ALTERATIONS IN JAW CLENCHING FORCE CONTROL IN PEOPLE WITH MYOGENIC TEMPOROMANDIBULAR DISORDERS

Testa M[1], Geri T[1], Pitance L[2], Lentz P[2], Gizzi L[3], Erlenwein J[4], Petkze F[4], Falla D[5]

1. Department of Neuroscience, Rehabilitation, Ophthalmology, Genetics, Maternal and Child Health, University of Genova, Italy

2. Institute of Clinical Research, Computed Assisted Robotic Surgery Lab, Université Catholique de Louvain, Belgium

3. Institute of Applied Mechanics (Civil Engineering), Chair II Continuum Biomechanics and Mechanobiology Research Group, University of Stuttgart, Germany

4. Pain Clinic, Center for Anesthesiology, Emergency and Intensive Care Medicine, University Hospital Göttingen, Germany

5. Centre of Precision Rehabilitation for Spinal Pain (CPR Spine), School of Sport, Exercise and Rehabilitation Sciences, College of Life and Environmental Sciences, University of Birmingham, UK

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Address for correspondence:
Professor Deborah Falla
Centre of Precision Rehabilitation for Spinal Pain (CPR Spine),
School of Sport, Exercise and Rehabilitation Sciences,
College of Life and Environmental Sciences,
University of Birmingham,
Birmingham, B15 2TT
UK
Tel: +44 (0)121 415 4220
Email: d.falla@bham.ac.uk

ABSTRACT

Isometric bite force control, via measures of force accuracy, force steadiness and force proprioception, was assessed in patients with myogenic temporomandibular disorders (TMDs) compared to healthy controls. Twelve people with myogenic TMDs and twelve age- and gender-matched asymptomatic controls performed maximal voluntary contractions (MVC) of unilateral jaw clenching followed by submaximal isometric contractions, with and without visual feedback of force, at 10, 30 50% and 70% MVC. Force performance was assessed with indices of accuracy (mean distance, MD) and precision (standard deviation, SD) and reported as a percentage of the MVC. A mixed-effect model was used to evaluate differences in MVC, MD and SD. The MVC was lower in the patient group when clenching either ipsilateral or contralateral to the side of greatest pain ($p<0.05$). No difference in MD was observed between groups. The SD depended on the interaction between group and painful side ($p = 0.04$) with patients displaying higher SD when executing the task with the most painful side when compared to the ipsilateral or contralateral sides of the control group. The reduced maximal bite force and force steadiness observed in people with myogenic pain may interfere with masticatory function and should be considered when planning therapeutic interventions for TMDs.

INTRODUCTION

Temporomandibular disorders (TMDs) refer to a heterogeneous group of conditions affecting the temporomandibular joint, masticatory muscles or both. The signs and symptoms of a TMD include pain together with functional and structural disturbances of the masticatory system [1, 2]. Even though the prevalence of TMDs varies considerably [3-7], they are the most common cause of orofacial pain of non-dental origin [8, 9], with women more affected than men [10].

TMDs are widely accepted to be a multifactorial disorder with biomechanical, neuromuscular and psychosocial factors all being potential contributing factors [2, 11]. Myogenic TMDs are one type of TMDs, mainly characterized by myofascial pain [2]. Craniomandibular function is dependent on the biomechanical and morphological components of the surrounding muscles and thus myogenic factors can play an important role in the development, perpetuation and maintenance of a TMD.

Fine control of the masticatory muscles occurs via sensory motor integration at different level of the central nervous system, based on afferent input from the periodontium, periarticular soft tissues and the muscles themselves [12-14]. Patients with myogenic TMD may have impaired masticatory function due to limited jaw movements and/or the presence of muscle pain [15]. Several studies have demonstrated the influence of nociceptive stimuli on somatosensory and motor function in the orofacial region [16, 17] and experimentally evoked muscle pain alters proprioceptive signals arising from jaw muscle spindles [18]. Not surprisingly, bite force can be impaired in patients with TMDs [19-21]. However, a very limited number of studies have investigated the accuracy and control of bite force and those that have been conducted, were on asymptomatic people [22-24]. To the best of our knowledge, no studies have evaluated the accuracy of bite force control in patients with myogenic TMD.

The present study aimed to assess isometric unilateral bite force control, via measures of force accuracy, force steadiness and force proprioception in patients with myogenic TMD compared to healthy controls. It was hypothesized that patients would display lower task accuracy and precision in a visually guided jaw clenching task compared to asymptomatic people. It was also expected that even greater between group differences would be observed when the subjects were asked to reproduce force targets without visual feedback.

