Graph: TMD group](image)

![Graph: Control group](image)

**Figure 23**—The coefficient of variance of TMD (a) and control (b) groups during slow maximum open-close movements (x-axis and y-axis represents 50th point / time and coefficient of variance respectively).

graphical display of the mean jaw movement for the slow maximum open-close tasks described earlier (see page 40 and 41).
**Fast movement**

In the fast maximum open-close movements, the coefficient of variance was greater for the TMD group. As with other jaw movements the TMD group showed a greater variation in the holding and return phases compared to the control group (see figure 24a and b). The coefficient of variance for open-close until pain was compared with the maximum open-close in the TMD group.

![Graph a: TMD group](image)

![Graph b: control group](image)

**Figure 24-** The coefficient of variance of TMD (a) and control (b) groups during fast maximum open-close movements (x-axis and y-axis represents 50th point / time and coefficient of variance respectively).

There was a similar variability between the two open-close movements irrespective of the perception of pain (see figure 25 a and b, 26 a and b).
Figure 25- The coefficient of variance of the TMD group during slow maximum open-close (a) compared with slow open-close movements until pain (b) (x-axis and y-axis represents 50th point / time and coefficient of variance respectively).

However, one significant difference was the slow tracking variability, which was greater for the return phase in the slow open-close movement until pain compared with the open-close to the maximum through the pain.
Figure 26- The coefficient of variance of the TMD group during fast maximum open-close (a) compared with fast open-close movements until pain (b) (x-axis and y-axis represents 50th point / time and coefficient of variance respectively).

EMG

Mean RMS values for each muscle for each task for control and TMD groups were calculated (see tables 2-6). The differences between the TMD and control groups were analysed using four common tasks at two speeds for the 5 muscles. Of the 40 sets of data, 29 showed reduced mean EMG and 11 showed increased mean EMG activity for
TMD group. Overall the TMD subjects showed a greater reduction in mean EMG activity.

The RMS values were analyzed using a Mann-Whitney U test to determine statistical significance. The data was further analyzed by calculating the group variance for intra-group variation. These results obtained are shown in tables 2 to 6.

Of 29 results with reduced mean EMG activity, 21 were statistically significant reduction in the TMD group. Of the 11 TMD’s that showed an increase in mean EMG, 2 (slow right and fast right movement on right temporalis) were statistically significant (see table 2).

<table>
<thead>
<tr>
<th></th>
<th>TOTAL TASK</th>
<th>SIGNIFICANT TASKS(P) / TOTAL TASKS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduced mean EMG in TMD group</td>
<td>29/40</td>
<td>21/29*</td>
</tr>
<tr>
<td>Increased mean EMG in TMD group</td>
<td>11/40</td>
<td>2/11*</td>
</tr>
<tr>
<td>Right and left lateral movements</td>
<td>20/40</td>
<td>13/20*</td>
</tr>
<tr>
<td>Protrusive movements</td>
<td>10/40</td>
<td>4/10*</td>
</tr>
<tr>
<td>Open-close movements</td>
<td>10/40</td>
<td>6/10*</td>
</tr>
<tr>
<td>Slow movements</td>
<td>20/40</td>
<td>12/20*</td>
</tr>
<tr>
<td>Fast movements</td>
<td>20/40</td>
<td>11/20*</td>
</tr>
</tbody>
</table>

Table 2. Analyses of mean EMG activity and total number of statistical significant tasks in different movements (* = p value <0.05).

For lateral movements, the analysis showed 13 of 20 results for all the muscles had statistically significant differences in EMG activity. Of 10 protrusive recordings, right and left masseter EMG 4 tasks were significantly greater for controls compared with the TMD group. Similarly, in 10 open and close movements, 6 showed a statistically significant difference between the control and TMD groups. Of 20 slow movement EMG values, 12 were significantly different between TMD and controls. Of 20 fast
movements, EMG of 11 showed a statistically significant difference between TMD and controls (see table 2).

