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Shoulder girdle muscle activity at rest and during jaw and shoulder movements in participants with and without temporomandibular disorders: A cross-sectional observational study

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ABSTRACT

Background: Previous studies have shown the effects of temporomandibular joint (TMJ) alignment on the shoulder girdle muscles. No previous research has investigated the difference in activity of these muscles in those with and without temporomandibular disorders (TMD).

Objective: The study aimed to compare the activity of the shoulder girdle muscles in participants with and without TMD. Furthermore, to determine if there was a relationship between pain and disability of the TMJ and shoulder girdle.

Methods: A cross-sectional observational study was performed on participants with and without TMD. An assessment of pain, disability, range of the TMJ, scapulohumeral rhythm and muscle activity of the biceps, medial deltoid, infraspinatus, inferior trapezius and serratus anterior bilaterally was done. Statistical analysis was performed using IBM SPSS Statistics Version 28 and Microsoft Excel.

Results: Compared to those without TMD, participants with TMD had lower activity of all shoulder muscles during shoulder movements with significant differences of the right biceps during shoulder abduction ($d = 0.33$, $p = 0.049$), left infraspinatus ($d = 0.38$, $p = 0.022$) and right infraspinatus during shoulder flexion ($d = 0.48$, $p = 0.004$) and abduction ($d = 0.33$, $p = 0.049$). Lower shoulder muscle activity in participants with TMD was also seen during jaw movements, except for the right inferior trapezius, medial deltoid and serratus anterior, which had higher activity in participants with TMD.

Conclusion: The majority of the shoulder muscles had lower activity at rest, during jaw and shoulder movements in participants with TMD.

1. Introduction

The American Academy of Orofacial Pain defines temporomandibular disorders (TMD) as: a group of conditions affecting the muscles of mastication, temporomandibular joint (TMJ) and surrounding structures (Valesan et al., 2021). This condition is the most common form of chronic pain in the facial region that is not of dental origin, with a prevalence of 31% in adults and 11% in children and adolescents (Valesan et al., 2021).

The high levels of chronicity and co-morbidity of TMD are similar to shoulder pain, which is the third most common musculoskeletal complaint after lower back and knee pain. Shoulder pain is associated with high chronicity levels, as 50% of patients who presented at a primary care level reported no improvement over a six-month period (Lucas et al., 2022). Therefore, a deeper understanding of the possible associations between the shoulder girdle and TMJ may provide insight into developing a framework of improved management for both conditions.

The connection between the two areas has been examined in a pilot study. The findings showed the effects of an occlusal splint and orofacial therapy led to significant improvements in range of motion (ROM) and pain in eight of the 11 participants with glenohumeral internal rotation deficit (Baum et al., 2019). These findings are similar to other studies that found occlusal splints increased the maximum voluntary contraction of biceps, triceps, sternocleidomastoid (SCM) and upper trapezius (Lee et al., 2013) and led to a higher peak torque of

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abduction/adduction and internal/external rotation (Dias et al., 2019) and deltoid strength (Chakfa et al., 2002), in healthy participants.

It is evident through the research reviewed that the shoulder girdle needs to be examined in further depth as to the prevalence and role it plays as an associated co-morbidity in participants with TMD. The only two shoulder girdle muscles that have been compared in those with and without TMD are SCM and trapezius and were only done so at rest and during maximal voluntary contraction (Pallegama et al., 2004; Sójka et al., 2017). According to the researcher's knowledge, no previous studies have investigated the differences in activity of other shoulder girdle muscles in participants with and without TMD at rest and during active and resisted jaw movements.

The aim of the study was to compare the activity of the shoulder girdle muscles in participants with and without TMD at rest and during jaw and shoulder movements. Furthermore, to determine if there was a relationship between the level of pain and disability of the TMJ and shoulder girdle.

2. Methods

2.1. Study design

A cross-sectional observational study was done. Ethics was approved by the Human Research Ethics Committee (Medical) at the *(information removed to allow for anonymous peer-review)* (M2111110 MED21-11-098). All procedures were followed according to the relevant institutional guidelines, and informed written consent was obtained for each participant prior to their participation in the study.

2.2. Participants and sampling

The study included participants between the ages of 18 and 70 years. In order for participants to be included in the TMD group they were required to get a score of two or more on a standardized screening questionnaire, the TMD-pain screener. It is a valid and reliable tool used to screen participants with pain related TMD. Furthermore, it is part of the Diagnostic Criteria for TMD (DC/TMD) which is the gold standard in diagnosing participants with TMD (Gonzalez et al., 2011).

The inclusion criteria for participants into the non-TMD group were a score of one or less on the TMD pain screener, which according to the tool means the absence of TMD. Both groups excluded participants who had received treatment on the shoulder girdle in the past three months, who had fibromyalgia, inflammatory arthritis, systemic inflammatory disorders, cardiac disease, cancer, peripheral vascular disease, previous jaw or shoulder surgery, were pregnant and those who were undergoing orthodontic treatment. The reason for this is occlusal splints have been shown to increase muscle activity of shoulder girdle muscles through optimizing TMJ alignment (Dias et al., 2019).

Furthermore, the effects of orthodontic treatment on level of pain in participants with TMD and their influence on disc displacement is not conclusive and therefore to prevent the effects of this as a confounding factor, their presence was excluded (Fernández-González et al., 2015). No specific dental conditions were excluded as there has been no evidence to show that lack of posterior teeth support or missing teeth increases pain in participants with TMD (Fernández-González et al., 2015). Parafunctional habits were not one of the exclusion criteria as part of the questionnaire, the Fonseca Anamnestic Index (FAI), was to determine how many of the participants clench and grind their teeth in order to determine potential associations.