METHODS

Participants

Twelve people (9 women) diagnosed with myogenic TMD and 12 age and gender matched asymptomatic controls were recruited for the study. Patients were assessed following the Diagnostic Criteria for Temporomandibular Disorders (DCTMDs) [2] and were included only if diagnosed with a pain related disorder of myogenic etiology (local myalgia, myofascial pain, myofascial pain with referral) with no other coexisting TMD diagnosis. Controls were included if they had no relevant history of craniofacial or neck pain/injury that limited their function and/or required treatment from a healthcare professional. Participants were excluded from both groups if they had any major circulatory, neurological, psychiatric or respiratory disorder, recent or current pregnancies, history of malignancy, previous spinal or craniomandibular surgery, dentures or dental bridges that do not allow the use of full bite force or absence of molar or premolar teeth (the absence of wisdom teeth was not considered). Participants were also excluded from both groups if they were taking medication such as opioids, anticonvulsants, antidepressants or regularly high dosed non-steroidal anti-inflammatory drugs (NSAIDs), while NSAIDs as needed were allowed.

Patients were recruited via the Universitätsmedizin Göttingen, Germany and controls via advertisement on University noticeboards. Initial screening was accomplished by telephone and eligible persons attended a baseline evaluation appointment where they were screened by a dentist and a medical doctor. Both groups were asked not to take NSAIDs on the day of the experiment.

Ethical approval for the study was granted by the local Ethics Committee and the procedures were conducted according to the Declaration of Helsinki. Participants provided written informed consent prior to testing.

Questionnaires

A questionnaire was administered to the patient group to document their average pain intensity and duration of pain. Patients also completed the German version of the Jaw Pain and Function scale (JPF,32 items,[25]); a measure of pain and functional impairment of the masticatory system. German versions of the Pain Catastrophizing Scale (PCS, 13 items, [26]) and the Tampa Scale for Kinesiophobia (TSK-DE, 17 items, [27]) were used to assess pain catastrophizing and fear-avoidance beliefs respectively. The German version of the Neck Disability Index (NDI) was used to assess pain-related disability specifically related to neck pain (10 items; [28]). Finally, the patients were asked to verbally rate their current level of perceived pain intensity at the beginning of the measurement session on an 11 point Numeric Rating Scale (NRS) anchored with “no pain” (0) and “the worst possible pain imaginable” (10).

Bite force

Bite force was registered with piezoresistive force transducers (Flexiforce A201; Tekscan, US) with a maximum load of 784.5 N. The force signal was amplified (2-channel force amplifier, OT Bioelettronica, Torino, Italy), sampled at 15 Hz and converted to digital form by a 16-bit analog-to-digital converter. For comfort, the force transducers were wrapped in 20 mm silicone pads. Two circular metal pucks on both sides of the sensitive area of each force sensor (9.7 mm diameter) provided correct force transmission. The force measuring device had a total thickness of 7 mm, width of 20 mm and length of 15 mm[29].

Experimental procedure

Participants were seated upright with their back, feet and arms supported, hips and knees at approximately 90 degrees. The force transducer was placed over the mandibular premolars with randomization of starting side. Unilateral bite force was visualized in real-time on a PC-monitor as a red cursor moving vertically. The monitor was placed at the subject's eye-level at a distance of 100 cm. The cursor height on the screen and bite force were linearly linked and thus provided intuitive visual feedback.

The highest of two maximal unilateral jaw clenching contractions was selected as the maximum voluntary contraction (MVC) for each side. Subjects were instructed to steadily build up their bite force to a maximum over 10 s. The maximal contractions were performed with verbal encouragement from an investigator and 60 s of rest was provided between contractions.

Participants were then allowed to practice to reach and hold a 30% MVC for ~10 s to familiarize themselves with the task. They then performed contractions to match force targets representing 10, 30, 50 and 70% of MVC which were displayed randomly. The force targets were displayed as rectangular steps with heights corresponding to the target percentage of MVC with a standard length at the target force of 12 s followed by 15 s of rest. After each submaximal force target with feedback on force, the subject was asked to perform the exact same force task without visual feedback. The entire procedure of four contractions under the two conditions (feedback, no feedback) was repeated for the contralateral side after 5 min of rest (Fig.1).

Data analysis

For the patient group, the painful and non-painful side were considered and in the case of bilateral symptoms, the side with the greatest pain intensity was considered as the painful side.

The following indices were calculated for each force target to characterize the task performance as described previously [30]:

- The Mean Distance (MD) indicates the overall task execution and is represented by the average value of the difference between the absolute values of the force delivered by the subject and the force target.
- The Standard Deviation (SD) characterizes the precision of the performance and measures the smoothness of force irrespective of the reference target.

The force indices were computed over the central 10 s of each reference target and reported as a percentage of the MVC. These indices are valid and reliable measures to characterize jaw-clenching performance [31].

The data from the painful side of the TMD group were matched with the homologous side for the control group and the same was done with the contralateral sides of both groups, thus producing a variable “Matching” that served to model the analysis.