EMG activity for TMD and control groups showed greater variance for the controls: for the digastric muscle - fast right, slow open, fast open (see table 2); and for left masseter- fast left, slow and fast protrusive (see table 5) movements. These 6 results showed a statistically significant differences between control and TMD groups. Of the TMD group EMG: for the digastric muscle - the slow and fast protrusive (see table 2); for right temporalis- the slow right (see table 4); and for right masseter- slow right and fast right (see table 6) movements, EMG activity showed greater variance compared with the control group. However of these tasks only one - slow right movement of the right temporalis showed a statistically significant difference. In summary, the greater group variance between control and TMD group indicate greater EMG activity for controls compared with TMD group.

**Digastric muscle**

In 6 of the 8 results, the data showed a statistically significant difference. The mean EMG activity was greater for 6 of the 8 results in the controls compared with the TMD group. The exceptions were slow and fast protrusive tasks where the mean EMG activity was greater in the TMD group. The difference in mean EMG activity was not statistically significant, which could be related to the greater variance in the TMD group. Similarly, for slow and fast open and fast right there was greater variance within the control group compared with the TMD group (see table 3). In jaw opening, the digastric muscle showed a decrease in mean EMG activity in the TMD group compared with the controls.
<table>
<thead>
<tr>
<th>Movements</th>
<th>p-value (*)</th>
<th>Group Variance</th>
<th>Control (mean)</th>
<th>TMD (mean)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Control</td>
<td>TMD</td>
<td></td>
</tr>
<tr>
<td>Slow right</td>
<td>0.048 *</td>
<td>0.458 †</td>
<td>0.375</td>
<td>0.8910</td>
</tr>
<tr>
<td>Fast right</td>
<td>0.003 *</td>
<td><strong>1.804 †</strong></td>
<td>0.804</td>
<td>1.5239</td>
</tr>
<tr>
<td>Slow left</td>
<td>0.000 *</td>
<td>0.664 †</td>
<td>0.246</td>
<td>1.0673</td>
</tr>
<tr>
<td>Fast left</td>
<td>0.003 *</td>
<td>0.595 †</td>
<td>0.500</td>
<td>1.1204</td>
</tr>
<tr>
<td>Slow protrusion</td>
<td>0.107</td>
<td>0.031</td>
<td><strong>1.080 †</strong></td>
<td>0.5579</td>
</tr>
<tr>
<td>Fast protrusion</td>
<td>0.137</td>
<td>0.110</td>
<td><strong>0.809 †</strong></td>
<td>0.8277</td>
</tr>
<tr>
<td>Slow open</td>
<td>0.000 *</td>
<td><strong>2.407 †</strong></td>
<td>0.638</td>
<td>3.1405</td>
</tr>
<tr>
<td>Fast open</td>
<td>0.000 *</td>
<td><strong>4.517 †</strong></td>
<td>0.352</td>
<td>4.0109</td>
</tr>
</tbody>
</table>

**Table 3** EMG activity in the digastric muscle († = the greater group variance for that movement. * = Significance at the .05 level).

**Left temporalis muscle**

The left temporalis showed a statistically significant difference only on ipsilateral

<table>
<thead>
<tr>
<th>Movements</th>
<th>p-value (*)</th>
<th>Group Variance</th>
<th>Control (mean)</th>
<th>TMD (mean)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Control</td>
<td>TMD</td>
<td></td>
</tr>
<tr>
<td>Slow right</td>
<td>0.125</td>
<td>0.073 †</td>
<td>0.025</td>
<td>0.5344</td>
</tr>
<tr>
<td>Fast right</td>
<td>0.747</td>
<td>0.052 †</td>
<td>0.028</td>
<td>0.5136</td>
</tr>
<tr>
<td>Slow left</td>
<td>0.003 *</td>
<td>0.121 †</td>
<td>0.024</td>
<td>0.7220</td>
</tr>
<tr>
<td>Fast left</td>
<td>0.009 *</td>
<td>0.214 †</td>
<td>0.038</td>
<td>0.7673</td>
</tr>
<tr>
<td>Slow protrusion</td>
<td>0.561</td>
<td>0.083 †</td>
<td>0.032</td>
<td>0.5167</td>
</tr>
<tr>
<td>Fast protrusion</td>
<td>0.385</td>
<td>0.297 †</td>
<td>0.031</td>
<td>0.6181</td>
</tr>
<tr>
<td>Slow open</td>
<td>0.759</td>
<td>0.168 †</td>
<td>0.033</td>
<td>0.5790</td>
</tr>
<tr>
<td>Fast open</td>
<td>0.444</td>
<td>0.262 †</td>
<td>0.031</td>
<td>0.6058</td>
</tr>
</tbody>
</table>