A consecutive sampling method was used for the group of participants with TMD. Individuals in the TMD group were invited to participate if they were a new patient at the researcher's practice, responded to the advertisement or put their email address on the researcher's previous questionnaire (Weinberg et al., 2023). Simultaneously, matched controls according to age (±5 years) and gender were invited to participate in the study through social media, other therapists and convenience sampling.

The sample size was calculated using Stata v16. It was based on a study that determined the difference in mean (SD) activity of 14 participants wearing an occlusal splint compared to a placebo splint. The muscles tested were the inferior trapezius (82.893 ± 4.81 compared to 72.123 ± 4.58) and pectoralis major (78.134 ± 5.07 compared to 58.546 ± 3.99) (Dias et al., 2019). Using a power of 80%, precision of 10% and adding 10% for each confounding variable, a sample size of 18 participants in each group was calculated.

2.3. Data collection and procedure

Data collection took place at the primary researcher's private physiotherapy practice in Johannesburg from January to May 2023. It was performed by a blind research assistant, who is a physiotherapist at the main researcher's practice.

Before the study commenced, a pilot study was conducted involving five participants. This was done by both the research assistant and the leading researcher, to ensure that the research assistant was performing all the assessments accurately as well as to determine the length of time needed for each assessment.

Participants filled in an online questionnaire using the REDCap system, which is an online application used to capture data (Harris et al., 2019). This was done on the same day as the physical examination and included questions on demographics, medical history, lifestyle and occupation, the researcher's questions on the TMJ and shoulder girdle, and standardized questionnaires. These were the Numerical Rating Scale (NRS), FAI, Steigerwald Maher TMD Disability Index (SMTDI) and the Shoulder Pain and Disability Index (SPADI).

The NRS was used to measure the current level of pain in the TMJ and consists of a horizontal line where participants rate their pain from zero (no pain) to 10 (worst possible pain) (Nugent et al., 2021). The FAI was used to determine the level of TMD and consisted of 10 questions with three options of responses: yes (10 points), sometimes (5 points) and no (0 points). The sum of the scores classifies the TMD into either no TMD (0–15 points), mild (20–45), moderate (50–65) or severe TMD (70–100) (Özdinç et al., 2020).

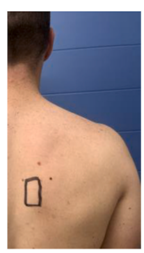
The STMDI consists of 10 questions relating to specialized functions of the TMJ, and each question is scored from zero to four, with the total score ranging between 0 and 40. The higher the rating, the higher the disability (Johnston et al., 2015). The questionnaire used for measuring pain and disability in the shoulder was the SPADI. It contains 13 questions with scores ranging from zero (no pain/difficulty) to 10 (worst possible pain/requires help with task). The total score can vary from zero to 100, with a higher score indicating more pain and disability (Thoomes-de Graaf et al., 2017).

The final part of the questionnaire consisted of the researcher's questions on the TMJ and shoulder girdle, including the presence of pain, clicking, previous injuries and management.

The first part of the physical examination measured the ROM of the TMJ during mouth opening and bilateral laterotrusion. This was done in sitting using a ruler, a standardized way of measuring ROM of the jaw (Skeie et al., 2018). The next component was measuring muscle activity of five shoulder girdle muscles bilaterally using surface electromyography (sEMG). These included the biceps, medial deltoid, infraspinatus, inferior trapezius and serratus anterior. Table 1 provides a detailed explanation and illustration of the placements of the electrodes. Before placement of the surface electrodes, the skin was shaved and cleaned with 80% isopropyl alcohol to reduce the effects of skin impedance. One surface electrode was placed on each muscle belly bilaterally. Sensor placement was adhered to with tape to ensure there was no movement of the electrode.

These shoulder girdle muscles were chosen as they are easily accessible with sEMG, give insight into the anterior, medial and posterior aspects of the shoulder girdle and include a combination of movers and stabilizers (Criswell and Cram, 2011).

Table 1
Surface electrode placement of biceps, medial deltoid, infraspinatus, inferior trapezius and serratus anterior muscles.

Muscle	Position of the electrode	Illustration
Biceps	Two thirds between the acromion and cubital fossa	
Medial deltoid	Lateral arm, 3 cm below the acromion process in a horizontal line.	
Infraspinatus	In the infrascapular fossa, 4 cm below the scapular spine	
Inferior trapezius	Next to the medial edge of the scapula, 5 cm below the scapular spine	
Serratus anterior	Below the axilla, medial and anterior to latissimus dorsi and posterior to pectoralis major	

Measurements of the muscle activity were taken at rest, during active mouth opening, right and left laterotrusion, resisted mouth opening, and resisted laterotrusion bilaterally. All participants sat with their backs supported by the same chair with a backrest, elbows on their thighs, and in 90° flexion with forearm supination. The instruction for the resting measurement was the separation of the teeth and lips and a relaxed jaw.

Participants practised the movements before the activity was measured, and three repetitions were done for each active movement with a 1-min rest between each test. For the resisted movements, participants performed a maximum isometric contraction mid-way through the range against the therapist's maximum resistance. This mid-way position was determined by the examiner's measurement of ROM of mouth opening and laterotrusion. This isometric contraction was held for 5 s each.

