ACTA ODONTOLOGICA SCANDINAVICA
2020, VOL. 78, NO. 4, 309–320
https://doi.org/10.1080/00016357.2019.1707868

Taylor & Francis
Taylor & Francis Group

Check for updates

ORIGINAL ARTICLE

# Effect of transcutaneous electrical nerve stimulation on jaw movement-evoked pain in patients with TMJ disc displacement without reduction and healthy controls

Yuanxiu Zhang[a,b,c,d], Jinglu Zhang[a,c], Lin Wang[a,b,c], Kelun Wang[c,e] and Peter Svensson[d,f,g]

[a]Jiangsu Key Laboratory of Oral Diseases, Nanjing Medical University, Nanjing, China; [b]Department of Orthodontics, Affiliated Hospital of Stomatology, Nanjing Medical University, Nanjing, China; [c]Orofacial Pain & TMD Research Unit, Institute of Stomatology, Affiliated Hospital of Stomatology, Nanjing Medical University, Nanjing, China; [d]Section of Orofacial Pain and Jaw Function, Department of Dentistry and Oral Health, Aarhus University, Aarhus, Denmark; [e]Center for Sensory-Motor Interaction (SMI), Aalborg University, Aalborg, Denmark; [f]Faculty of Odontology, Malmö University, Malmö, Sweden; [g]Scandinavian Center for Orofacial Neurosciences, (SCON), Aarhus, Denmark

**ABSTRACT**

**Objective:** Transcutaneous electrical nerve stimulation (TENS) may serve as non-invasive intervention for painful temporomandibular disorders (TMD) to improve jaw motor function, but its efficacy is still debated. This parallel study evaluated the effect of TENS on pain and movement patterns after repeated jaw movements in patients with painful temporomandibular joints (TMJ) and disc displacement without reduction (DDwoR), and compared with healthy controls.

**Material and Methods:** 20 patients with TMJ pain and DDwoR and 20 age- and gender-matched healthy volunteers were randomly assigned to TENS/sham TENS (sTENS) intervention groups in a block design (10 in each group). Participants performed 20 repeated jaw movements (4 x 5 sessions), and reported pain intensity on a 0–10 Numerical Rating Scale (NRS) subsequently both before and after the intervention. Data were tested by repeated measures analysis of variance (ANOVA).

**Results:** Significant increase of pain intensity and reduction of opening range were shown within repeated jaw movements in TMJ pain patients in contrast to healthy participants ($p \leq .001$). Pain was significantly reduced during repeated open-close ($p = .007$), fast open-close ($p = .016$) and horizontal movements ($p = .023$), accompanied with increased opening range ($p = .033$) and open-close velocity ($p = .019$) with TENS intervention when compared with sTENS group ($p > .05$) in TMJ pain patients.

**Conclusions:** This study indicated that movement-evoked pain was reduced either spontaneously or by sTENS in TMJ pain patients with DDwoR, and interestingly, that TENS could attenuate movement-evoked pain and improve jaw motor function during repeated jaw movements. The findings may have implications for TENS treatment in TMJ pain patients with DDwoR.

**ARTICLE HISTORY**
Received 2 August 2019
Revised 29 November 2019
Accepted 17 December 2019

**KEYWORDS**
Temporomandibular Disorders; Disc displacement without reduction; Facial pain; Mandibular movements; Transcutaneous electrical nerve stimulation

## Introduction

There is evidence showing that repetition-induced pain might have different mechanisms and prognosis from spontaneous chronic pain [1–4]. Temporal summation-evoked pain is considered to be the result of responses from C nociceptive afferent neurons [4–7]. Individuals with hyperalgesia to repeated motor performance might show lower pain thresholds as well as more functional impairment due to a central pain inhibitory dysfunction [8–11]. So far there is no information on how movement-evoked pain in patients with painful temporomandibular disorders (TMD) can be best managed. Recently, it was demonstrated that patients with painful temporomandibular joints (TMJ) had a pronounced temporal summation of simple jaw movements in terms of self-reported pain scores and decreases in jaw movement capacity [12].

TMJ disc displacement without reduction (DDwoR) is a common type of internal derangement that may be accompanied with chronic TMJ pain, and sometimes, with compromised mandibular kinematics [13]. The physiological purpose for such changes in jaw motor function might be a protection of the painful TMJs against further damage, and this may provide a better chance for healing of the masticatory system [14]. It has been reported that people with chronic pain can present with deficits in jaw motor performance, which can be expressed as decreased speed and amplitude of movements associated with decreased activity in the agonist phase and increased activity in the antagonist phase of dynamic muscle contractions – the so-called pain adaptation model [15]. The findings from our previous study demonstrated that repetition of various jaw movements led to an increase in perceived pain and decreases in the jaw movement distances. These results can be interpreted to be in

**CONTACT** Jinglu Zhang zhangjinglu@njmu.edu.cn Orofacial Pain & TMD Research Unit, Institute of Stomatology, Affiliated Hospital of Stomatology, Nanjing Medical University, 136 Hanzhong Road, Nanjing, 210029, China

© 2019 Acta Odontologica Scandinavica Society

accordance with the pain adaptation model and more specifically the integrated pain adaption model, by showing that the temporal summation of pain may play a significant role in shaping and adapting the jaw motor behaviour [12]. Overall, such findings may also be consistent with the observation that temporal summation of nociceptive inputs can play a crucial role for the maintenance of a sensitised state in TMJ pain patients with DDwoR [16,17].

Transcutaneous electrical nerve stimulation (TENS), the electrical stimulation of pulsed currents delivered to the skin surface, is a non-invasive technique often used as a pain management intervention with sufficient clinical effects in reducing pain although the efficacy and specificity has been contested [18]. Some studies showed no evidence of TENS effectiveness in terms of jaw opening distance or muscular activity [19–21]. In other studies, however, short-term effects of TENS have been shown to decrease pain and improve the masticatory muscle activity in patients with chronic TMD [22–25]. Also, TENS delivered at higher intensities appear to generate greater pain relief [26]. Interestingly, it has been shown that repetition-induced summation of activity-related pain can be demonstrated in healthy individuals in whom musculoskeletal pain had been experimentally induced with a delayed-onset muscle soreness (DOMS) model, and that TENS led to a significant reduction in such pain conditions [27].

A question of interest is how the application of TENS might influence repetition-evoked pain and pain-generated dysfunction in chronic TMJ arthralgia with DDwoR. The proposed goals for chronic musculoskeletal pain treatment are pain reduction as well as function improvement [28]. Therefore, the present study aimed to clarify the change of dynamic self-reported pain and movement pattern following repeated jaw movements in patients with painful TMJ and DDwoR in comparison with a matched control group, and to test whether TENS would be effective in attenuating the movement-evoked pain in the painful TMJ with DDwoR. The hypothesis was that TENS would cause pain reduction and motor improvement during repeated jaw movements in patients with TMJ pain and DDwoR.

## Materials and methods

### Participants

Twenty TMJ pain patients with DDwoR (10 men and 10 women, aged 25–38 years) and 20 age- and gender-matched healthy individuals participated in this study. The patients were recruited from the clinic of the Affiliated Stomatological Hospital of Nanjing Medical University, P. R. China. The inclusion criteria were: (1) chronic TMJ pain (TMJ arthralgia, pain duration >3 months), (2) no jaw opening limitation, and (3) a diagnosis of bilateral DDwoR. The exclusion criteria were as follows: (1) any systemic disorder (e.g. rheumatological diseases, heart diseases, psychological disorders), (2) any history of neuromuscular diseases, musculoskeletal injuries or jaw muscle pain. After receiving an initial interview, 67 patients who had no jaw opening limitation but the chief complaint of TMJ pain over three months and a history of joint sounds were referred for screening. The potential participants were assessed by a calibrated investigator according to the Diagnostic Criteria for TMD (DC/TMD) for the diagnosis of arthralgia [29], and then by a bilateral TMJ magnetic resonance imaging (MRI) (Philips-Acheiva, Magnetom Vision, Siemens, Erlangen, Germany) for the diagnosis of DDwoR. After selection, 20 participants met the inclusion criteria of chronic TMJ arthralgia and bilateral DDwoR. All the patients who met the inclusion criteria were included in the TMJ pain with DDwoR group. The duration of TMJ pain was 6–18 months among the included patients. No previous treatment was given to the participants. The control participants were recruited from Nanjing Medical University and were screened and examined with the same procedure. All participants were notified of the procedures and purpose of this study, and informed written consent was obtained from all volunteers before initiation of the study. Experimental procedures were approved by the clinical/human experimentation panel from Ethics Committee of Affiliated Stomatological Hospital of Nanjing Medical University, and in accordance with the Helsinki Declaration (Approval number: PJ2015-001-01). No monetary incentives were given to volunteers.