**Table 4** EMG activity in the left temporalis muscle († = the greater group variance for that movement. * = Significance at the .05 level).

movement. The mean EMG was significantly greater in the control group for left lateral movement compared with the TMD group (see table 4). Left temporalis in
ipsilateral movement showed decreased activity in the TMD group compared with the controls. However, the data for right lateral, protrusion and open-close movements did not show a statistically significant difference between TMD and control groups.

**Right temporalis muscle**

The right temporalis showed similar results to the left, where a statistically significant difference between control and TMD groups was observed in right lateral movement (see table 5). Unlike the left temporalis which showed greater mean EMG activity in

<table>
<thead>
<tr>
<th>Movements</th>
<th>p-value</th>
<th>Group Variance</th>
<th>Control (mean)</th>
<th>TMD (mean)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(°)</td>
<td>Control</td>
<td>TMD</td>
<td></td>
</tr>
<tr>
<td>Slow right</td>
<td>0.024 *</td>
<td>0.090</td>
<td>0.578 †</td>
<td>0.6325</td>
</tr>
<tr>
<td>Fast right</td>
<td>0.019 *</td>
<td>0.486</td>
<td>0.575 †</td>
<td>0.7685</td>
</tr>
<tr>
<td>Slow left</td>
<td>0.440</td>
<td>0.067 †</td>
<td>0.014</td>
<td>0.4971</td>
</tr>
<tr>
<td>Fast left</td>
<td>0.796</td>
<td>0.069</td>
<td>0.384 †</td>
<td>0.4853</td>
</tr>
<tr>
<td>Slow protrusion</td>
<td>0.961</td>
<td>0.254 †</td>
<td>0.068</td>
<td>0.4936</td>
</tr>
<tr>
<td>Fast protrusion</td>
<td>0.165</td>
<td>0.019</td>
<td>0.067 †</td>
<td>0.4007</td>
</tr>
<tr>
<td>Slow open</td>
<td>0.119</td>
<td>0.024</td>
<td>0.028 †</td>
<td>0.4130</td>
</tr>
<tr>
<td>Fast open</td>
<td>0.341</td>
<td>0.047</td>
<td>0.091 †</td>
<td>0.4808</td>
</tr>
</tbody>
</table>

**Table 5** EMG activity in the right temporalis muscle (* = the greater group variance for that movement. † = Significance at the .05 level). The control group, for the right temporalis; greater mean EMG activity was observed in the TMD group.

**Left masseter muscle**

All tasks showed statistically significant difference for the left masseter muscle EMG except for fast right lateral movements. The mean EMG activity for the other tasks showed greater activity in the controls compared with the TMD group.
<table>
<thead>
<tr>
<th>Movements</th>
<th>p-value (*</th>
<th>Group Variance</th>
<th>Control (mean)</th>
<th>TMD (mean)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Control</td>
<td>TMD</td>
<td></td>
</tr>
<tr>
<td>Slow right</td>
<td>0.027 *</td>
<td>0.018</td>
<td>0.21 †</td>
<td>0.4700</td>
</tr>
<tr>
<td>Fast right</td>
<td>0.939</td>
<td>0.009</td>
<td>0.018 †</td>
<td>0.4559</td>
</tr>
<tr>
<td>Slow left</td>
<td>0.021 *</td>
<td>0.035</td>
<td>0.037 †</td>
<td>0.5356</td>
</tr>
<tr>
<td>Fast left</td>
<td>0.039 *</td>
<td>0.308 †</td>
<td>0.039</td>
<td>0.6628</td>
</tr>
<tr>
<td>Slow protrusion</td>
<td>0.000 *</td>
<td>0.452 †</td>
<td>0.024</td>
<td>0.8965</td>
</tr>
<tr>
<td>Fast protrusion</td>
<td>0.024 *</td>
<td>0.792 †</td>
<td>0.024</td>
<td>0.9027</td>
</tr>
<tr>
<td>Slow open</td>
<td>0.000 *</td>
<td>0.021 †</td>
<td>0.019</td>
<td>0.5358</td>
</tr>
<tr>
<td>Fast open</td>
<td>0.000 *</td>
<td>0.026 †</td>
<td>0.016</td>
<td>0.6055</td>
</tr>
</tbody>
</table>

Table 6 EMG activity in the left masseter muscle († = the greater group variance for that movement. * = Significance at the .05 level).