Muscle activity was also measured while participants performed the Scapular Dyskinesis Test (SDT), which is a visually based test used to determine scapular dyskinesia. In standing, participants performed five repetitions of shoulder flexion and abduction with dumbbells, according to their weight, while the examiner rated the scapula movement as normal, subtle or abnormal (Christiansen et al., 2017).

2.4. Surface electromyography and data processing

Data from the sEMG was recorded using the Delsys Trigno Wireless EMG System (Delsys Inc, Natick, MA). Signals were amplified with a band-pass filter of 20–450 Hz and a sampling rate of 1000 Hz. The Signal Quality Monitor provided by Delsys was used in the real-time collection screen within EMGworks Acquisition. This enabled the research assistant to ensure that e that the quality of the signal quality remained acceptable throughout the collection.

The mean values of the middle 3 s of the isometric movements and 10 s of the active movements of the three repetitions were used for normalisation. To remove the inherent offset from the signals, a calculation script offered by Delsys EMGworks Analysis software known as "remove mean" was applied, along with autoscaling, which were specifically meant to remove the offset from the signals. An amplitude analysis of the raw data was then done to calculate the root mean square.

2.5. Data analysis

The IBM Statistical Package for the Social Science Version 26 (IBM Corp., Armonk, New York) was used to analyse all data. Descriptive data, including participants' gender, lifestyle, occupation, medical history, and previous TMJ and shoulder girdle treatment, presence of pain, previous injury and popping/clicking of the shoulder, and DT scores, were presented as frequencies. Age, ROM and FAI scores were reported as means and standard deviation. The NRS, SPADI, STMDI scores and muscle activity were reported as medians and interquartile ranges.

For sEMG, the data was analysed using EMGworks Software (Delsys Inc., Salford, Greater Manchester, United Kingdom) and was exported to Matlab (Version 7.2., the Mathworks Inc., Natick, United States of America) for analysis.

The Fisher's exact test was used to determine the differences in ages, presence of medical conditions, use of daily medication, previous surgery, occupation involving heavy lifting and computer work, exercise participation, hand dominance, previous treatment of the TMJ, presence of pain, previous injuries, treatment and popping/clicking of the shoulder between the two groups. The Chi-square test was used to determine the correlations between the presence of pain in the shoulder with the presence of pain in the TMJ and the ability to fit three fingers in the mouth.

The strength of association for the above variables where the Fisher's exact test and Chi-square test were used, was measured with the Cramer's V test. A value of 0–0.10 indicated no relationship, 0.10–0.30 a weak relationship, 0.30–0.50 and > 0.50 a strong association (Kim, 2017). The distribution of interval data was analysed using the Shapiro Wilk test and, based on the findings, the total NRS, STMDI, SPADI, SDT scores and muscle activity values were found to be not normally distributed ($p < 0.05$), and therefore, non-parametric analysis was done. The total FAI and ROM scores were found to be normally distributed ($p > 0.05$), and therefore, parametric analysis was done.

The Independent-Sample's T Test was used to determine if there were differences between the groups FAI and ROM scores, with Cohen's *d* indicating the effect size. The Mann-Whitney *U* test was used to determine if there was a difference between groups on the NRS, SPADI and STMDI questionnaires, EMG activity of the shoulder girdle muscles and SDT scores. Cohen's *d* was calculated to determine the effect size using the Z score from the results. An effect size of 0.20 was seen as small, 0.50 as medium and large as 0.80 and above (Serdar et al., 2021).

The Spearman Rank test was used to determine correlations between SPADI pain, disability and total scores with FAI and STMDI total scores.

The strength of association was measured using the Spearman's rank correlation coefficient, where a perfect correlation was regarded as 1, strong as 0.7–0.9, moderate as 0.4–0.6 and weak as 0.1–0.3 in both directions (Akoglu, 2018).

3. Results

3.1. Participants' characteristics, TMJ and shoulder-related variables between the groups

A total of 36 participants were included in the study: 18 in the TMD group (15 females, three males, mean (SD) age of 34.78 (±16.23)) and 18 in the non-TMD group (14 females and four males, mean (SD) age of 37.50 (±14.62)) with no significant differences between ages ($p = 0.171$). Also of similarity was that the majority of participants had no medical conditions (89%), had jobs that did not involve heavy lifting (72%) but did involve computer work (72%), and both groups were right hand dominant ($n = 17$, 94%). These similarities highlight the low level of extraneous variables between the groups (see Table 2).

Table 2 summarizes the socio-demographic information of participants in both groups.

Table 3 shows the comparisons between the groups' previous treatment of the TMJ and shoulder girdle, presence of pain, previous injuries and popping/clicking of the shoulder, with the only significant difference with a large effect size being the previous treatment of the TMJ. Table 3 also shows the differences in NRS, FAI, SPADI and STMDI scores and ROM between the two groups.

Although not significant, more than double of the participants in the TMD group reported receiving previous treatment of the shoulder ($n = 11$, 61%) and having shoulder pain ($n = 13$, 72%) compared to the non-TMD group ($n = 5$, 28%).

No significant differences were found between the groups' ROM on right laterotrusion ($d = 0.08$, $p = 0.632$), left laterotrusion ($d = 0.04$, $p = 0.815$) and SDT scores ($d = 0.31$, $p = 0.096$ on the right and $d = 0$, $p = 1$ on the left). Majority of participants in the TMD group had obvious ($n = 10$, 55%) or subtle scapular dyskinesia ($n = 8$, 44%) bilaterally compared to the non-TMD group, with majority having obvious dyskinesia on the left and subtle dyskinesia on the right ($n = 10$, 55%).