### Study protocol

This study followed the principles of a randomised controlled trial but is more considered a mechanistic study than a clinical intervention study. Both TMJ pain patients with DDwoR and control participants were randomly assigned to two groups in a block design (equal numbers in each group, 10 participants): TENS and sham TENS (sTENS) group (Figure 1(A)). Three different scans of mandibular motor function were recorded with the use of a Cranio-Mandibular Evaluation System (K7, Myotronics-noroned; INCKent, WA, USA), i.e. scan 1: maximum opening distance; scan 2: open-close velocity, and scan 3: maximum horizontal movement range (see “Jaw movement recordings” for more details). All participants performed 4 continuous repetitive jaw movements $\times$ 5 sequential sessions (3 s intervals between each session) of mandibular movements for each scan with the starting and ending point at the intercuspal position (ICP), i.e. a total of 20 repeated and standardised jaw movements were recorded for each scan. The pain intensity at the TMJ area was scored by the participants on 0–10 NRS immediately after each session, i.e. an overall average of the 4 continuous movements. There were 10 min of rest between each of the three scans (Figure 1(B)). The data from the scans (i.e. the repetitive jaw movements) and NRS were collected by the same investigator before and after TENS/sTENS application for all participants (Figure 1(A)).

### MRI technique

MRI of the TMJs was carried out by using a 1.5-T MRI machine (Philips-Acheiva, Magnetom Vision, Siemens, Erlangen, Germany) in both sagittal and coronal planes to determine the position of the articular discs and the status of related tissue. Sagittal oblique T2-weighted images (T2WI)

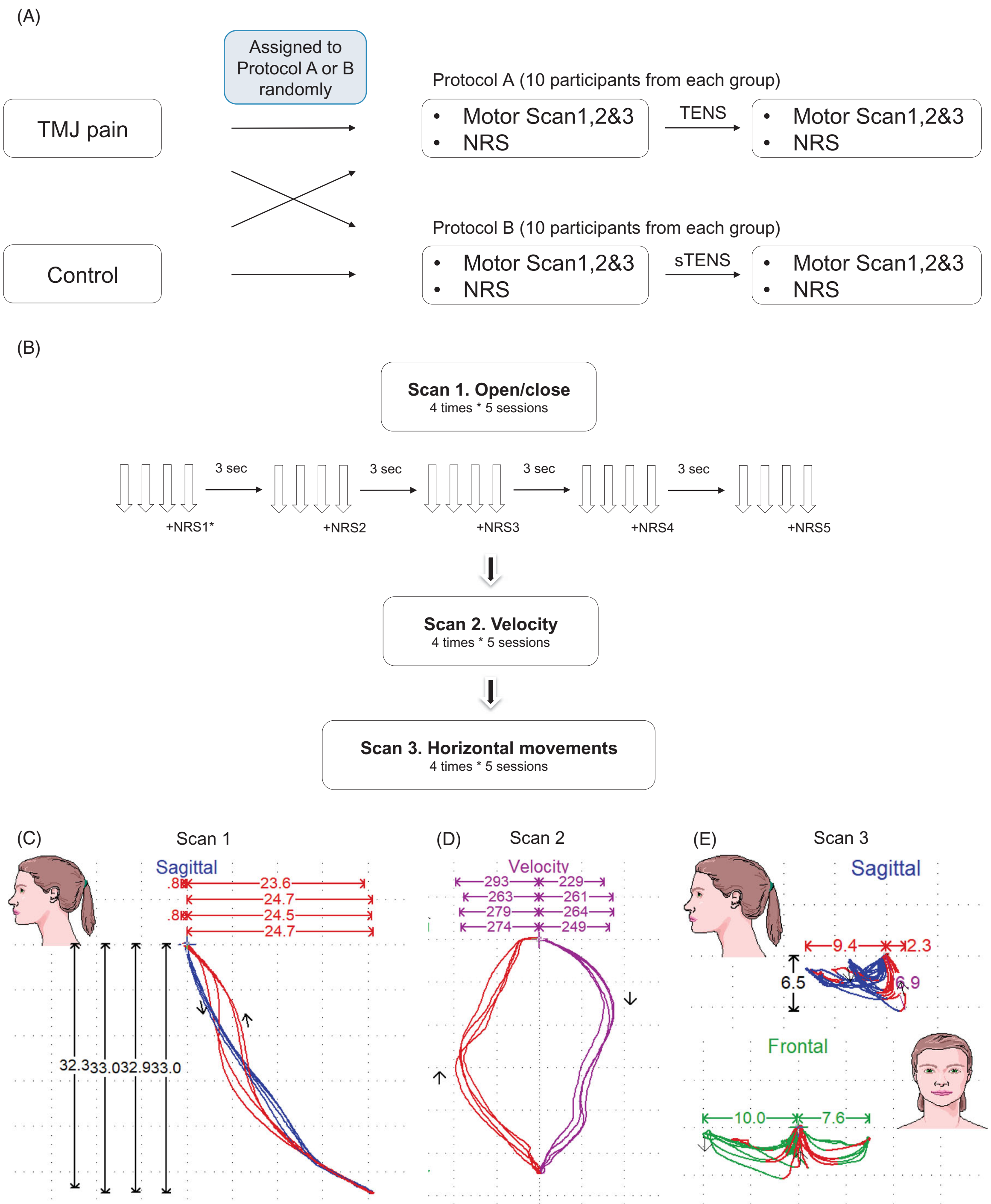


**Figure 1.** Flow-charts of the study protocol. (A) The participants were randomly assigned to one of the protocols. (B) Three different jaw movements were applied, and the Numerical Rating Scale (NRS) scores of pain were recorded after every fourth movement. (C)-(E) Different scans of repeated movements of mandible. * The NRS 1 is as also considered the baseline NRS.

and proton density (PD) weighted images were taken in maximum intercuspal position and full mouth opening positions (TR = 3000/3500 ms, TE = 120/30 ms respectively) and coronal PD weighted images in closed mouth position (TR = 3500 ms, TE = 30 ms). Section thickness was 2 mm with a 0.2 mm intersection gap. The field of view was settled with 12 cm for sagittal images and 18 cm for coronal images. The diagnosis of DDwoR according to MRI was provided by an experienced radiologist.

### *Jaw movement recordings*

A magnet was installed on the labial side of the lower central incisors of each participant without occlusal interference from the upper teeth in ICP. The participants were instructed to sit up straight and stare horizontally forward at a fixed object. Then the jaw tracker which consisted of an eyeglass frame and sensor array was placed on the head. After connecting the jaw tracker to the computer and finishing all the adjustment, the following scans began to be recorded in sequence: Scan 1) The total opening distance (TOD) of maximum open-close movements: The participants, in their ICP position, were instructed to open their jaws as wide as possible (even with pain) and then close to ICP and subsequently again to open as wide as possible following a computer-generated rhythm at the speed of 70 mm/s. The total length of the movement vectors during the maximum opening position was recorded, which was termed TOD (Figure 1(C)). Scan 2). The average opening and closing velocity of the lower jaw at the fastest speed: the participants were instructed to open maximally and close as fast as possible, with the beginning and end point of ICP. The average opening and closing velocities were recorded (Figure 1(D)). Scan 3) The range of motion during horizontal jaw movements in three directions: the participants were asked to protrude their lower jaw as far as possible (even if painful) and then to move the lower jaw as far as possible to the right and to the left to obtain the maximum laterotrusive positions (even if painful). The length of each of the jaw movement vectors was recorded (Figure 1(E)). Meanwhile, participants verbally gave pain intensity ratings in the TMJ area immediately after every 4th continuous movement using the 0–10 NRS with the endpoints 0 (no pain) and 10 (most pain imaginable) (Figure 1(B)).

### *TENS/sTENS application*

The electrical stimulation was generated *via* a TENS unit (J5 Myo-monitor; Myotronics-noromed, INC., Seatile, USA). The TENS parameters were rectangular pulse current waveforms with 500 μs pulse duration and 1.5 s interval. The stimulation intensity was set below pain threshold. Electrical stimulation was delivered through self-adhesive carbon rubber electrodes positioned over the TMJ region bilaterally. Muscle contraction was seen during the application. TENS lasted for 45 min with a green light flashing. For the sTENS protocol, the same device with the same green light flashing for 45 min was used, but with no electrical output. Participants were explained that a new way of treatment would be applied with the use of the device, and stressed that it was not painful and that it would be quite normal not to feel any kind of sensation/stimulation during the process. After the TENS/sTENS treatment, all participants were asked the question: "which treatment do you think you have received?" to exam if the blinding was successful [30].