However, there was greater variance within the control group for fast left, slow and fast protrusion compared with the TMD group (see table 6). The data showed decreased muscle activity during opening and ipsilateral movements in TMD group.

**Right masseter muscle**

Most tasks showed a statistically significant difference between TMD and the control groups. Six of the 8 tasks showed a significant difference and all 6 of these tasks showed greater mean EMG activity in the controls compared with the TMD group. Right lateral movements showed greater mean EMG in the TMD group, however the difference was not statistically significant, which may relate to the greater variance in EMG for the TMD group (see table 7). Similarly, greater variance was seen with protrusive and open-close movements for control group. In the TMD group, the right masseter showed an increased EMG activity during right lateral movement and reduced activity in jaw opening.
<table>
<thead>
<tr>
<th>Movements</th>
<th>p-value (°)</th>
<th>Group Variance</th>
<th>Control (mean)</th>
<th>TMD (mean)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Control</td>
<td>TMD</td>
</tr>
<tr>
<td>Slow right</td>
<td>0.082</td>
<td>0.027</td>
<td>1.231 †</td>
<td>0.4838</td>
</tr>
<tr>
<td>Fast right</td>
<td>0.137</td>
<td>0.034</td>
<td>1.202 †</td>
<td>0.4993</td>
</tr>
<tr>
<td>Slow left</td>
<td>0.012 *</td>
<td>0.037</td>
<td>0.074 †</td>
<td>0.5759</td>
</tr>
<tr>
<td>Fast left</td>
<td>0.056 *</td>
<td>0.026</td>
<td>0.041 †</td>
<td>0.5836</td>
</tr>
<tr>
<td>Slow protrusion</td>
<td>0.000 *</td>
<td>0.154 †</td>
<td>0.050</td>
<td>0.7889</td>
</tr>
<tr>
<td>Fast protrusion</td>
<td>0.000 *</td>
<td>0.356 †</td>
<td>0.050</td>
<td>0.8976</td>
</tr>
<tr>
<td>Slow open</td>
<td>0.000 *</td>
<td>0.120 †</td>
<td>0.030</td>
<td>0.6214</td>
</tr>
<tr>
<td>Fast open</td>
<td>0.002 *</td>
<td>0.357 †</td>
<td>0.042</td>
<td>0.6901</td>
</tr>
</tbody>
</table>

Table 7 EMG activity in the left masseter muscle († = the greater group variance for that movement. * = Significance at the .05 level).

A Wilcoxon signed ranks test was applied to the RMS values of the TMD group for maximum open and open until pain. Eight of 10 differences between tasks showed a statistically significant difference (see table 7). However the data on right and left temporalis for fast movement was not significantly different (see table 8).

<table>
<thead>
<tr>
<th></th>
<th>Rt masseter</th>
<th>Lt masseter</th>
<th>Rt temporalis</th>
<th>Lt temporalis</th>
<th>Digastric</th>
</tr>
</thead>
<tbody>
<tr>
<td>mso - so</td>
<td>0.003*</td>
<td>0.012*</td>
<td>0.001*</td>
<td>0.007*</td>
<td>0.000*</td>
</tr>
<tr>
<td>mfo - fo</td>
<td>0.007*</td>
<td>0.001*</td>
<td>0.073</td>
<td>0.094</td>
<td>0.000*</td>
</tr>
</tbody>
</table>

Table 8 The difference between the tasks in the TMD group during open until pain and maximum open through the pain movements. 
(*= p value <0.05). [mso = maximum slow open, so = slow open until pain, mfo = maximum fast open and fo = fast open until pain]
Pain intensity

Pain intensity experienced by symptomatic subjects was measured with VAS scores recorded at the end of each trial. Each subject’s data were analysed qualitatively by plotting VAS scores with time. The graphs show all trials within each task with the x-axis showing the position of the first trial of each task, that is, SR1 = slow right, FR1 = fast right, SL1 = slow left, FL1 = fast left, SP1 = slow protrusive, FP1 = fast protrusive, SO1 = slow open, FO1 = fast open, MSO1 = maximum slow open and MFO1 = maximum fast open; and the y-axis the pain score from 0 to 100.