The results of the individual questions of the FAI, STMDI and SPADI questionnaires are represented graphically in Figs. 1–3, respectively.

Vertical bars represent standard deviations; FAI, Fonseca Anamnestic Index; SD, standard deviation; TMD, temporomandibular disorders.

Vertical bars represent standard deviations; SD, standard deviation; STMDI, Steigerwald Maher TMD Disability Index; TMD, temporomandibular disorders.

*Social activities refer to singing, laughing, playing musical instruments.

**Jaw activities refer to yawning, opening the mouth and opening the mouth wide.

Vertical bars represent standard deviations; SD, standard deviation; SPADI, Shoulder Pain and Disability Index; TMD, temporomandibular disorders.

The first set of questions 1–5 are part of the pain subscale of SPADI. The second set of questions 1–8 are part of the disability subscale of SPADI.

3.2. Comparisons of muscle activity between the TMD and non-TMD groups

Table 4 shows the differences in muscle activity between the groups.

All the shoulder muscles had higher activity in the participants without TMD, compared to those with TMD with the exceptions of the left medial deltoid and right inferior trapezius which were higher during all jaw movements as well as at rest for the right inferior trapezius. The left serratus anterior also had higher activity in participants with TMD at rest and during all jaw movements except for active left laterotrusion. Similarly, the left biceps had higher activity in the TMD group during active left laterotrusion and the resisted jaw movements. The only other exception was the right medial deltoid which had higher activity in participants with TMD during resisted mouth opening and significantly higher activity during resisted right laterotrusion ($d = 0.34$, $p = 0.044$).

Despite the differences in muscle activity between the groups, no significant results were found during rest and left active and resisted laterotrusion. Significant differences were seen during mouth opening, right laterotrusion and resisted mouth opening with significantly lower activity of the right infraspinatus ($d = 0.39$, $p = 0.22$, $d = 0.35$, $p = 0.40$, $d = 0.36$ and $p = 0.031$) and serratus anterior ($d = 0.37$, $p = 0.027$, $d = 0.37$, $p = 0.029$ and $d = 0.38$, $p = 0.025$) respectively in participants with TMD compared to those without. The right infraspinatus also had significantly lower activity ($d = 0.39$, $p = 0.022$) in participants with TMD during resisted right laterotrusion.

Table 2
Medical, surgical, occupation and exercise factors of participants in both groups ($n = 36$).

	TMD group ($n = 18$)	Non-TMD group ($n = 18$)	Differences between groups	
Medical and lifestyle variables	Frequency (%)	Frequency (%)	p value[a]	Effect size[b]
Presence of medical conditions			1.00	0
Yes	4 (22)	3 (17)		
No	14 (78)	15 (83)		
Use of daily medication			0.146	0.32
Yes	8 (44)	3 (17)		
No	10 (56)	14 (78)		
Medication type				
Anti-hypertensives	0 (0)	2 (11)		
Cholesterol	2 (11)	0		
Hypothyroidism	2 (11)	1 (6)		
Oral contraceptive	2 (11)	1 (6)		
Psychiatric (anti-depressants, mood stabilisers)	3 (17)	0 (0)		
Previous surgery			0.092	0.34
Yes	14 (78)	7 (39)		
No	4 (22)	11 (61)		
Type of surgery				
Caesarean section	1 (6)	4 (22)		
Jaw	2 (11)	0 (0)		
GIT	5 (28)	0 (0)		
Tonsil removal	2 (11)	1 (6)		
Wisdom tooth removal	4 (22)	2 (11)		
Occupation				
Allied health/doctor	4 (22)	7 (39)		
Educator/teacher	4 (22)	3 (17)		
Office job	4 (22)	8 (44)		
Student/unemployed	6 (33)	0 (0)		
Occupation involves heavy lifting			1.00	0
Yes	5 (28)	5 (28)		
No	13 (72)	13 (72)		
Occupation involves computer work			1.00	0
Yes	13 (72)	13 (72)		
No	5 (28)	5 (28)		
Amount per day (hours)				
0–1	5 (28)	5 (28)		
2–3	5 (28)	4 (22)		
4–5	3 (17)	8 (44)		
≥6	5 (28)	1 (6)		
Exercise participation			1.00	
Yes	16 (89)	17 (94)		
No	2 (11)	1 (6)		
Frequency per week				
Once	8 (44)	8 (44)		
Twice or more	8 (44)	9 (50)		

TMD, temporomandibular disorders.

Table 3
Comparisons between previous treatment, injuries and the presence of pain, popping/clicking, levels of pain, function and disability of the TMJ and shoulder girdle in participants between groups (n = 36).