Statistical analysis

A mixed-effect model was used to evaluate differences in MVC, MD and SD. The distribution of data was firstly explored with a Cullen and Frey graph, and then the data were fit to candidate distributions and the goodness of fit assessed using the Anderson-Darling (AD) statistics and the Akaike Information Criterion (AIC) [32]. As the MVC (AD = 2.15, AIC = 3039.76) followed a Gamma distribution while MD (AD = 1.72, AIC = 2283.64) and

SD (AD = 0.6, AIC = 1768.36) followed a lognormal distribution, subsequent analyses were performed using a generalized linear mixed-effects model with Penalized quasi-likelihood estimation method [33]. The between-subjects variable Group (2 levels: patients, controls) and the within-subjects variables Matching (2 levels: matched, unmatched) were treated as fixed effects. In the model for MVC, the subjects were considered as crossed random effects with random slopes and intercepts across group. In the models for MD and SD, Feedback (2 levels: with feedback, without feedback) and Target (4 levels: 10, 30, 50, and 70% MVC) were considered as nested random effects with random slopes and intercepts across group. The chi-squared test was used to assess model fit with $p < .05$ considered as significant. Significant interactions were further tested with multiple comparisons using the least square means approximation and p values were adjusted with the Tukey method [34]. All analyses were carried out in the R environment [35] using the lme4 package [36] and data were plotted using ggplot2 [37].

Results are reported as mean and standard error in the Figures and as mean and 95% Confidence Intervals (CI) in the text and Tables.

RESULTS

Participant characteristics are presented in Table 1. No differences in age, weight or height were detected between groups (all $p > .05$).

Maximal contractions

The interaction between group and matching was not significant ($\chi^2(1) = 2.32$, p = .12). However, a significant main effect of group was observed ($\chi^2(1) = 6.61$, p = .01) with lower MVC values measured from the patient group (255.1 N, 95%CI = 192.7 – 337.5) compared to the control group (376.7 N, 95%CI: 321.9 – 440.9).

Force variables

Figure 2 presents the results of the MD (reported as % of MVC), presented for the different conditions and different force levels together with the intercepts for each level of the random variables across groups. Each level of the random effect variable Target nested in the feedback conditions, gave different intercepts to the model (represented as solid and dashed lines at the bottom of each panel in Figure 2) which increased across Target and Feedback with subtle effects of the variable Group on the random slope. For the condition with feedback, the intercepts were 1.32 for 10%MVC, 1.35 for 30%MVC, 1.60 for 50%MVC, and 1.95 for 70%MVC. For the condition without feedback the intercepts were 1.80, 2.30, 2.65, and 2.97 for 10, 30, 50, and 70%MVC respectively.

Neither the interaction between group and matching (χ^2 (1) = 0.07, p = .79) nor the main effects of group (χ^2 (1) = 0.79, p = .37) or matching (χ^2 (1) = 0.99, p = .32) were significant (Figure 3).

Data for the SD of force (reported as % of MVC) for the different conditions and different force levels are presented in Figure 4. In relation to the random effects, each level of the variable Target nested in the feedback conditions gave different intercepts to the model (represented as solid and dashed lines at the bottom of each panel in Figure 4) that were different between the condition with and without feedback. As for MD, the intercepts increased across force levels in the condition with feedback (10%MVC = 0.24, 30%MVC = 0.85, 50%MVC = 1.45, 70%MVC = 2.19). The model intercepts were higher in the condition without visual feedback (10%MVC = 0.61, 30%MVC = 1.51, 50%MVC = 1.70, 70%MVC = 1.27) despite a lower intercept of 70% MVC with respect to 30 and 50% MVC.

The SD of force was dependent on the interaction between group and matched side (χ^2 (1) = 4.21, p = .04). The multiple comparisons revealed that the SD of the most painful side of the patient group (SD = 4.89, 95% CI = 3.48 – 6.90) was significantly higher than the matched side (response ratio = 0.66, t ratio = -3.28, $p < .01$) and the unmatched side (response ratio = 1.34, t ratio = 2.69, $p < .05$) of the control group (Figure 5).

DISCUSSION

An isometric force-matching task was used to assess differences in the control of unilateral jaw clenching force between patients with myogenic TMD and asymptomatic controls in conditions with and without visual feedback of force. A reduced maximal bite force and force steadiness was observed in people with myogenic TMD when performing submaximal contractions.

Maximal contractions

The maximal jaw clenching force measured for the control group (376.7 N), is comparable with previous reports [38, 39] even though some studies report higher values [40, 41]. Maximal force had a clear tendency to be lower for the participants with TMD, regardless of the side tested. Previous studies show mixed results with some reporting lower maximal jaw clenching force in patients with TMD [38, 40] and others not [42, 43]. The lack of consensus in classifying TMD patients and the variety of dynamometers and procedures used to measure maximal force may partially explain these conflicting results. For example, locating the sensor between the more anteriorly positioned teeth, reduces the force output because of the disadvantageous lever arm [44]. Moreover, the heterogeneous character of TMDs makes it hard to directly compare results to other studies due to widely varying patient samples. The patients in the current study presented with relatively low levels of pain and jaw disability (Table 1) and maximal jaw clenching strength may be expected to be more affected in those with greater symptoms. A reduced MVC could be attributed to an unconscious mechanism of pain anticipation. However no subject reported concern or actual pain during the execution of the task.