Subject A showed a gradual increase in pain (VAS scores) throughout the recordings. There was a greater variation in the fast right movements and no pain in fast left movements (see FR1 and FL1, figure 27). Greater pain (VAS scores) were reported for maximum slow and fast opening. Overall, subject A had more pain (greater increase in VAS scores) with slow jaw movements.

![Graph](image)

**Figure 27-** Subject A VAS scores

Subject B experienced mild to moderate pain with VAS scores of between 10 and 40 for most trials. Pain recorded (VAS scores) were highest for fast right and slow protrusive movements and a greater fluctuation in the VAS scores for fast right
movement (see FR1, SP1, figure 28), which are supported by the subject’s RDC/TMD diagnosis of right side symptoms. The pain reported by the subjects showed a gradual decrease in VAS scores from fast protrusive movements onwards and maintained constant at a level of 10 to 20.

![Figure 28- Subject B VAS scores](image)

Subject C did not show a different pattern from other subjects with greater variability in VAS scores throughout the tasks suggesting a greater variability in the level of subjective pain experienced with the jaw movements. The highest VAS score was noted for the last trial of the slow right movement (see SR1- 5th point on figure 29).

![Figure 29- Subject C VAS scores](image)
**Subject D** showed gradual increase in VAS scores for right lateral, left lateral and protrusive slow movements compared with scores for fast movements. However, there was a gradual decrease in scores for slow and fast opening until pain (see SO1 and FO1 in figure 30). Maximum VAS scores were noted for maximum slow and fast maximum opening (see MSO1 and FSO1 in figure 30).

![Graph showing VAS scores for Subject D](image1)

**Figure 30-** Subject D VAS scores

**Subject E** showed an overall increase in pain (VAS scores) for slow compared with fast movements (see SL1, SR1, SP1, SO1 and MSO1 in figure 31). Maximum VAS scores were recorded for slow right, slow open until pain and slow maximum opening (see SR1, SO1 and MSO1 in figure 31).

![Graph showing VAS scores for Subject E](image2)

**Figure 31-** Subject E VAS scores
Subject F showed gradual increase in VAS scores throughout the trial. An increase in VAS scores during slow movements was seen; and a gradual drop with fast movements (see FR1, FL1, FP1, FO1 and MFO1 in figure 32). Maximum VAS scores recorded for slow right, slow open until pain and slow maximum opening (see SR1, SO1 and MSO1 in figure 32).

![Figure 32- Subject F VAS scores](image)

Subject G showed a gradual increase in VAS scores during laterotrusive movements (SR1 to FL1 in figure 33) and reduced VAS scores for protrusion (SP1 and FP1 in figure 33), and a gradual increase in VAS scores for opening (SO1 to MFO1 in figure 33).

![Figure 33- Subject G VAS scores](image)

An increase in VAS scores was recorded for slow protrusive and maximum open movements, compared with fast protrusive and maximum open.
Subject H showed a consistent pattern of increase in subjective pain (VAS scores) for slow movements (see SR1, SL1, SO1 and MSO1 in figure 34) and decrease or steady VAS scores for fast movements, with the exception of protrusive, where greater VAS scores were noted for the fast (see FP1 in figure 34).

![Figure 34- Subject H VAS scores](image)

Subject I showed a gradual increase in VAS scores throughout the trial. VAS scores were highest for maximum slow open-close movements (MSO1 in figure 35).