### *Statistical analysis*

The maximum opening distance, the velocity of fast open-close movements and horizontal movement in three directions were derived from the average of four movements in each session. The NRS pain scores were recorded at the end of the fourth movement in each session, generating five values from five sessions (NRS 1–5). A four-way analysis of variance (ANOVA) model with repeated measures was performed to analyse the effects of the within-subject factors of time (2 levels: before TENS/sTENS and after TENS/sTENS) and session (5 levels: session 1–5), as well as the effects of the between-subject factors of group (2 levels: control and TMJ pain with DDwoR) and intervention (2 levels: TENS and sTENS) on NRS scores and jaw opening distance. A five-way ANOVA model with repeated measures was performed to analyse the effects of the within-subject factors of mode (2 levels: open and close for the fast open-close velocity; 3 levels: protrusion, left and right for the horizontal movement range), time and session, as well as the effects of the between-subject factors of group and intervention in terms of fast open-close velocity and horizontal movement range. Tukey HSD post hoc tests were applied when main effects and/or interactions were significant. Fisher's exact test for a contingency table was used for assessment of the blinding procedure [30]. All statistical calculations were performed using STATISTICA (version 10.0; StatSoft. Inc., Tulsa, OK, USA). The data were presented as mean ± standard error of mean (SEM) and levels of $p < .05$ were considered statistically significant.

## Results

All participants completed all procedures in the experiment. Blinding was successful in both groups as no statistical difference was found between the proportion of participants who correctly identified the intervention and those who did not (Fisher's exact test, $p > .05$) (Table 1).

The mean values of NRS and jaw movement distance are shown in Table 2.

### *Pain assessment*

#### Pain during normal jaw opening and closing

There was a statistically significant main effect of group (ANOVA, $F = 77.7$, $p < .001$) and session (ANOVA, $F = 49.35$, $p < .001$), and also significant interactions between time, group and intervention (ANOVA, $F = 8.26$, $p = .007$), and between session and group (ANOVA, $F = 37.57$, $p < .001$) (Table 3). Post-hoc tests showed that the NRS pain scores were significantly decreased after TENS compared to that before TENS by 0.8 ± 0.4 in the TMJ pain with DDwoR TENS group (ANOVA, $p = .031$), but not in the TMJ pain with DDwoR sTENS group or in the control TENS/sTENS groups (ANOVA, $p > .05$) (Table 3). Additionally, the NRS scores of pain in session 5 was increased by 1.2 ± 0.1 compared to the session 1 in the TMJ pain with DDwoR group (ANOVA, $p < .001$) when compared with the control group (ANOVA, $p = .989$) (Table 3).

**Table 1.** Number of subjects by intervention assignment and guess in 2 × 3 format.

| Group | Intervention | Correct | Incorrect | Don't know | Total |
|---|---|---|---|---|---|
| Control | TENS | 7 | 2 | 1 | 10 |
| | sTENS | 5 | 5 | 0 | 10 |
| TMJ pain | TENS | 7 | 2 | 1 | 10 |
| | sTENS | 4 | 6 | 0 | 10 |
| Total | | 23 | 15 | 2 | 40 |

Table 2. The mean values of repeated NRS, jaw movement distance, and velocity in the open-close, the fast open-close and the horizontal movements.

| | TMJ pain (20 participants) | | | | Control (20 participants) | | | |
|---|---|---|---|---|---|---|---|---|
| | TENS (10 participants) | | sTENS (10 participants) | | TENS (10 participants) | | sTENS (10 participants) | |
| | Before | After | Before | After | Before | After | Before | After |
| NRS in open-close movements (0–10) | 2.5 ± 0.5* | 1.7 ± 0.3 | 2.4 ± 0.4 | 3.1 ± 0.4 | 0.1 ± 0.1 | 0.1 ± 0.1 | 0.0 ± 0.0 | 0.0 ± 0.0 |
| NRS in fast open-close movements (0–10) | 4.5 ± 0.5 | 3.5 ± 0.4 | 3.9 ± 0.4 | 4.5 ± 0.7 | 0.4 ± 0.2 | 0.2 ± 0.2 | 0.1 ± 0.1 | 0.0 ± 0.0 |
| NRS in horizontal movements (0–10) | 4.4 ± 0.5 | 3.2 ± 0.5 | 3.6 ± 0.4 | 3.4 ± 0.5 | 0.6 ± 0.2 | 0.2 ± 0.1 | 0.4 ± 0.3 | 0.2 ± 0.2 |
| TOD in open-close movements (mm) | 40.5 ± 2.3 | 41.5 ± 2.2 | 41.0 ± 1.4 | 39.5 ± 2.0 | 43.2 ± 2.0 | 43.6 ± 1.8 | 42.7 ± 2.1 | 42.4 ± 2.3 |
| AOV in fast open-close movements (mm/s) | 152.2 ± 12.1 | 164.9 ± 15.2 | 160.8 ± 11.2 | 144.5 ± 10.5 | 173.4 ± 10.1 | 170.6 ± 9.1 | 139.2 ± 8.7 | 140.9 ± 12.7 |
| ACV in fast open-close movements (mm/s) | 144.1 ± 20.6 | 156.3 ± 20.0 | 140.4 ± 16.5 | 129.8 ± 16.2 | 188.3 ± 11.5 | 199.1 ± 12.3 | 133.3 ± 8.7 | 143.3 ± 6.9 |
| PD in horizontal movements (mm) | 6.4 ± 0.4 | 6.8 ± 0.3 | 6.9 ± 0.8 | 7.2 ± 0.7 | 7.7 ± 0.5 | 7.7 ± 0.8 | 5.9 ± 0.8 | 5.7 ± 0.7 |
| LMD in horizontal movements (mm) | 5.4 ± 0.6 | 6.3 ± 0.4 | 6.7 ± 1.0 | 6.6 ± 0.5 | 6.4 ± 0.7 | 6.3 ± 0.7 | 6.7 ± 1.3 | 5.3 ± 0.7 |
| RMD in horizontal movements (mm) | 6.1 ± 0.4 | 6.7 ± 0.6 | 7.6 ± 1.1 | 7.7 ± 1.0 | 6.0 ± 0.6 | 5.8 ± 0.5 | 5.6 ± 0.8 | 5.2 ± 0.7 |

*Values are Mean ± SEM. Mean = the average of 5 sessions.
NRS: Numeric rating scale; TOD: Total opening distance; AOV: Average opening velocity; ACV: Average closing velocity; PD: Protrusion distance; LMD: Left movement distance; RMD: Right movement distance; sTENS: sham TENS.

Table 3. The statistical value of the main effects and the interactions of NRS in the open-close and the fast open-close movements.

| | | | | | Interaction | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Time[a] | Session[b] | Time[a] × Group[a] × Intervention | | Session[a] × Group | |
| NRS | Group | Intervention | *p* | *p* | F | *p* | F | *p* |
| NRS (OC) | TMJ pain | TENS | .031 | <.001 | 8.26 | .007 | 37.57 | <.001 |
| | | sTENS | .141 | | | | | |
| | Control | TENS | 1.000 | .989 | | | | |
| | | sTENS | 1.000 | | | | | |
| NRS (fast OC) | TMJ pain | TENS | .038 | <.001 | 6.4 | .016 | 9.2 | <.001 |
| | | sTENS | .447 | | | | | |
| | Control | TENS | .999 | .677 | | | | |
| | | sTENS | .999 | | | | | |

NRS: Numeric rating scale; OC: Open-close movement; Fast OC: Fast open-close movement.
[a]The difference of NRS between “before TENS/sTENS” and “after TENS/sTENS”.
[b]The difference of NRS between “session1” and “session5”.