Submaximal contractions

The values of the error indices in the asymptomatic controls were consistent with those found in the validation study of the gnatodynamometer which was used in this study [31]. Force steadiness was decreased for the patient group on the (most)painful side when compared to both sides of the control group thus reflecting the difficulty in delivering constant bite force regardless of the influence of feedback and force level. The presence of muscle pain may have increased the recruitment of larger motor units which produce larger and unfused twitches, resulting in increased force fluctuations [45, 46].

Higher values of SD were observed for the patient group compared to the control group but only on the (most)painful side even if 75% of the patients reported bilateral symptoms. Higher than average fluctuations of force (SD) during submaximal contractions has been associated with muscle fatigue [47] and pain and has been observed for other chronic musculoskeletal pain disorders [48-50]. In the presence of pain, the central nervous system adopts compensatory strategies to accomplish motor tasks and this may involve the recruitment of motor units belonging to different muscle compartments [51] or modulation of synergistic and antagonistic muscle activity [52]. Such compensatory strategies can allow a motor task to be performed albeit with diminished precision, here represented by reduced force steadiness, namely an increase of the force signal variability which was independent from the target force level. The expectation of pain can also elicit compensatory strategies [53]. Reduced force steadiness has been previously identified in other body regions in the presence of chronic pain [41- 43] yet this is the first study to examine force control from the jaw elevator muscles in people with myogenic TMD. Further studies are needed to better clarify the neurophysiological mechanisms underpinning reduced force steadiness in chronic pain populations.

Contractions without visual feedback

When visual feedback is used to maintain an isometric muscle contraction, voluntary visuomotor correction contributes to muscle force fluctuations, and therefore force steadiness may be greater in conditions without visual feedback [54, 55]. The present results in terms of model intercepts, however, show a tendency for increased force steadiness without feedback throughout the lower force range (10% 30% and 50%) and reduced force steadiness only for the contraction at 70% MVC. The reduction in force steadiness may however, not be a robust indicator in the condition without feedback. In contrast to previous studies where the subjects were asked to maintain a contraction force and then visual feedback was removed, in the present study the subjects were requested to reproduce a contraction force from a resting condition since the main interest was to assess their ability to replicate the force target (proprioception). We often observed that the force signal drifted away from the target during the conditions without feedback, which would have influenced the measurement of SD.

As expected, the intercepts of MD were higher during the condition without feedback compared to the condition with feedback at force levels 30%, 50% and 70% MVC. However, at the lower force level (10% MVC), the subjects in both groups were able to replicate the force target with the same degree of accuracy as for the targets in the condition with visual feedback. This could be partly explained by the stimulus encoding properties of periodontal mechanoreceptors which are known to play a role in bite force development and fine motor regulation [56, 57]. Periodontal mechanoreceptor sensitivity to static tooth loading is highest at low forces [57, 58] which is physiologically sound since in normal chewing of mixed food, the forces rarely exceed 50–70 N [59]. Ten percent MVC is the only force level of our investigation falling within the physiological range of tooth loading. Thus, the findings suggest that at this low level of force, the information provided by the periodontal receptors fully compensates for the lack of visual information, and that the presence of a myogenic TMD does not interfere with bite force control.

Some methodological considerations should be noted. Firstly, the sample size was not determined a priori and a convenience sample was selected yet this formed a relatively small group. However, despite the small sample size, clear differences were identified between our patient and control group. Nevertheless, these results should not be generalized or extrapolated to all people with myogenic TMDs. The participants performed a number of tasks and muscle fatigue was not monitored across the experiment. However, randomization of the task sequence (side and force level) should have prevented bias due to muscle fatigue. Secondly, the study population presented with relatively low levels of pain which may not mirror the majority of myogenic TMD patients. Potentially, even greater disturbances in jaw control would be present in patients with higher levels of pain or disability.

Piezoresistive sensors, like those used, present with a certain drift related to the time of continuous loading. Their drift was ascertained in a laboratory test which showed less than 1% drift after 4 minutes of continuous loading with 390 N [29], which is of negligible clinical relevance.

Conclusion

Reduced maximal bite force and force steadiness was observed in people with myogenic TMD when performing submaximal jaw clenching contractions. Such impaired control of jaw clenching may interfere with masticatory function and should be assessed during the examination of the temporomandibular joint and considered when planning therapeutic interventions for people with a TMD.

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TABLE

Table 1: Baseline characteristics of the TMD and control groups. Values are presented as mean ± SD.