![Figure 35- Subject I VAS scores](image)

Overall, the results showed progressive increase in pain with no greater variation in VAS scores for slow and fast movements.
The overall pattern of VAS scores within the symptomatic group showed a gradual increase in pain intensity during the recordings. All subjects began with a relative low pain intensity score, which increased by the end of the trials. Seven of nine symptomatic subjects showed greater pain intensity during slow than during fast movements. There were exceptions: subject B showed higher pain intensity for fast right movements; subject D pain intensity decreased from 45 to 15 during slow and fast open-close until pain and subject G showed greater pain intensity for most trials of fast movement except for protrusive and maximum open-close. Two subjects C and G showed greater variation in pain intensity throughout the trial, which was different from the pattern of the other symptomatic subjects.
DISCUSSION

Jaw muscle dysfunction is the most common problem observed in TMD patients, presenting with abnormal and/or restricted jaw movements. Electronic measurement of jaw movements (jaw tracking) and jaw muscle function (EMG) may possibly provide data that could be used clinically to assist in diagnosis and management of patients (Cooper 1997). However, the value of EMG and jaw tracking data is controversial and there is a need for controlled clinical studies (Mohl 1990).

The present study aimed to determine whether there was evidence to support the hypothesis that TMD patients differ from asymptomatic subjects (controls) in the amount of the jaw displacement in maximum excursions, the ability to reproducibly follow a target, and the variability in jaw movements within the groups. The study further looked at the difference in EMG activity during the out-going phases of open-close, laterotrusive and protrusive movements. In particular, a decrease in the EMG activity for digastric and an increase for masseter in the TMD group during the out-going phase of open-close movements supports the pain adaptation model (Lund et al 1991).

The present study showed a greater difference in the amount of jaw displacement in maximum excursions, between the TMD and control groups. The range and the standard deviations were greater for the TMD group, whilst the mean displacement values were greater in the control group. Qualitatively, there was greater variation in jaw movements between TMD and controls. The TMD group showed greater difficulty in carrying out slow compared with the fast jaw movements, and a reduced ability to follow the target. The TMD group showed greater intra- and inter-group variability within a jaw
movement sequence and these data support the hypothesis that the TMD group showed a reduced displacement and greater difficulty in jaw movements compared with the controls. Further, the overall EMG data showed significantly reduced mean EMG activity for all muscles in the TMD group compared with controls (29/40 tasks). The most significant EMG activity was for the digastric muscle followed by the masseter; for the temporalis muscle, significant differences were noted only for ipsilateral movements. During maximum jaw opening reduced digastric EMG was noted, however, the masseter EMG was not found to be greater in the TMD group. This suggests that these results do not support Lund's hypothesis of decreased agonistic activity and increased antagonistic activity during painful jaw movements.

Age range of control and TMD groups were 32 ± 4 years and 37 ± 11 years respectively, which falls within the most prevalent age range for TMD patients i.e. 20-40 years (Solberg 1986, Laskin and Block 1986 and Howard 1991). The control group consists of 6 female and 3 male subjects, and the TMD group 8 female and 1 male patients. The groups were not age and gender matched due to a limited sample size.

The TMD group comprised of disk displacement with reduction (2 patients), bilateral arthromyalgia (4 patients) and unilateral arthromyalgia (3 patients). TMD group lacked homogeneity in diagnostic sub-types. Masumi et al (2002) evaluated whether TMD subgroups could be differentiated using maximum jaw motion measurements. They concluded that these measurements could not reliably differentiate TMD sub-groups (except for disc displacement without reduction), although there was a relationship with the severity of TMD. Hence, the use of a heterogenous TMD group to assess maximum jaw displacement as a single group will probably not introduce an error in the analysis.
However, the same cannot be said for EMG data from a heterogenous group. The literature suggests that there are differences in EMG activity between arthrogenous and myogenous sub-types of TMD (Naeiji and Hansson 1986 and Liu 1999), and no differences in the EMG activity irrespective of whether the symptoms are unilateral or bilateral (Humsi et al 1989, Lund et al 1991, Schwartz et al 1993 and Svensson et al 1996).

**Jaw movements in TMD subjects**

Jaw movement restriction and deviation is one of the cardinal signs of TMD. In this study, jaw movements were described by both qualitative and quantitative analyses. Studies measuring jaw displacement by using a ruler, showed a significant difference in the amount of jaw displacement (Hesse et al 1996, Miller et al 1999, Celic et al 2003). Whilst, studies measuring jaw displacement with jaw tracking devices did not show a significant difference (Clark et al 1986, Feine et al 1988, Neilsen et al 1990 and Tsolka et al 1994). This may be due to problems in methodology, such as non-linearity of the recording device, lack of clinical controlled studies, inappropriate statistical analysis and lack of consideration of diagnostic sub-types in TMD.