	TMD group (n = 18)	Non-TMD group (n = 18)	Differences between groups	
	Number of responses (%)	Number of responses (%)	p value[a]	Effect size[b]
Previous treatment of the TMJ	Yes: 16 (89) No: 2 (11)	Yes: 0 No: 18 (100)	<0.001	1.00
Shoulder pain	Yes: 13 (72) No: 5 (28)	Yes: 5 (28) No: 13 (72)	0.002	0.58
Previous shoulder injury	Yes: 2 (11) No: 16 (89)	Yes: 3 (17) No: 15 (83)	1.00	0
Previous treatment of the shoulder	Yes: 11 (61) No: 7 (39)	Yes: 5 (28) No: 13 (72)	0.012	0.34
Shoulder popping/ clicking	Yes: 4 (22) No: 14 (78)	Yes: 4 (22) No: 14 (78)	1.00	0
	Mean (SD)	**Mean (SD)**	**p value[c]**	**Effect size[d]**
FAI	59.50 (±16.06)	21.44 (±20.44)	<0.001	0.76
ROM:				
Mouth opening	3.68 (±2.57)	4.30 (±0.63)	0.005	0.46
R laterotrusion	1.28 (±0.41)	1.18 (±0.33)	0.632	0.08
L laterotrusion	1.15 (±0.48)	1.1 (±0.25)	0.815	0.04
	Median and interquartiles (Q25 – Q75)	**Median and interquartiles (Q25 – Q75)**	**p value[e]**	**Effect size[d]**
NRS	5.5 (3.75, 7)	0 (0, 4.25)	<0.001	0.62
SPADI Pain	15 (0, 39.25)	0 (0, 4.5)	<0.009	0.45
SPADI Disability	8.5 (0, 25.25)	0 (0, 2.25)	<0.01	0.44
SPADI Total	23.5 (0, 64.5)	0 (0, 6.75)	<0.009	0.45
STMDI Total	7 (4.50, 11.75)	0 (0, 0.25)	<0.001	0.70

FAI, Fonseca Anamnestic Index; IQR, interquartile range; NRS, Numerical Rating Scale; ROM, range of motion; SD, standard deviation; SPADI, Shoulder Pain and Disability Index; STMDI, Steigerwald/Maher TMD disability; TMD, temporomandibular disorder; TMJ, temporomandibular joint; L, left; R, right.
[a] : Fisher's exact test.
[b] Cramer's V.
[c] Independent sample's *t*-test.
[d] Cohen's *d*.
[e] Mann Whitney *U* test.

The shoulder muscles had the same pattern of a lower activity in participants with TMD during shoulder flexion and abduction, with no exceptions. Significant differences were seen in the right infraspinatus during shoulder flexion (d = 0.48, p = 0.004) and abduction (d = 0.33, p = 0.049). During shoulder abduction, there were also significant differences between the right biceps (d = 0.33, p = 0.049) and left infraspinatus (d = 0.38, p = 0.022).

3.3. *Correlations between the TMJ and shoulder girdle pain, function and disability*

There were significant, moderate positive correlations between SPADI pain and total scores with FAI (r = 0.48, p = 0.003) and STMDI scores (r = 0.46, p = 0.005) and SPADI disability with FAI (r = 0.46, p = 0.004) and STMDI total scores (r = 0.45, p = 0.006) (Table 5). Another correlation found was a significant, strong relationship between pain in the shoulder and pain in the TMJ (p < 0.001, Cramer's V = 0.707) as well as being able to fit three fingers in the mouth (p = 0.029, Cramer's V = 0.502).

4. Discussion

In this study, we investigated whether there was a difference in muscle activity of the five shoulder girdle muscles in participants with and without TMD, and if there were correlations between pain and disability of the TMJ and shoulder girdle. Our findings showed that there were indeed differences between the two groups, with the majority of muscles exhibiting lower activity in participants with TMD. There were some variances observed at rest and during jaw active and resisted movements with no exceptions during shoulder abduction and flexion. The reason for this may be due to the presence of pain causing a lower maximum voluntary contraction which highlights the potential effects of pain in the TMJ on the shoulder girdle (Graven-Nielsen and Arendt-Nielsen, 2008).

For participants to be included into the non-TMD group, they had to achieve a score of one or less on the TMD pain screener. Despite this, the scores on the FAI showed that some participants in the non-TMD group presented with mild TMD. However, in support of them being included in this group, the results showed that none of them had received previous treatment of their TMJ and the total median score for TMJ pain was zero, which was significantly lower than the TMD group.

It is encouraging to compare the baseline pain, ROM and rate of clenching in the current study to that of the findings of 50 participants with TMD by Sójka et al. (2017). The median pain of the participants in the TMD group of the current study was slightly higher at 5.5 compared to 4 in the other study. A potential reason could be that they only

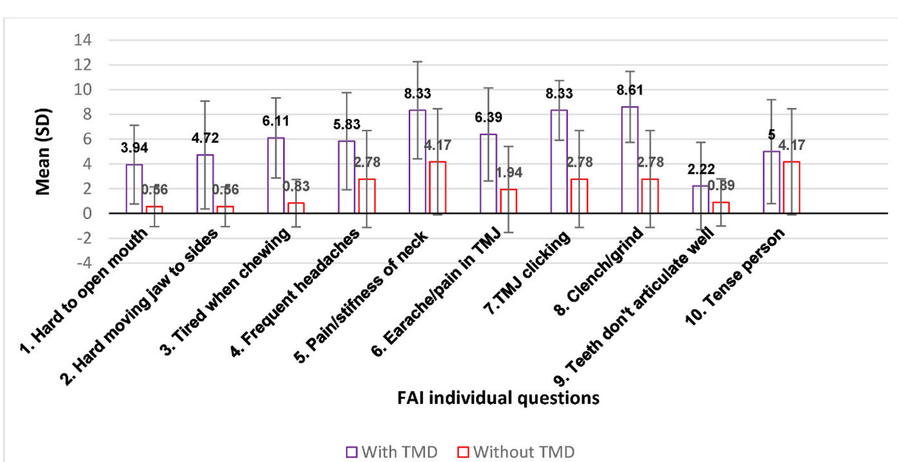


Fig. 1. Mean scores and standard deviations of responses to the FAI in participants with TMD (n = 18) and without TMD (n = 18).