### *Pain during fast opening and closing*

There was a statistically significant main effect of group (ANOVA, $F = 129.8$, $p < .001$) and session (ANOVA, $F = 21.1$, $p < .001$). There were significant interactions between time, group and intervention (ANOVA, $F = 6.4$, $p = .016$), between time and intervention (ANOVA, $F = 8.3$, $p = .007$), and between session and group (ANOVA, $F = 9.2$, $p < .001$) (Table 3). Post-hoc tests showed that the NRS pain scores were significantly decreased after TENS compared to that before TENS by 1.0 ± 0.3 in the TMJ pain with DDwoR TENS group (ANOVA, $p = .038$), but not in the TMJ pain DDwoR sTENS group or in the control TENS/sTENS groups (ANOVA, $p > .05$) (Table 3). Moreover, the NRS in session 5 was increased by 1.3 ± 0.3 compared to the session 1 in the TMJ pain with DDwoR group (ANOVA, $p < .001$), but not in the control group (ANOVA, $p = .677$) (Table 3).

### *Pain during horizontal movements*

There was a statistically significant main effect of group (ANOVA, $F = 94.69$, $p < .001$), time (ANOVA, $F = 17.59$, $p < .001$) and session (ANOVA, $F = 20.78$, $p < .001$). There were significant interactions between time and intervention (ANOVA, $F = 5.63$, $p = .023$), and between session and group (ANOVA, $F = 8.12$, $p < .001$). Post-hoc tests showed that the NRS pain scores were significantly decreased after TENS compared to that before TENS by 0.8 ± 0.2 in the TENS group (ANOVA, $p < .001$), but not in the sTENS group (ANOVA, $p = .577$). The NRS pain score in the TMJ pain with DDwoR TENS group was decreased by 1.2 ± 0.3, and the NRS pain score in the control TENS group was decreased by 0.4 ± 0.2. Additionally, the NRS in session 5 was increased by 1.0 ± 0.2 compared to the session 1 in the TMJ pain with DDwoR group (ANOVA, $p < .001$), but not in the control group (ANOVA, $p = .215$).

The results showed decreased levels of NRS pain scores after TENS compared to that before TENS in the TMJ pain with DDwoR group, however the temporal summation of pain remained unchanged. Figure 2 shows the changes of NRS during repeated movements, in which a value of “change” is obtained by subtracting the session of NRS before TENS/sTENS intervention and the corresponding session after intervention (e.g. NRS1 before intervention minus NRS1 after intervention). In that case, a negative value stands for the increase of NRS after intervention.

## *Jaw functional assessment*

### *Total opening distance (TOD)*

There was a statistically significant main effect of session (ANOVA, $F = 4.397$, $p = .002$). There were significant interactions between time, session and intervention (ANOVA, $F = 2.706$, $p = .033$), between time and intervention (ANOVA, $F = 6.044$, $p = .019$), and between session and group (ANOVA, $F = 5.966$, $p < .001$). Post-hoc tests showed that the TOD in session 5 was decreased by 2.1 ± 0.6 mm after sTENS

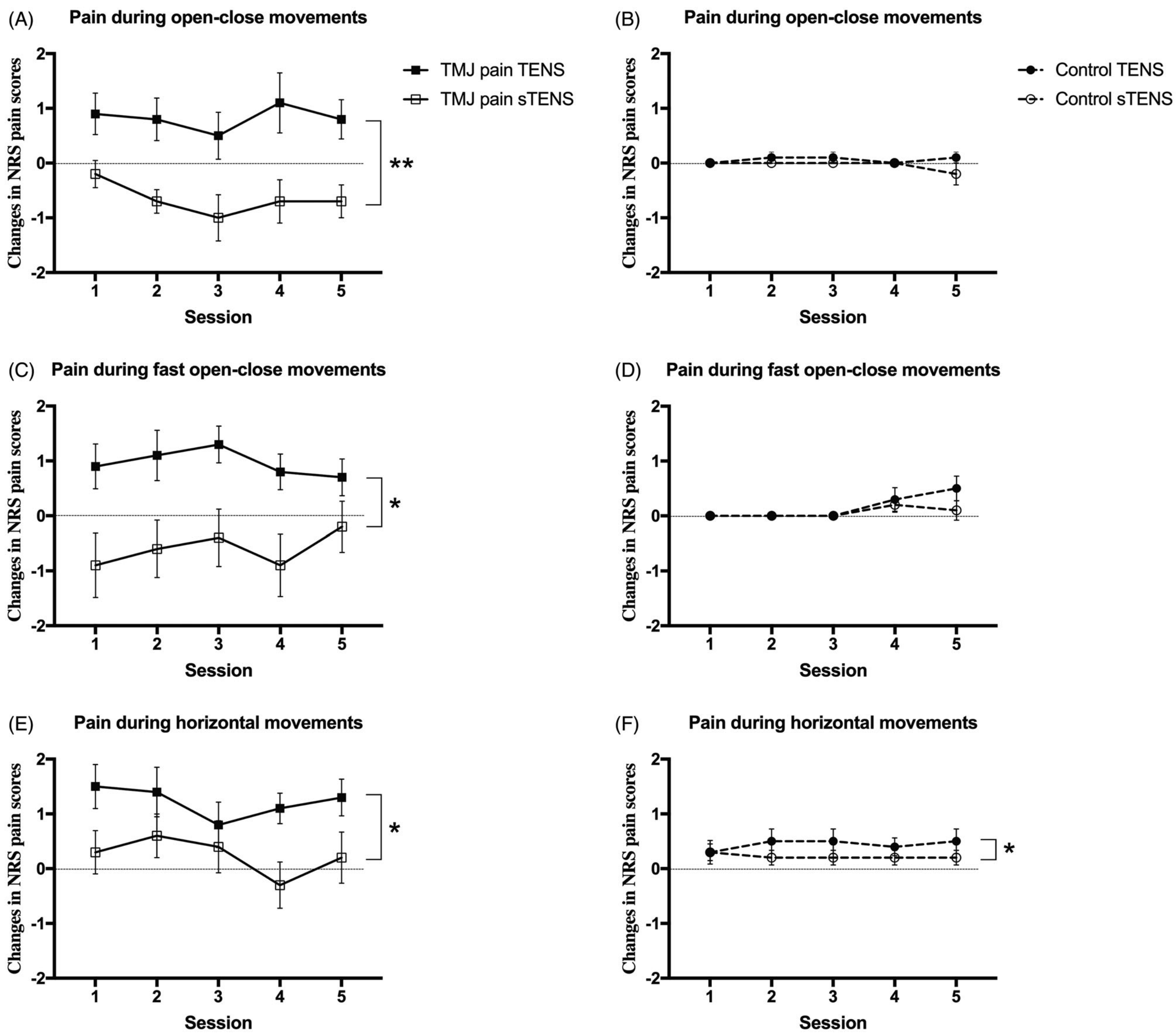


**Figure 2.** Change of Numerical Rating Scale (NRS) scores of pain evoked by three different movement patterns. (A)-(B) Change of NRS pain scores in open-close movements in the TMJ pain group with DDwoR and in the control group. (C)-(D) Change of NRS pain scores in fast movements in the TMJ pain group with DDwoR and in the control group. (E)-(F) Change of NRS pain scores in horizontal movements in the TMJ pain group with DDwoR and in the control group. *represents the significance between groups with different methods of treatment (TENS/sTENS) ($p < .05$); **represents the significance between groups with different methods of treatment (TENS/sTENS) ($p < .01$). Mean ± SEMs are presented.

compared to that before sTENS (ANOVA, $p < .001$), while there was no significant difference of TOD before and after TENS intervention (ANOVA, $p = .548$). Meanwhile, the TOD in session 5 was decreased by 2.3 ± 0.6 mm compared to the session 1 in the TMJ pain with DDwoR group (ANOVA, $p < .001$), but not in the control group (ANOVA, $p = .999$). Therefore, the TOD decreased less over repeated jaw movements after TENS compared to that before TENS in the TMJ pain with DDwoR group.

## *Average velocity of fast movements*

There was a statistically significant main effect of intervention (ANOVA, $F = 5.821$, $p = .021$). There were significant interactions between mode, time, session, group and intervention (ANOVA, $F = 3.057$, $p = .019$), between time, group and intervention (ANOVA, $F = 5.755$, $p = .022$), and between time, session and group (ANOVA, $F = 3.886$, $p = .005$) (Table 4). Post-hoc tests showed an increase of average opening velocity (AOV) (ANOVA, $p = .039$) and an increase of average closing velocity (ACV) (ANOVA, $p < .001$) in session 5 after the TENS intervention compared to that from session 5 before TENS in the TMJ pain with DDwoR group (Table 4). Therefore, the average velocity decreased less over repeated jaw movements after TENS compared to that before TENS in the TMJ pain with DDwoR group.

## *Horizontal movement range*

There was neither any significant main effect nor significant interactions for the horizontal movement ranges in three directions.