Characteristic	TMD (n=12)	Control (n=12)
Age (yrs)	30.9 ± 7.4	31.4 ± 7.9
Gender (% female)	75	75
Height (cm)	169.1 ± 8.7	171.9 ± 9.1
Weight (kg)	62.9 ± 10.5	66.0 ± 9.2
Duration of Pain (months)	69.6 ± 37.6	
Current Pain Intensity (NRS)	1.6 ± 1.5	
Side of the greatest pain (Right, Left, %)	58.4, 41.6	
Bilateral Pain (%)	75	
JPF (%)	13.4 ± 5.4	
NDI (%)	17.6 ± 7.0	
TSK	28.0 ± 530	
PCS	9.3 ± 11.1	

Abbreviations: NRS (Numerical rating scale for intensity of neck pain); JPF (Jaw Pain and Function); NDI (Neck Disability Index); TSK (Tampa Scale for Kinesiophobia); PCS (Pain Catastrophizing Scale)

CAPTIONS

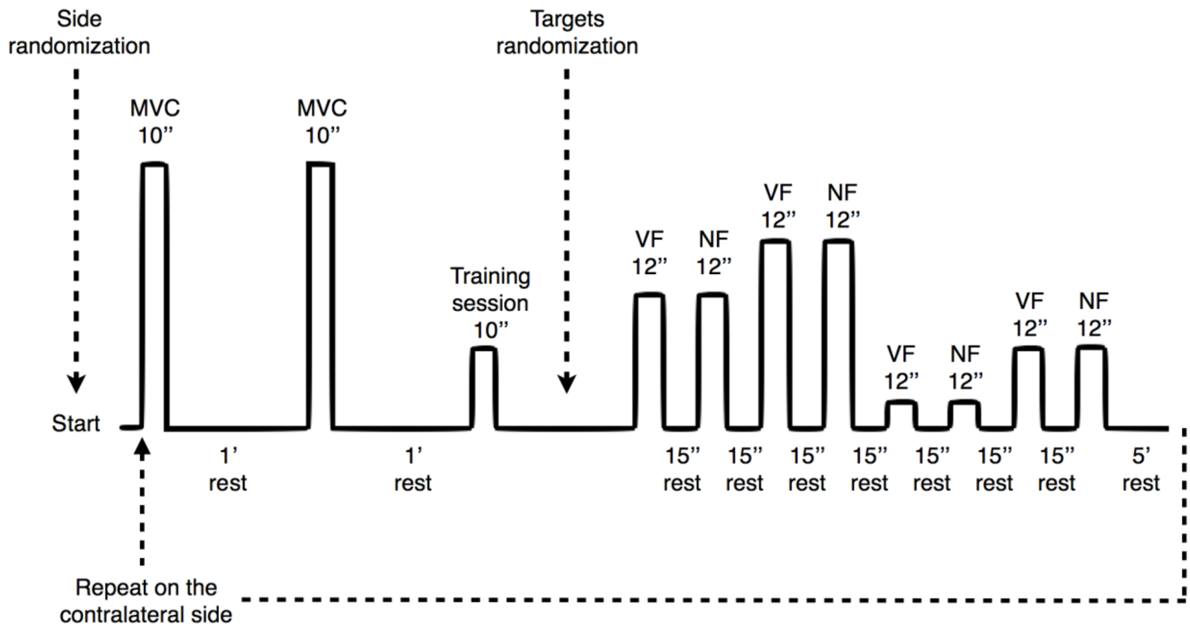
Figure 1: Flow chart of the experiment procedure