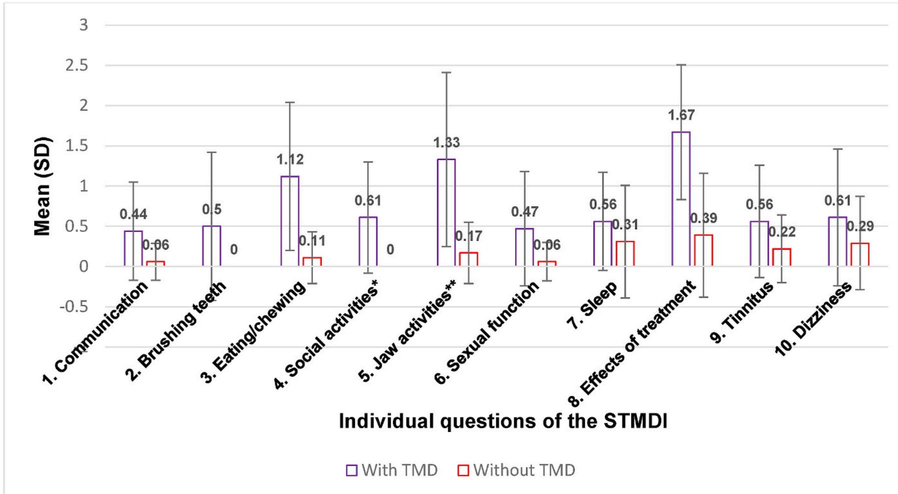


Fig. 2. Mean scores and standard deviations of responses to the STMDI in participants with TMD (n = 18) and without TMD (n = 18).

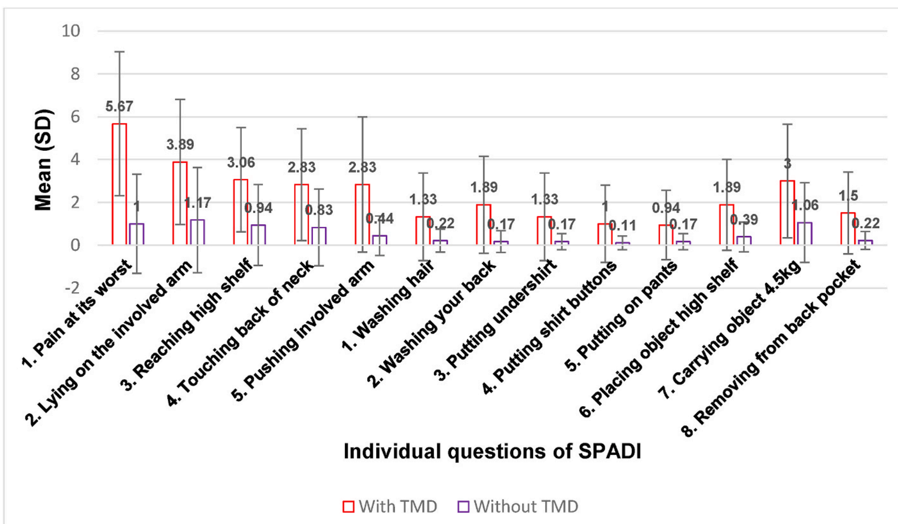


Fig. 3. Mean scores and standard deviations of responses to the SPADI in participants with TMD (n = 18) and without TMD (n = 18).

included females who have been shown to have a higher rate of seeking treatment for TMD at 86%, compared to men (Trize et al., 2018).

In the same study by Sójka et al. (2017), 75% of participants had a ROM on mouth opening less than 40 mm which is similar to the current TMD group who had a mean (SD) ROM of 3.68 cm (±2.57). The rate of their clenching was reported at 86%, which was also similar to the participants in the current study with a mean score of 8.61 (±2.87) of clenching/grinding on the FAI. These similarities are encouraging as the study used the DC/TMD, which is the gold standard extensive assessment tool used to diagnose TMD. The DC/TMD also classifies the type of TMD and those participants all had myogenous TMD and therefore based on the similarities it is possible that the participants in the current study were more likely to have myogenous TMD compared to arthrogenous.

In relation to the specific movements tested, majority of muscles had lower activity at rest in participants with TMD compared to those without. However, the differences were negligible with very small effect sizes which means the results should be interpreted with caution and may have low clinical relevance. These findings were in contrast to previous research testing the muscle activity of the SCM and upper trapezius at rest in participants with and without TMD (Pallegama et al., 2004). The reason for the differences may be due to the higher recruitment of motor units of these muscles to provide more stability of the head to allow improved movement of the TMJ in participants with TMD. Therefore, showing that the shoulder girdle muscles may not be recruited at rest in those with TMD as they do not provide a stabilising effect for the TMJ.

However, this was in contrast to the pattern seen as the demand on the jaw increased from active to resisted movements, the activity of more shoulder girdle muscles became higher in the participants with TMD. The potential reason for this could be that as jaw movements become resisted, there is an increased need for control and stability of the TMJ. This may be harder for those with TMD, leading to the increased recruitment of distal area such as the shoulder girdle. This has been shown through the ergogenic effects of clenching with studies showing that during clenching there is an increase in shoulder girdle muscle strength and endurance (Alghadir et al., 2018; Ferrario et al., 2001).