Figures 3–5 show the changes of opening range, average velocity and horizontal range during repeated movements, in

Table 4. The statistical value of the main effects and the interactions of jaw average velocity in the repeated fast open-close movements.

| | | Time[a] | Interaction: Mode[a] × Time[a] × Session[a] × Group[a] × Intervention | |
|---|---|---|---|---|
| Group | Intervention | $p$ | F | P |
| AOV | | | 3.057 | 0.019 |
| TMJ pain | TENS | .039 | | |
| | sTENS | .998 | | |
| Control | TENS | .999 | | |
| | sTENS | .999 | | |
| ACV | | | | |
| TMJ pain | TENS | <.001 | | |
| | sTENS | .999 | | |
| Control | TENS | .999 | | |
| | sTENS | .999 | | |

AOV: Average opening velocity; ACV: Average closing velocity.
[a]The difference of average velocity between "before TENS/sTENS" and "after TENS/sTENS" in session5.

which a value of "change" is derived from the session of NRS before TENS/sTENS intervention subtracting the corresponding session after intervention (e.g. the baseline TOD before intervention minus the baseline TOD after intervention). Therefore, a negative value stands for an increase after intervention.

## Discussion

In the present study, a significant reduction of self-reported pain intensity and improvement of jaw motor performance during repetitions of standardised movements in the TMJ pain with DDwoR group was observed when TENS was applied but not in the matched control group. Based on the success of blinding, this finding suggests that the TENS

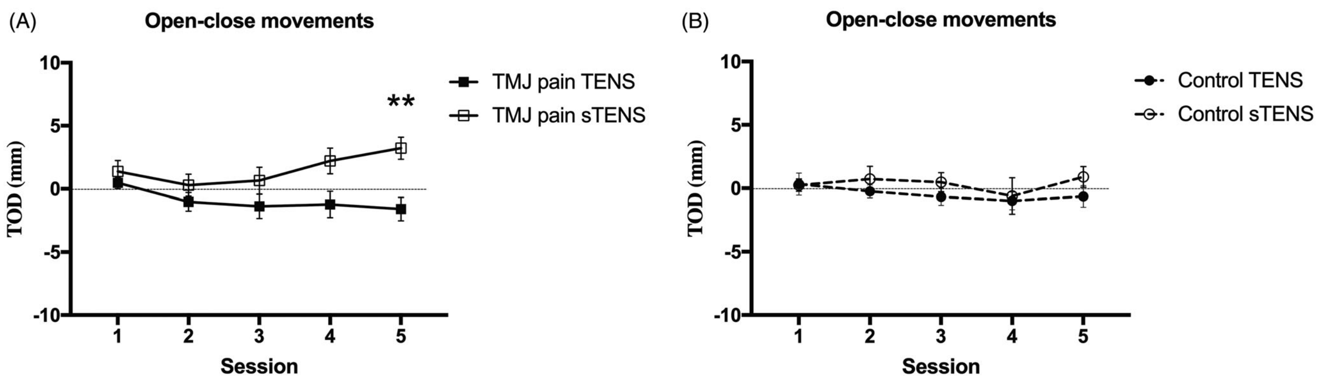


Figure 3. Change of total opening distance (TOD) in repeated open-close movements in the TMJ pain group with DDwoR and in the control group. **represents the significance of change between groups with different methods of treatment (TENS/sTENS) ($p < .001$). Mean ± SEMs are presented.

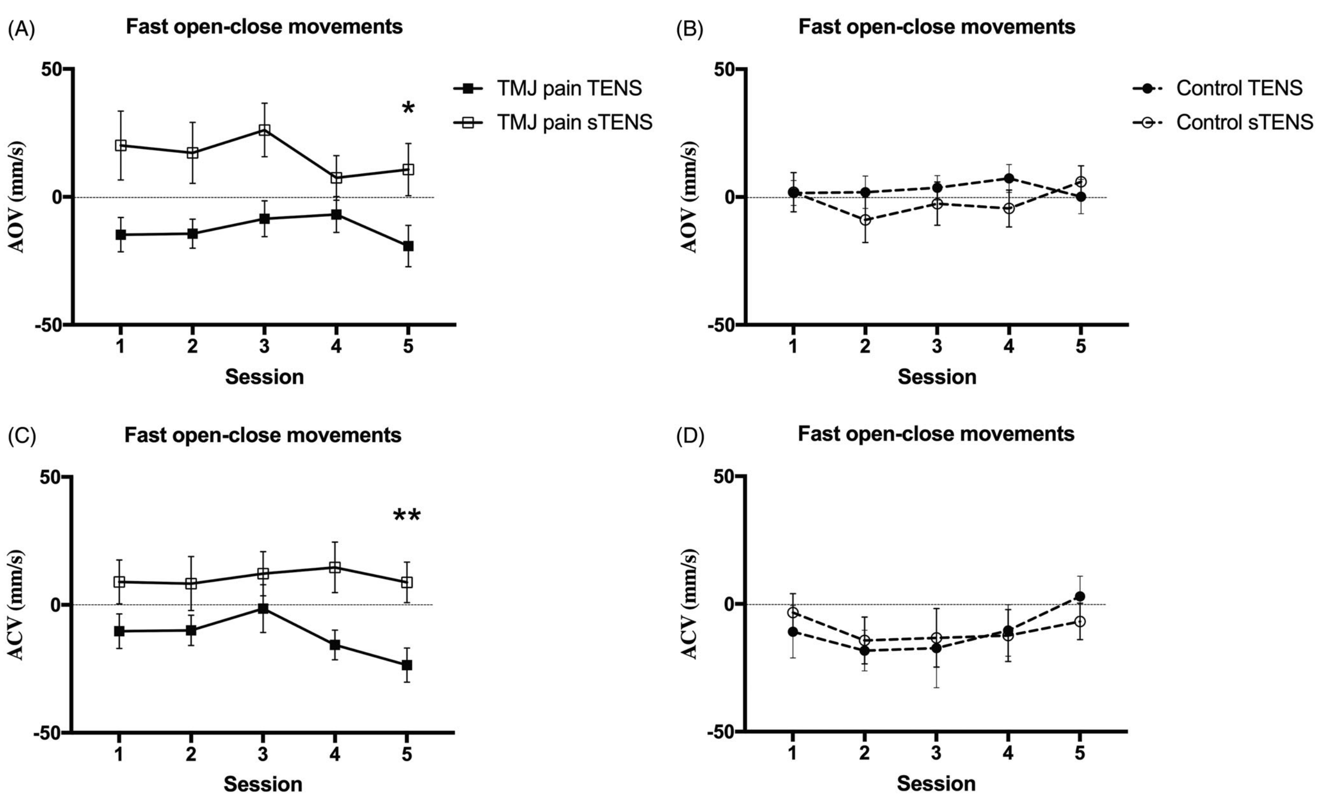


Figure 4. Change of average velocity in repeated fast jaw movements. (A)-(B) Change of average opening velocity (AOV) in the TMJ pain group with DDwoR and in the control group. (C)-(D) Change of average closing velocity (ACV) in the TMJ pain group with DDwoR and in the control group. *represents the significance between time ($p < .05$); **represents the significance between time ($p < .001$). Mean ± SEMs are presented.