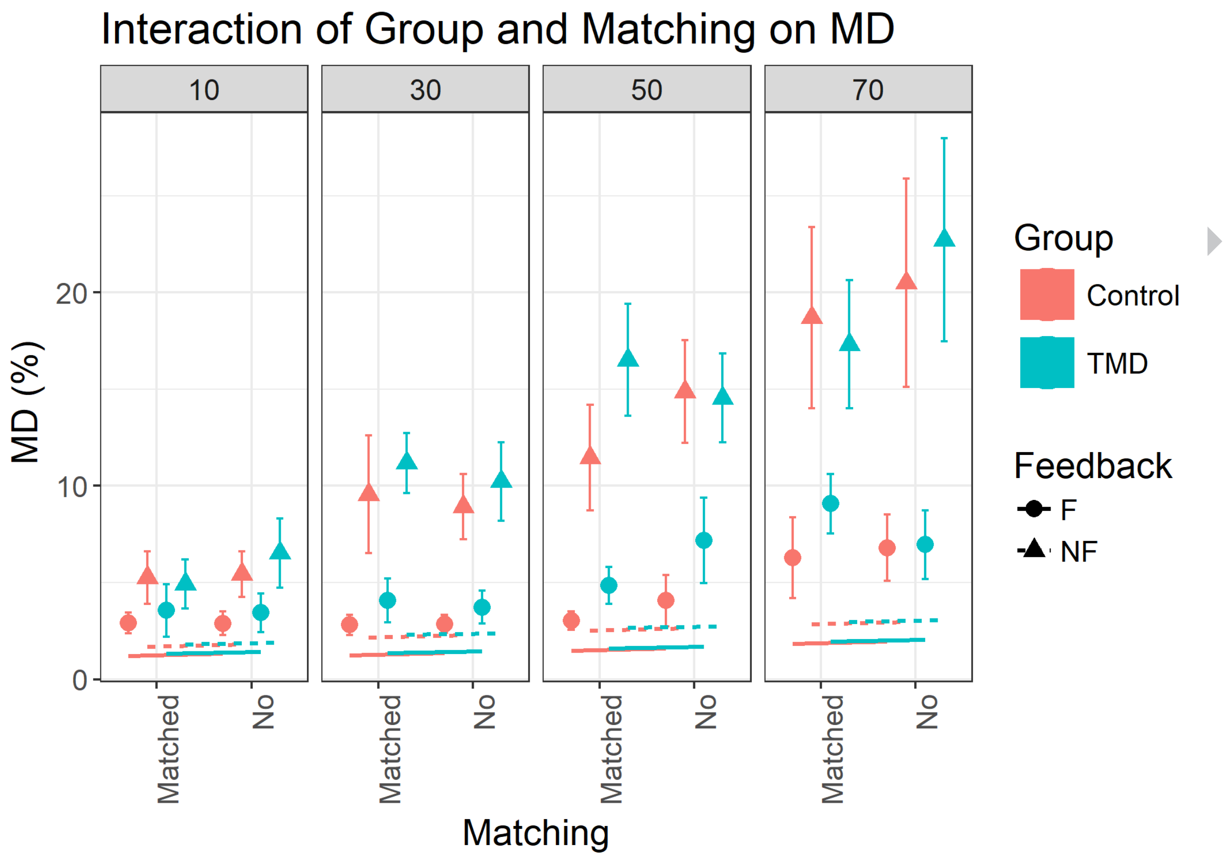
Figure 2. The mean distance (MD), calculated as the average value of the difference between the absolute values of the force delivered by the subject and the force target, of the control group and group with temporomandibular disorders, TMD performing unilateral jaw clenching of both sides (Matching) at 10, 30, 50 and 70% of the maximal voluntary contraction (MVC) both with (circles) and without (triangles) visual feedback on force. Data are presented as mean and standard error. The lines at the bottom of each panel represent the random slope intercepts across the group of the nested random effects target (panels) and feedback (with feedback = solid lines, without feedback = dashed lines).

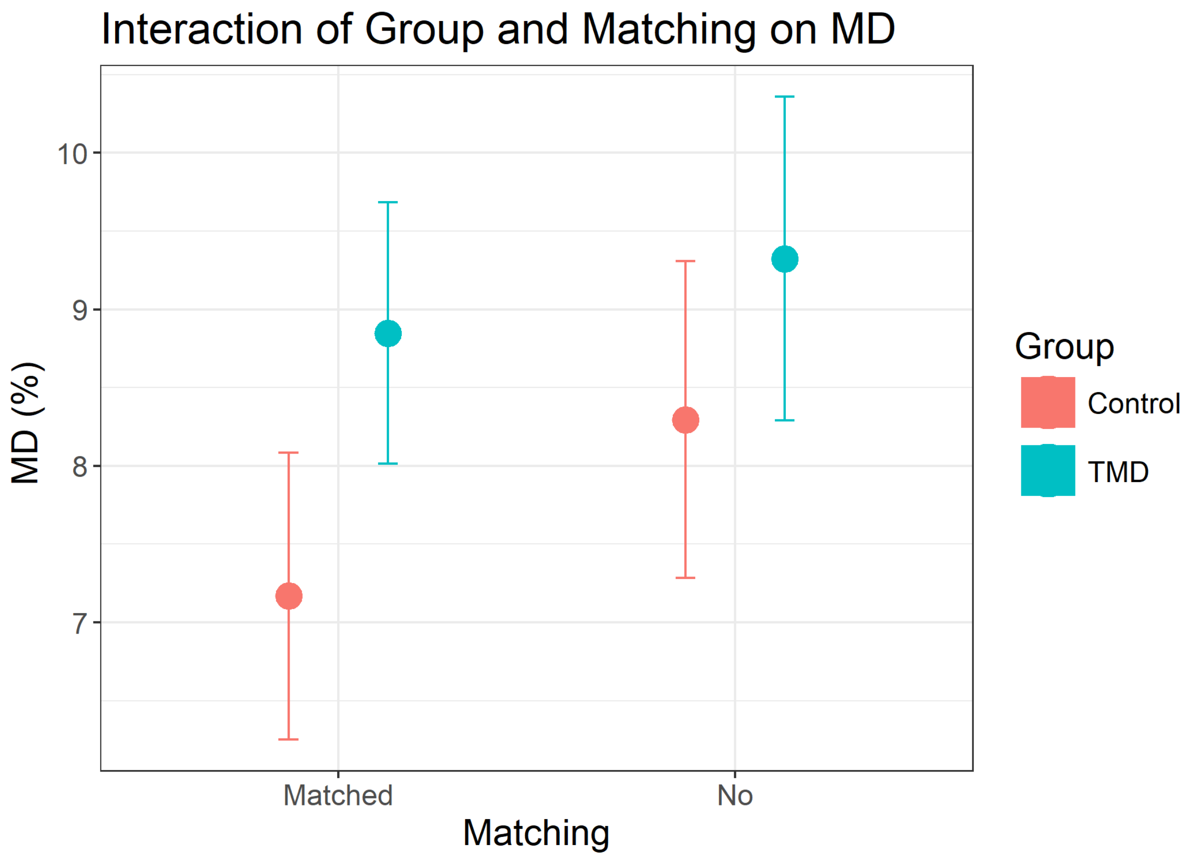
Figure 3. The interaction of the fixed effects of Group and Matching (Matched = the (most)painful side of the patient and the homologous side of the control group according to laterality, No = the contralateral sides for both groups) on the Mean Distance (MD). Data are presented as mean and standard error.