The smaller sample size and the heterogeneous nature of the TMD group determined that the magnitude of mandibular movements to be analysed using descriptive statistics *i.e* calculating mean and standard deviation of the mean trials of each task for subjects in each group.

The TMD group in the present study showed greater restriction in the amount of jaw displacement compared with the control group which showed jaw displacement in the “normal range”(open-close of 40 to 45 mm, lateral of 8 to 10 mm and protrusive
movements of 7 to 8 mm- Dworkin and LeResche 1992). This variation in range of movement of the TMD group may be attributed to 2 patients (diagnosed with disk displacement with reduction) who showed greater restriction in the amount of jaw displacements compared with other TMD patients. Similar results were noted in studies by Clark and Lynn (1986). Four TMD patients, showed restriction in jaw displacement in most of the movements, while the other TMD patients were within or nearer to the “normal range” of jaw movements.

An open-close movement of less than 40 to 42 mm, lateral movement of less than 8 mm and protrusive movement less than 7 mm is considered to be restricted jaw movement (Clark et al 1989, Dworkin et al 1990, Celic et al 2003). The present study showed a mean maximum mouth opening of 40 mm for controls and 33 mm for the TMD group, lateral movements of 11 mm for controls and 7 mm for TMD group, and protrusive movements of 8.7 mm for controls and 5.9 mm for TMD group. In this study, the TMD group showed greater restriction and significant differences in open-close, lateral and protrusive movements. In past studies, Clark and Lynn (1986), Feine et al (1988), Nielsen et al (1990) and Tsolka et al (1994), measured the amount of displacement using kinesiographic recordings, but did not find a significant difference in jaw movements between control subjects and TMD patients. These results could be related to technical and recording errors in the jaw tracking devices that do not take into account the non-linearity of jaw movements. The results in the present study are more accurate as the JAWS-3D system for recording jaw movements has accounted for this inaccuracy. The amount of jaw displacements in the present study agrees with Miller et al (1999) and Celic et al (2003) who showed statistically significant differences in jaw movements measured clinically using a ruler, between control and TMD groups, within clinical sub-
types of myogenous and arthrogenous TMD. In the present study, the amount of
displacement on right and left lateral movements for both TMD and controls was not
different. A similar result was seen in Furuya’s (1975) study, and a contradicting result
by Nielsen et al (1990) who described a significant difference in the amount of right and
left lateral displacement. Although significant results were obtained in the present study
for jaw displacement, variable factors on jaw displacement such as age and gender could

Qualitative analysis of jaw movements indicated a decreased ability for the TMD group
to move the jaw in a defined direction compared with controls. The difference was more
pronounced during slow compared with fast jaw movements. TMD subjects showed
greater difficulty in stabilizing the jaw during hold and return phases of the jaw
movement task, however with fast movement; little variation was noted between the
groups. The TMD group showed consistent outward movements, where as greater
variability was noted on returning to “rest” position, which was similar to conclusions by
Monteiro et al (1987). Some TMD subjects could not return to the starting point during
maximum slow opening. These findings indicate a decreased ability to move the jaw in a
defined direction and a decreased accuracy of jaw movements, which is in agreement
with results reported by Clark and Lynn (1986) and Monteiro et al (1987), who showed
significant differences in accuracy ratio for lateral movements.

Decreased ability to move the jaw in a defined direction was further analysed by looking
at the variability within the group for each task and then compared between the groups.
The coefficient of variance values plotted for each task for both control and TMD groups
showed greater variation in jaw movement in the TMD group for right and left lateral,
protrusive and open-close movements. However, the control group showed similar
variability in protrusive movements, suggesting that both TMD and control groups had equal difficulty in protrusive movements. An interesting finding of this study was when maximum open-close movement was compared with open-close until pain in TMD group, there was greater variability in the return phase of open-close until pain movement.