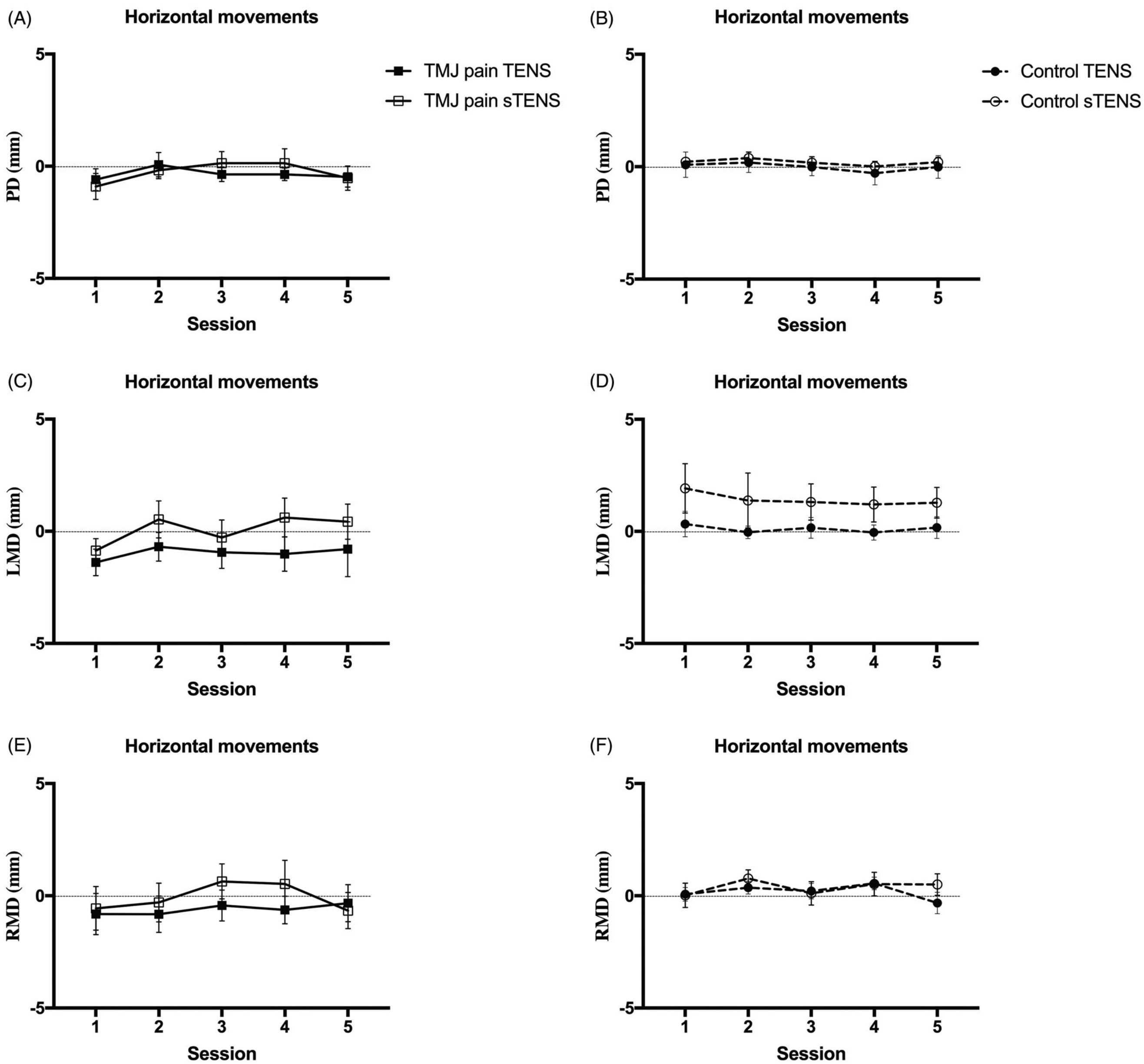


**Figure 5.** Change of horizontal movement distance in repeated horizontal jaw movements. (A)-(B) The change of protrusion distance (PD) in the TMJ pain group with DDwoR and in the control group. (C)-(D) The change of left movement distance (LMD) in the TMJ pain group with DDwoR and in the control group. (E)-(F) The change of right movement distance (RMD) in the TMJ pain group with DDwoR and in the control group. Mean ± SEMs are presented.

application appeared to be effective in view of pain relief on repetition-induced pain in TMJ arthralgia associated with DDwoR. Meanwhile, it also seems that patients with arthralgia-associated DDwoR might have functional improvement of motor summation effects with TENS intervention.

## *TENS may alleviate movement-evoked pain in TMJ pain patients with DDwoR*

The increase in pain intensity (wind-up) caused by temporal summation stimulation is a combination of psychophysical and neurophysiologic process, which can especially be enhanced in pathological pain conditions [31]. The wind-up can result from repetitive stimulation of peripheral C-fibres at the rate of once every three seconds or less [6,7,32]. Both central and peripheral sensitisation might be involved in the pain encoding mechanism of wind-up with inter-stimulus intervals at 3 and 5 s [33]. Central neuron excitation as well as peripheral inflammatory substances such as bradykinin, serotonin etc. generated after nociceptive stimulus will lead to increased pain sensitivity [6,34,35]. In a previous study, it was demonstrated that repeated jaw movements in TMJ arthralgia with DDwoR patients could serve as adequate stimuli to drive temporal summation with increased pain intensity and reduced jaw movement capacity [12].

Although some studies have shown no effect of TENS in reducing muscular activity or increasing jaw opening [19, 36], other researchers have claimed the clinical effectiveness of TENS by showing the reduced facial pain or deep pain sensitivity [22], the successful control on acute and chronic pain [37], the relaxed masticatory muscles [37,38], or the increased jaw opening distance in TMD patients [23].

Different theories have been brought forward to explain the TENS effects. One theory is that repetitive muscle contractions caused by the TENS stimulation to motor nerves can increase blood flow and decrease accumulated toxins, which could lead to alleviation of pain [39]. A second theory, in line with the gate control theory, would suggest that nociceptive activity at the level of the dorsal horn (and brainstem) could be inhibited by activity in large diameter and myelinated afferent nerve fibres [40]. Nevertheless, both central and peripheral processes would be likely to be involved in a TENS-related electroanalgesia [41].

Accordingly, a decrease of 1–2 points or approximately 30% in the NRS is considered a clinical significant improvement or reasonable satisfaction [42]. In the present study, the TMJ pain with DDwoR group following TENS treatment showed a pain reduction around 1–2 on a 0–10 NRS across the repeated sessions when compared to the sTENS group, which seems to have clinical importance. One explanation could be that TENS can attenuate the pain generated from repeated motor summation in TMJ arthralgia with DDwoR patients. Another explanation could be that a slightly reduced baseline pain intensity may lead to a smaller pain increase due to motor summation. It could be suggested based on these findings that TENS may be considered at least a complimentary technique to manage activity-related pain in TMJ pain with DDwoR patients. Further studies will be needed to clarify the potential effects of TENS on acute versus chronic pain conditions. It seems interesting that a flat occlusal splint can provide more improvements in pain relief in patients with DDwoR when compared with TENS [43]. Therefore we cannot overlook the potential contribution in terms of pain from the retrodiscal band due to increased pressure generated from the displaced intra-articular structures, at least in the short-term of the DDwoR. However, further studies on larger samples will be needed to determine the effectiveness of TENS in DDwoR with chronic pain.

Another finding is that the pain increase caused by motor summation was not influenced by the application of TENS, since the TMJ pain with DDwoR group showed increased pain intensity over repeated jaw movements despite of the TENS intervention. Again, this phenomenon is consistent with the theory that central pain inhibitory dysfuction plays a crucial role in individuals with hyperalgesia when repeated motor movements are performed [8–11].

## *Functional improvement after TENS application*

The pain-adaptation model focussed on a reflex-based and subconscious inhibition of jaw muscles caused by the existence of pain in the TMJ or related muscles [15]. While in the integrated pain-adaptation model, multidimensional components were brought forward to explain the relationship between the many different and individual manifestations of chronic pain and motor function [44]. However, it remains to be clarified how jaw movements may change due to different types or intensity of pain.

In the present study, the changes of movement capacity were observed in terms of increased total opening distance and average open-close velocity in response to motor summation with the TENS intervention in the TMJ pain with DDwoR patients. On these bases, it may reflect the fact that with decreased pain intensity after the TENS intervention, motor summation mechanisms will generate less functional inhibition in terms of jaw opening distance and movement velocity. As the theory of the pain-adaptation model suggests that jaw motor function and muscle activity will be impaired in accordance with increased pain in jaw muscles or TMJ [15,44], the result is consistent with the hypothesis that a reduction of self-reported pain will lead to improvement of motor function. However, it should be noticed that the functional improvement did not appear to be simultaneously changed with the reduction of evoked pain intensity, since there was pain relief (reduction) across all 5 sessions, but only delayed functional improvement in the last session 5. Therefore, the pain-adaptation model and integrated pain-adaption model might not fully explain the relationship between the acute pain and functional rehabilitation generated over repetitions of movements. It should also be noted that a significant limitation in the present study is the relatively small sample size in the TENS and sTENS groups. Future research is needed to clarify how the perception and awareness of different types of TMD pain would regulate jaw motor behaviour.

It has been suggested that the compression stress is mainly located in the posterior band in DDwoR compared with the intermediate zone in a healthy disc [45]. The repeated horizontal movements did not show any change in jaw motor function in the present study. A possible explanation could be that the TENS intervention mainly reduced the pain, perhaps in the fully vasculated retrodiscal region, however both the protrusive and latertrusive movements generate less pain in the fully vascular region compared to open-close movements. The TENS seems not to have any major effect on the horizontal movements, which is consistent with the notion that motor performance may not necessarily be jeopardised without the increase of pain during functional movements.