Figure 4: The standard deviation (SD) of force, a measure of the smoothness of force irrespective of the reference target, of the control group and group with temporomandibular disorders, TMD, performing unilateral jaw clenching on both sides (Matching) at 10, 30, 50 and 70% of the maximal voluntary contraction (MVC) both with (circles) and without (triangles) visual feedback on force. Data are presented as mean and standard error. The lines at the bottom of each panel represent the random slope intercepts across group of the nested random effects target (panels) and feedback (with feedback = solid lines, without feedback = dashed lines).

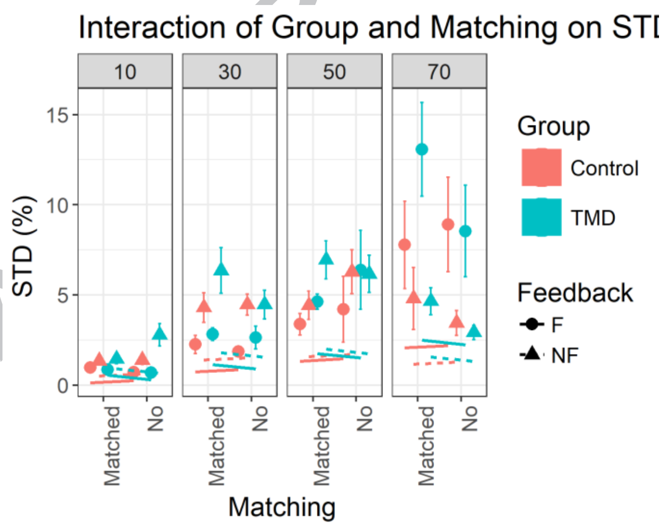
Figure 5. The interaction of the fixed effects of Group and Matching (Matched = the (most)painful side of the patient and the homologous side of the control group according to laterality, No = the contralateral sides for both groups) on the Standard Deviation (SD).



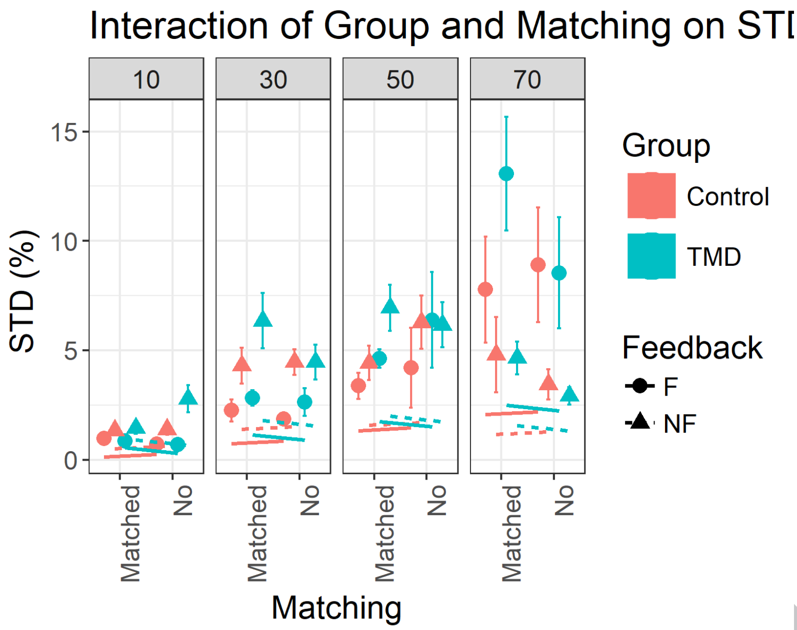

Interaction of Group and Matching on MD
10
30
50
70
MD (%)
20
10
0
Matched
No
Matching
Group
Control
TMD
Feedback
F
NF



Interaction of Group and Matching on MD
MD (%)
10
9
8
7
Matched
No
Matching
Group
Control
TMD



Interaction of Group and Matching on STI
10
30
50
70
STD (%)
15
10
5
0
Matched
No
Matching
Group
Control
TMD
Feedback
F
NF



Interaction of Group and Matching on STI
10
30
50
70
STD (%)
15
10
5
0
Matched
No
Matching
Group
Control
TMD
Feedback
F
NF