In summary, TMD subjects showed greater variability in reproducing a predetermined mandibular position and greater variability in locating a predetermined target position. Greater variability was also noted for slow compared with the fast movements. Most TMD subjects reported greater pain intensity scores during slow compared with the fast movements. Interestingly TMD patients with pain showed a tendency to limit or avoid the range of movements and reported increased discomfort and pain when the trials were longer, particularly on maximum open through pain. They also had difficulties in holding the jaw in a particular position and while returning to “rest” position. It appears that, in the present study the range, pattern and the fine control of jaw movements were altered in the TMD group. Comparing pain intensity scores with jaw movements, most jaw movements with a higher pain intensity score did not relate to changes in jaw movement patterns. Similar results were reported in study by Monteiro et al (1987). However, for most of the subjects a gradual increase in pain was reported during slow movements as the number of trials progressed. These data are consistent with the emerging understanding that pain has distinct effects on motor function and that increased motor activity exacerbates pain (Stohler 1999, Svensson and Graven-Nielsen 2001). This provides substantial evidence to support the hypothesis that the TMD patients could be differentiated from controls in the amount of jaw displacement and the variability of jaw movements.
EMG in TMD subjects

The overall EMG activity of all tasks in all jaw muscles studied showed a reduced EMG activity for the TMD group compared with controls with maximum excursive movements. Of the 40 tasks, 29 showed reduced EMG activity in the TMD group. A statistically significant difference in EMG activity was noted for most of the lateral and open-close movements, but less for protrusive movements. These results suggest that pain inhibits the activity of the alpha-motor neuron pool and subjects with pain use their jaw muscle with less intensity. These results are similar to the reports of Stohler et al (1985 and 1999), Møller et al (1989), Nielsen et al (1990), Lund et al (1991) and Svensson et al (1996 and 1997). The control group, however, showed greater group variance for 6 of the 29 EMG tasks suggestive of greater variance within the results.

EMG activity for the digastric muscle during opening was found to be reduced for the TMD group compared with controls. The masseter muscle did not show greater EMG activity in the TMD group in the out-going phase of jaw movements, and for lateral movement anterior temporalis showed contradictory results where left temporalis EMG activity was reduced for left lateral movements in the TMD group (a similar result was obtained by Pinho et al 2000) and right temporalis EMG was found to be greater on right lateral movements. During protrusion only right and left masseter activity was significant and reduced for the TMD group. These results do not agree with studies supporting the pain adaptation model described by Lund et al (1991) nor with the findings of Stohler et al (1985) and Mongini et al (1989) who reported that jaw closing muscles of TMD patients were active during opening (till half of the maximum opening). This study indicates reduction in digastric activity for the TMD group for most tasks; however the TMD group did not show increased EMG activity for the masseter. The results suggest
that our data does not support the pain adaptation model as described by Lund et al (1991). It was assumed that the variability in EMG activity between and within the TMD and control groups did not allow statistical significance, which could be related to sample size and the non-matched sample groups with respect to gender, age, muscle and craniofacial size etc.

**Future studies**

The present study examined the differences in TMD patients and asymptomatic controls in jaw muscle EMG activity and in jaw movements, which considered the amount of jaw displacement and jaw movement reproducibility at slow and fast speeds. Limitations of this study included a small sample size, subjects were not age and gender matched, there was a heterogeneous pool of TMD subjects and only the out-going phase of the EMG data was analysed. Although the results suggested a difference between the TMD and the control groups, the limitations above do not allow specific diagnostic implications to be made. On the other hand, these data indicate clear differences between patients and control subjects and provide evidence to document improvement in jaw movement that might correspond with relief of symptoms.

Future studies need to include the following: a larger sample size, age and gender matching of subjects, more comprehensive selection criteria, specific diagnostic subtypes and analyzing EMG activity in each phase of jaw movements (“rest”, out-going, hold and the return phase). A carefully designed protocol including the above factors would reduce the within-group variability, and provide results that would more likely provide better diagnostic and prognostic indicators of TMD.
CONCLUSIONS

➢ TMD patients exhibit greater reduction in jaw displacement and greater variability in jaw movements compared with asymptomatic controls.

➢ TMD patients showed an overall statistically significant reduction in the EMG activity compared with the controls.

➢ Analysis of EMG activity to test Lund’s pain adaptation model, did not support the hypothesis that there is a decreased agonist activity and an increased antagonist activity during opening jaw movements.
BIBLIOGRAPHY