## *TENS effects in healthy controls and future application on experimental models*

Experimental pain models of intense dynamic contractions, like mimicking tooth-grinding activity and resisted jaw opening and closing movements, have successfully induced short-lasting fatigue and pain in the jaw-closing muscles in healthy individuals with rapid disappearance after cessation of the exercise [46–48]. There are also long-lasting experimental pain models, both physically and chemically generated, whose effects can last up to a few days [49–52]. With the eccentric contraction of the jaw muscles, pain would occur several hours after the exercise and peak between 24 h and 48 h [51,53].

In the present study, the repeated concentric contraction failed to generate significant self-reported pain in healthy individuals, which may due to the less effectiveness of concentric contraction and low frequency to cause painful symptoms. There were two more findings though, one is that a small amount of pain reduction (0.4 out of 10) was observed in the healthy TENS group during repeated horizontal movements. The other one is that, for the TMJ pain with DDwoR sTENS group who reported increased pain over repeated jaw movements actually showed no difference of pain intensity after sTENS. One possible explanation is that the repeated jaw opening would only cause a short-time increase of pain in TMJ arthralgia with DDwoR patients with spontaneous relief within 45 min; another possibility could be that the sTENS intervention would provide a placebo or psychological effect for pain relief. However, it may also be the other way round that the high expectancy of the "TENS treatment" was the result rather than the cause of the movement-evoked pain relief. Future studies that introduce a third group without intervention (TENS/sTENS) may help clarify this issue. We assume that the repeated nociceptive stimulation due to the jaw opening and the TENS/sTENS intervention could be applied in an experimental pain study to test the different behaviour between healthy individuals, experimental pain models and the clinical TMJ pain patients. Further studies will still be needed to investigate specific time patterns of the evoked pain triggered by motor summation and at different intensities. It is also important to choose the proper experimental models with long-lasting duration, since some experimental models may last for several hours up to a few days and therefore better mimicking clinical pain conditions [49–54].

Finally, it should be acknowledged that there may limitations in the present study such as the accuracy of the jaw tracking device and the relatively small sample size and moderate power in the statistical analyses. The natural jaw movements could, indeed, be interfered by the application of the jaw tracker. Gender-differences should also be taken into account in future pain studies. The disc displacements have a high prevalence between 20 and 40 years of age, while the inflammatory-degenerative joint disorders take place over the age of 50 years [55,56], therefore the involvement of broader range of ages with different types of pathophysiology is necessary in future studies. Although the blinding was successful statistically, more than half of the participant in TENS group correctly guessed the treatment, which would potentially cause the overrating of the TENS effect. Furthermore, the same investigator made the experiments, collecting the self-reported pain before and after the intervention in both groups, which may cause bias from both respondents and the researcher, e.g. if the participants intended to satisfy the examiners, or if the investigator formed a belief before testing. Long-term follow up of the effects of TENS on movement-evoked pain in patients with acute DDwoR with limited opening will be needed in future studies. In addition, it would be interesting to test the impact of TENS to the chewing capacity, in view of the observation that nearly 1/3 of patients with TMD pain showed pain relief rather than pain increase during mastication [57].

In conclusion, the present study has demonstrated that TENS attenuates motor-generated pain in TMJ arthralgia with DDwoR patients, with the improvement of jaw motor capacity during repeated jaw movements. Besides, the elimination of movement-evoked pain was observed in the TMJ pain with DDwoR group with sTENS intervention. These findings suggested that the movement-evoked pain would diminish either spontaneously or by sTENS (placebo or psychological effect) within 45 min, and more importantly, provided better understanding of the effect of TENS in terms of pain intensity and motor summation mechanisms in TMJ pain patients with DDwoR. In view of the fact that the motor-generated pain may be closely related to central hyperalgesia and maintenance of persistent pain conditions [58], the effect of TENS on activity-related pain relief suggests a therapeutic potential for clinical application of TENS in chronic TMJ pain patients with DDwoR.

## Acknowledgments

The authors thank all the staff of Orofacial Pain and TMD Research Unit, Institute of Stomatology, Affiliated Hospital of Stomatology, Nanjing Medical University for their selfless help. Author contributions: Lin Wang and Jinglu Zhang contributed equally to this work and should be considered co-corresponding authors.

## Disclosure statement

No potential conflict of interest was reported by the authors.

## Funding

This work was supported by the National Natural Science Foundation of China [81830031, 81570959]; and the Priority Academic Programme Development of Jiangsu Higher Education Institutions [PAPD-2018-87]; and the Natural Science Foundation of Jiangsu Province [BL2014073 and 15KJA320002 to Lin Wang]; and Six Distinguished Talent [2016-WSW-008] and the Jiangsu Provincial Key Medical Discipline [zdxka2016026]; and State Scholarship Fund from China Scholar Council [201708320348].

## ORCID

Yuanxiu Zhang http://orcid.org/0000-0001-6935-4155

## References

[1] Staud R, Craggs JG, Robinson ME, et al. Brain activity related to temporal summation of C-fiber evoked pain. Pain. 2007;129(1):130–142.
[2] Wippert PM, Wiebking C. [Adaptation to physical activity and mental stress in the context of pain: Psychobiological aspects. Schmerz. 2016;30(5):429–436.
[3] Parker RS, Lewis GN, Rice DA, et al. Is motor cortical excitability altered in people with chronic pain? A systematic review and meta-analysis. Brain Stimul. 2016;9(4):488–500.
[4] Coderre TJ, Katz J, Vaccarino AL, et al. Contribution of central neuroplasticity to pathological pain: review of clinical and experimental evidence. Pain. 1993;52(3):259–285.
[5] Dougherty PM, Palecek J, Paleckova V, et al. The role of NMDA and non-NMDA excitatory amino acid receptors in the excitation of primate spinothalamic tract neurons by mechanical, chemical, thermal, and electrical stimuli. J Neurosci. 1992;12(8):3025–3041.
[6] Mendell LM. Physiological properties of unmyelinated fiber projection to the spinal cord. Exp Neurol. 1966;16(3):316–332.

[7] Price DD, Hayes RL, Ruda M, et al. Spatial and temporal transformations of input to spinothalamic tract neurons and their relation to somatic sensations. J Neurophysiol. 1978;41(4):933–947.

[8] George SZ, Wittmer VT, Fillingim RB, et al. Fear-avoidance beliefs and temporal summation of evoked thermal pain influence self-report of disability in patients with chronic low back pain. J Occup Rehabil. 2006;16(1):92–108.

[9] Staud R, Robinson ME, Price DD. Temporal summation of second pain and its maintenance are useful for characterizing widespread central sensitization of fibromyalgia patients. J Pain. 2007; 8(11):893–901.

[10] Staud R, Cannon RC, Mauderli AP, et al. Temporal summation of pain from mechanical stimulation of muscle tissue in normal controls and subjects with fibromyalgia syndrome. Pain. 2003;102(1): 87–95.

[11] Staud R, Robinson ME, Vierck CJ, Jr, et al. Diffuse noxious inhibitory controls (DNIC) attenuate temporal summation of second pain in normal males but not in normal females or fibromyalgia patients. Pain. 2003;101(1):167–174.

[12] Zhang Y, Shao S, Zhang J, et al. Temporal summation and motor function modulation during repeated jaw movements in patients with temporomandibular disorder pain and healthy controls. Pain. 2017;158(7):1272–1279.

[13] Tasaki MM, Westesson PL, Isberg AM, et al. Classification and prevalence of temporomandibular joint disk displacement in patients and symptom-free volunteers. Am J Orthod Dentofacial Orthop. 1996;109(3):249–262.

[14] Lobbezoo F, van Selms MK, Naeije M. Masticatory muscle pain and disordered jaw motor behaviour: literature review over the past decade. Arch Oral Biol. 2006;51(9):713–720.

[15] Lund JP, Donga R, Widmer CG, et al. The pain-adaptation model: a discussion of the relationship between chronic musculoskeletal pain and motor activity. Can J Physiol Pharmacol. 1991;69(5): 683–694.

[16] Sarlani E, Grace EG, Reynolds MA, et al. Sex differences in temporal summation of pain and aftersensations following repetitive noxious mechanical stimulation. Pain. 2004;109(1):115–123.

[17] Svensson P, Arendt-Nielsen L, Bjerring P, et al. Human mastication modulated by experimental trigeminal and extra-trigeminal painful stimuli. J Oral Rehabil. 1996;23(12):838–848.