Marco Testa graduated in Physical Education in 1985 and in Physiotherapy in 1988. He works as assistant professor at the Department of Neuroscience, Rehabilitation, Ophthalmology, Genetic, Maternal and Child Health of the University of Genova – Campus of Savona. He is president of the Master in Rehabilitation of Musculoskeletal Disorders (www.masteromt.unige.it). He teaches Manual Therapy in the School of Physiotherapy and Physical Medicine and Rehabilitation at the Medical Specialty of Rheumatology of the University of Genova. His didactic, clinical and scientific interests concern the field of musculoskeletal rehabilitation, with special attention to cervical and temporomandibular disorders. His recent research activities include: Clinical validation and implementation of a visual feedback system for assessment of motor control of bite and pinching force, Development and validation of a "sensorised" sit to stand test, Investigation of Placebo mechanisms in musculoskeletal rehabilitation. Holder of an international patent on a system of evaluation of the mandibular motor control, he is member of the editorial board of Manual Therapy Journal, Archives of Physiotherapy and Scienza Riabilitativa.

Tommaso Geri graduated in Physiotherapy in 2005 at the University of Firenze, took a PGCert in Rehabilitation of Musculoskeletal Disorders at the University of Genova - Campus of Savona in 2008, and a MSc in Sciences of Health Professions of Rehabilitation in 2012 at the University of Firenze. In 2016, he earned a PhD in Sciences of Motor and Sport Activities at the University of Genova. He works as a research fellow at the Department of Neuroscience, Rehabilitation, Ophthalmology, Genetic, Maternal and Child Health of the University of Genova – Campus of Savona. He is lecturer of the Master in Rehabilitation of Musculoskeletal Disorders (www.masteromt.unige.it). He works as a private practitioner in Pistoia (PT, Italy) and Maresca (PT, Italy) as physiotherapist specialized in rehabilitation of musculoskeletal disorders.

Laurent Pitance is an Assistant Professor in musculoskeletal physiotherapy at the Université Catholique de Louvain (UCL) and researcher at the Institute of Experimental and Clinical Research (IREC). His area of research focuses on orofacial pain and more particularly temporomandibular disorders as well as cervical spine disorders. Laurent Pitance also retains a substantial clinical activity as a physiotherapist in the Department of Stomatology and Maxillofacial Surgery of Cliniques Universitaires Saint-Luc (Brussels) where he has developed a particular skill in the management of cervical and orofacial pain. He also participates in the training of dentists at the UCL School of Dentistry and Stomatology.

Philippe Lentz is a physiotherapist in the orthopedic/traumatic unit at Centre Hospitalier du Nord, Luxembourg. He completed his master's degree in manual therapy and sports physiotherapy at Université Catholique de Louvain, Belgium.

Leonardo Gizzi received his degree in BIomedical Engineering at University "La Sapienza" in 2006 and his PhD in Sport Sciences and Health (human physiology) in 2010 at University "Foro Italico", in Rome, Italy . From 2008 to 2010 he was research fellow in Department of Health Science and Technology of Aalborg University. From 2011 to 2016 he served as postdoctoral scientist and head of the Motor Physiology and Biomechanics Laboratory at Universitätsmedizin Göttingen where he worked at the Pain Clinic and the the Institute of Neurorehabilitation Systems.

Since 2016 he serves as Senior Research Associate at the Continuum Biomechanics and Mechanobiology Research Group at University of Stuttgart. At the present he co-authored 29 peer-reviewed papers and over 35 conference contributions.

His research focuses on the neuromechanics of human movement (from individual motor units to muscle synergies, in healthy individuals, clinical settings and sports) and the development and validation of 3D continuum and finite elements neuromusculoskeletal models.

Joachim Erlenwein is a Medical Doctor working in the Pain Clinic, Center for Anesthesiology, Emergency and Intensive Care Medicine, University Hospital Göttingen, Germany.

Frank Petkze is a Medical Doctor and Director of the Pain Clinic, Center for Anesthesiology, Emergency and Intensive Care Medicine, University Hospital Göttingen, Germany.

Deborah Falla is Chair in Rehabilitation Science and Physiotherapy at the University of Birmingham, UK and is the Director of the Centre of Precision Rehabilitation for Spinal Pain (CPR Spine). Her research focus is on optimizing the management of musculoskeletal disorders with a particular interest in spinal pain. She has published over 170 papers in international, peer-reviewed journals, and more than 200 conference papers/abstracts including over 30 invited/keynote lectures She has received several recognitions and awards for her work including the German Pain Research Prize in 2014, the George J. Davies - James A. Gould Excellence in Clinical Inquiry Award in 2009 and the Delsys Prize for Electromyography Innovation in 2004. Professor Falla is an author/editor of three books including the latest published in 2018 entitled “Management of neck pain disorders: a research informed approach” (Elsevier). Professor Falla acts as an Associate Editor for Musculoskeletal Science & Practice, the Journal of Electromyography and Kinesiology and IEEE Transactions on Neural Systems & Rehabilitation Engineering. Since 2016, she is President of the International Society of Electrophysiology and Kinesiology (ISEK).