Another possible reason for the higher recruitment of the shoulder girdle muscles during resisted movements is based on the concept of rotating synergistic muscles to facilitate higher levels of muscle activity. This idea is seen through synchronised motor unit recruitment where one set of muscles takes over the activity while another set recovers while maintaining the constant overall force. This is seen between the

Table 4
Differences in activity of the five shoulder girdle muscles at rest and during jaw and shoulder movements between participants with TMD (n = 18) and without TMD (n = 18).

Muscle activity (μVolts)	TMD group (n = 18)	Non-TMD group (n = 18)	Differences between groups	
	Median (IQR)	Median (IQR)	Effect size[a]	p[b]
Rest				
R biceps	4.8 (3.4, 22.7)	5.9 (3.5, 25.4)	0.13	0.463
L biceps	4.3 (3.3, 7.0)	4.4 (2.9, 11.5)	0.01	0.987
R med. Deltoid	19.9 (8.2, 44.6)	28.0 (8.4, 55.9)	0.23	0.184
L med. Deltoid	7.8 (5.7, 16.5)	8.2 (5.3, 19.2)	0.11	0.961
R infraspinatus	10.4 (3.9, 27.7)	25.4 (5.1, 59.8)	0.33	0.053
L infraspinatus	6.7 (4.1, 21.6)	8.1 (4.2, 30.1)	0.18	0.303
R inf. Trapezius	5.8 (4.3, 14.1)	5.5 (4.1, 14.3)	0.11	0.596
L inf. Trapezius	7.5 (5.0, 19.7)	10.8 (5.5, 37.5)	0.24	0.163
R SA	2.9 (2.57, 8.5)	4.4 (2.8, 14.6)	0.33	0.053
L SA	4.0 (3.3, 5.1)	3.9 (2.4, 5.2)	0.08	0.503
Active Opening				
R biceps	5.2 (3.7, 8.4)	5.6 (4.3, 43.7)	0.25	0.152
L biceps	4.2 (3.2, 5.8)	4.5 (3.0, 5.9)	0.05	0.791
R med. Deltoid	20.6 (7.4, 44.1)	28.3 (7.7, 60.2)	0.17	0.339
L med. Deltoid	6.97 (4.1, 12.5)	6.0 (3.4, 8.8)	0.28	0.104
R infraspinatus	1.2 (0.6, 2.6)	22.4 (7.9, 37.0)	0.39	0.022
L infraspinatus	7.9 (4.1, 20.1)	11.0 (4.9, 26.8)	0.22	0.203
R inf. Trapezius	6.1 (4.7, 11.5)	5.8 (4.4, 10.3)	0.13	0.443
L inf. Trapezius	7.7 (5.1, 17.5)	9.6 (5.1, 19.8)	0.16	0.372
R SA	3.0 (2.4, 6.2)	3.4 (2.7, 50.3)	0.37	0.027
L SA	3.9 (3.5, 4.7)	3.8 (3.2, 4.5)	0.18	0.308
Active R laterotrusion				
R biceps	4.7 (3.1, 10.6)	5.2 (3.8, 19.4)	0.19	0.279
L biceps	4.2 (3.1, 5.6)	4.4 (3.0, 5.4)	0.01	0.963
R med. Deltoid	19.8 (6.9, 41.9)	25.4 (7.3, 62.3)	0.15	0.389
L med. Deltoid	6.5 (3.8, 15.4)	6.1 (3.6, 11.4)	0.21	0.214
R infraspinatus	9.9 (3.9, 22.8)	16.9 (5.0, 35.5)	0.35	0.040
L infraspinatus	6.3 (4.4, 16.2)	8.1 (5.3, 34.6)	0.33	0.051
R inf. Trapezius	5.3 (3.9, 10.5)	4.9 (3.5, 8.2)	0.26	0.134
L inf. Trapezius	8.3 (4.9, 17.3)	8.3 (4.9, 29.2)	0.13	0.462
R SA	2.6 (2.3, 6.1)	2.7 (2.6, 42.2)	0.37	0.029
L SA	4.0 (3.4, 5.3)	3.9 (3.3, 6.7)	0.10	0.563
Active L laterotrusion				
R biceps	4.8 (3.4, 10.0)	5.3 (3.8, 13.9)	0.13	0.462
L biceps	4.0 (3.3, 5.7)	4.2 (3.2, 5.2)	0.01	0.963
R med. Deltoid	20.3 (7.9, 39.0)	24.4 (6.8, 59.2)	0.11	0.521
L med. Deltoid	7.4 (4.1, 16.1)	6.2 (3.4, 10.5)	0.29	0.085
R infraspinatus	9.8 (4.2, 23.1)	16.2 (3.3, 35.1)	0.22	0.192
L infraspinatus	6.4 (5.1, 16.4)	9.3 (5.2, 30.2)	0.25	0.152
R inf. Trapezius	5.9 (3.8, 11.8)	4.7 (3.4, 10.3)	0.22	0.203
L inf. Trapezius	8.7 (5.0, 16.0)	10.3 (5.0, 18.6)	0.10	0.584
R SA	2.9 (2.3, 6.5)	2.9 (2.5, 40.9)	0.02	0.118
L SA	3.9 (3.5, 6.0)	4.0 (3.5, 6.0)	0.05	0.791
Resisted opening				