[18] Johnson M. Transcutaneous electrical nerve stimulation: review of effectiveness. Nurs Stand. 2014;28(40):44–53.

[19] Treacy K. Awareness/relaxation training and transcutaneous electrical neural stimulation in the treatment of bruxism. J Oral Rehabil. 1999;26(4):280–287.

[20] Alvarez-Arenal A, Junquera LM, Fernandez JP, et al. Effect of occlusal splint and transcutaneous electric nerve stimulation on the signs and symptoms of temporomandibular disorders in patients with bruxism. J Oral Rehabil. 2002;29(9):858–863.

[21] McNeely ML, Armijo Olivo S, Magee DJ. A systematic review of the effectiveness of physical therapy interventions for temporomandibular disorders. Phys Ther. 2006;86(5):710–725.

[22] Ferreira AP, Costa DR, Oliveira AI, et al. Short-term transcutaneous electrical nerve stimulation reduces pain and improves the masticatory muscle activity in temporomandibular disorder patients: a randomized controlled trial. J Appl Oral Sci. 2017;25(2):112–120.

[23] Nunez SC, Garcez AS, Suzuki SS, et al. Management of mouth opening in patients with temporomandibular disorders through low-level laser therapy and transcutaneous electrical neural stimulation. Photomed Laser Surg. 2006;24(1):45–49.

[24] Didier H, Marchetti C, Borromeo G, et al. Persistent idiopathic facial pain: multidisciplinary approach and assumption of comorbidity. Neurol Sci. 2010;31(S1):189–195.

[25] Monaco A, Sgolastra F, Ciarrocchi I, et al. Effects of transcutaneous electrical nervous stimulation on electromyographic and kinesiographic activity of patients with temporomandibular disorders: a placebo-controlled study. J Electromyogr Kinesiol. 2012; 22(3):463–468.

[26] Chen CC, Johnson MI. An investigation into the hypoalgesic effects of high- and low-frequency transcutaneous electrical nerve stimulation (TENS) on experimentally-induced blunt pressure pain in healthy human participants. J Pain. 2010;11(1):53–61.

[27] Mankovsky-Arnold T, Wideman TH, Lariviere C, et al. TENS attenuates repetition-induced summation of activity-related pain following experimentally induced muscle soreness. J Pain. 2013;14(11): 1416–1424.

[28] Gourlay DL, Heit HA, Almahrezi A. Universal precautions in pain medicine: a rational approach to the treatment of chronic pain. Pain Med. 2005;6(2):107–112.

[29] Schiffman E, Ohrbach R, Truelove E. et al. Diagnostic Criteria for Temporomandibular Disorders (DC/TMD) for Clinical and Research Applications: recommendations of the International RDC/TMD Consortium Network* and Orofacial Pain Special Interest Group†. J Oral Facial Pain Headache. 2014;28(1):6–27.

[30] Hughes JR, Krahn D. Blindness and the validity of the double-blind procedure. J Clin Psychopharmacol. 1985;5(3):138–142.

[31] Ren K. Wind-up and the NMDA receptor: from animal studies to humans. Pain. 1994;59(2):157–158.

[32] Price DD, Hu JW, Dubner R, et al. Peripheral suppression of first pain and central summation of second pain evoked by noxious heat pulses. Pain. 1977;3(1):57–68.

[33] Nie H, Arendt-Nielsen L, Andersen H, et al. Temporal summation of pain evoked by mechanical stimulation in deep and superficial tissue. J Pain. 2005;6(6):348–355.

[34] Mense S. Nervous outflow from skeletal muscle following chemical noxious stimulation. J Physiol. 1977;267(1):75–88.

[35] Fock S, Mense S. Excitatory effects of 5-hydroxytryptamine, histamine and potassium ions on muscular group IV afferent units: a comparison with bradykinin. Brain Res. 1976;105(3):459–469.

[36] Rodrigues D, Siriani AO, Berzin F. Effect of conventional TENS on pain and electromyographic activity of masticatory muscles in TMD patients. Braz Oral Res. 2004;18(4):290–295.

[37] Awan KH, Patil S. The role of transcutaneous electrical nerve stimulation in the management of temporomandibular joint disorder. J Contemp Dent Pract. 2015;16(12):984–986.

[38] Mummolo S Dds P, Nota A Dds P, Tecco S, et al. Ultra-low-frequency transcutaneous electric nerve stimulation (ULF-TENS) in subjects with craniofacial pain: a retrospective study. Cranio. 2018;8:1–6.

[39] Gomez CE, Christensen LV. Stimulus-response latencies of two instruments delivering transcutaneous electrical neuromuscular stimulation (TENS). J Oral Rehabil. 1991;18(1):87–94.

[40] Melzack R, Wall PD. Pain mechanisms: a new theory. Science. 1965;150(3699):971–979.

[41] Seifi M, Ebadifar A, Kabiri S, et al. Comparative effectiveness of Low Level Laser therapy and transcutaneous electric nerve stimulation on temporomandibular joint disorders. J Lasers Med Sci. 2017;8(Suppl 1):S27–S31.

[42] Salaffi F, Stancati A, Silvestri CA, et al. Minimal clinically important changes in chronic musculoskeletal pain intensity measured on a numerical rating scale. Eur J Pain. 2004;8(4):283–291.

[43] Linde C, Isacsson G, Jonsson BG. Outcome of 6-week treatment with transcutaneous electric nerve stimulation compared with splint on symptomatic temporomandibular joint disk displacement without reduction. Acta Odontol Scand. 1995;53(2):92–98.

[44] Peck CC, Murray GM, Gerzina TM. How does pain affect jaw muscle activity? The integrated pain adaptation model. Aust Dent J. 2008;53(3):201–207.

[45] Perez del Palomar A, Doblare M. An accurate simulation model of anteriorly displaced TMJ discs with and without reduction. Med Eng Phys. 2007;29(2):216–226.

[46] Farella M, Bakke M, Michelotti A, et al. Effects of prolonged gum chewing on pain and fatigue in human jaw muscles. Eur J Oral Sci. 2001;109(2):81–85.

[47] Arima T, Svensson P, Arendt-Nielsen L. Experimental grinding in healthy subjects: a model for postexercise jaw muscle soreness? J Orofac Pain. 1999;13(2):104–114.

[48] Svensson P, Arendt-Nielsen L. Effect of topical NSAID on post-exercise jaw muscle soreness: a placebo-controlled experimental study. J Musculoskelet Pain. 1995;3(4):41–58.

[49] Svensson P, Castrillon E, Cairns BE. Nerve growth factor-evoked masseter muscle sensitization and perturbation of jaw motor function in healthy women. J Orofac Pain. 2008;22(4):340–348.

[50] Svensson P, Cairns BE, Wang K, et al. Injection of nerve growth factor into human masseter muscle evokes long-lasting mechanical allodynia and hyperalgesia. Pain. 2003;104(1):241–247.

[51] Koutris M, Lobbezoo F, Sumer NC, et al. Is myofascial pain in temporomandibular disorder patients a manifestation of delayed-onset muscle soreness? Clin J Pain. 2013;29(8):712–716.

[52] Turker KS, Koutris M, Sumer NC, et al. Provocation of delayed-onset muscle soreness in the human jaw-closing muscles. Arch Oral Biol. 2010;55(9):621–626.

[53] Proske U, Morgan DL. Muscle damage from eccentric exercise: mechanism, mechanical signs, adaptation and clinical applications. J Physiol. 2001;537(2):333–345.

[54] Ahmad M, Hollender L, Anderson Q, et al. Research diagnostic criteria for temporomandibular disorders (RDC/TMD): development of image analysis criteria and examiner reliability for image analysis. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2009; 107(6):844–860.

[55] Manfredini D, Guarda-Nardini L, Winocur E, et al. Research diagnostic criteria for temporomandibular disorders: a systematic review of axis I epidemiologic findings. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2011;112(4):453–462.

[56] Manfredini D, Piccotti F, Ferronato G, et al. Age peaks of different RDC/TMD diagnoses in a patient population. J Dent. 2010;38(5): 392–399.

[57] Dao TT, Lund JP, Lavigne GJ. Pain responses to experimental chewing in myofascial pain patients. J Dent Res. 1994;73(6): 1163–1167.

[58] Price DD, Staud R, Robinson ME, et al. Enhanced temporal summation of second pain and its central modulation in fibromyalgia patients. Pain. 2002;99(1):49–59.