R biceps	4.9 (3.4, 12.4)	5.5 (3.8, 21,0)	0.15	0.389
L biceps	4.8 (3.1, 6.7)	4.4 (2.9, 5.8)	0.16	0.355
R med. Deltoid	11.8 (5.5, 30.1)	11.1 (5.0, 29.0)	0.13	0.443
L med. Deltoid	6.2 (4.4, 16.0)	5.7 (4.3, 8.3)	0.33	0.051
R infraspinatus	10.1 (4.2, 21.8)	16.6 (7.6, 33.3)	0.36	0.031
L infraspinatus	7.1 (4.4, 16.9)	7.6 (5.2, 21.6)	0.21	0.226
R inf. Trapezius	5.7 (4.1, 14.9)	5.1 (3.9, 11.0)	0.20	0.252
L inf. Trapezius	7.0 (5.2, 15.4)	7.7 (5.2, 15.4)	0.04	0.839
R SA	3.1 (2.4, 6.8)	3.6 (2.7, 88.2)	0.38	0.025
L SA	4.3 (3.7, 5.9)	4.0 (3.3, 8.9)	0.17	0.323
Resisted R laterotrusion				
R biceps	5.0 (3.3, 6.1)	5.2 (3.5, 9.2)	0.10	0.584
L biceps	4.6 (3.0, 6.7)	4.4 (2.7, 8.7)	0.03	0.888
R med. Deltoid	7.7 (4.3, 17.8)	9.1 (4.0, 20.0)	0.01	0.963
L med. Deltoid	6.4 (3.6, 15.5)	5.7 (3.5, 8.3)	0.34	0.044
R infraspinatus	8.3 (4.3, 19.4)	12.6 (6.9, 23.4)	0.39	0.022
L infraspinatus	6.7 (4.4, 16.7)	7.2 (4.7, 21.0)	0.18	0.293
R inf. Trapezius	5.9 (4.6, 10.0)	5.5 (4.0, 9.5)	0.21	0.214
L inf. Trapezius	8.1 (4.6, 14.7)	9.0 (4.4, 18.6)	0.06	0.743
R SA	3.0 (2.3, 6.9)	3.6 (2.5, 24.2)	0.27	0.109
L SA	4.6 (3.4, 6.1)	4.1 (3.3, 6.7)	0.07	0.673
Resisted L laterotrusion				
R biceps	5.5 (3.9, 10.6)	5.7 (4.0, 11.2)	0.12	0.501
L biceps	4.2 (3.4, 6.8)	4.0 (2.8, 5.6)	0.18	0.293
R med. Deltoid	17.5 (6.2, 47.0)	19.5 (5.4, 58.5)	0.07	0.673
L med. Deltoid	6.3 (3.9, 13.5)	4.9 (3.6, 9.9)	0.29	0.085
R infraspinatus	11.3 (4.3, 23.0)	18.0 (8.5, 39.8)	0.29	0.085
L infraspinatus	6.6 (4.4, 14.6)	7.5 (4.7, 22.7)	0.24	0.175
R inf. Trapezius	5.3 (4.1, 9.2)	5.0 (4.0, 9.7)	0.09	0.606
L inf. Trapezius	9.5 (5.5, 17.7)	9.7 (5.2, 25.4)	0.04	0.815
R SA	29.8 (22.5, 63.7)	3.5 (2.4, 32.4)	0.26	0.126
L SA	4.9 (3.8, 6.3)	4.7 (3.3, 6.8)	0.17	0.339
Shoulder flexion				
R biceps	63.7 (29.2, 279.1)	74.7 (45.6, 480.1)	0.23	0.181
L biceps	60.1 (35.0, 80.0)	70.4 (35.3, 133.6)	0.19	0.265
R med. Deltoid	107.6 (59.4, 195.4)	135.1 (66.5, 232.6)	0.25	0.152
L med. Deltoid	109.8 (62.8, 159.4)	132.2 (88.9, 217.9)	0.21	0.214
R infraspinatus	53.0 (25.2, 335.8)	241.8 (51.9, 635.6)	0.48	0.004
L infraspinatus	60.2 (34.1, 151.3)	63.5 (34.2, 120.3)	0.03	0.888
R inf. Trapezius	45.9 (18.6, 402.3)	239.8 (23.0, 487.2)	0.26	0.134
L inf. Trapezius	63.1 (34.9, 277.2)	112.5 (40.1, 758.4)	0.30	0.079
R SA	52.0 (16.6, 400.4)	195.1 (28.2, 650.6)	0.25	0.153
L SA	55.2 (17.7, 54.0)	328.8 (29.4, 681.8)	0.30	0.074
Shoulder abduction				
R biceps	42.7 (21.7, 362.6)	53.3 (34.4, 461.0)	0.33	0.049
L biceps	38.5 (27.3, 76.0)	56.6 (30.7, 84.3)	0.25	0.153
R med. Deltoid	163.6 (96.7, 296.9)	187.6 (107.3, 392.2)	0.21	0.232
L med. Deltoid	156.8 (90.3, 230.1)	158.9 (87.7, 253.4)	0.05	0.782
R infraspinatus	45.2 (25.3, 82.2)	62.8 (32.3, 275.1)	0.33	0.049
L infraspinatus	46.7 (26.7, 179.9)	67.9 (37.3, 193.7)	0.38	0.022
R inf. Trapezius	37.2 (13.4, 189.3)	47.2 (10.6, 202.9)	0.12	0.483
L inf. Trapezius	59.4 (26.6, 248.7)	80.2 (34.3, 321.4)	0.20	0.245
R SA	47.3 (16.5, 346.7)	86.3 (30.4, 504.6)	0.27	0.118
L SA	26.4 (17.0, 38.3)	31.6 (17.7, 448.1)	0.21	0.232

Inf, inferior; Lat, lateral; L, left; Med, medial; R, right; SA, serratus anterior.
[a] Mann Whitney *U* test.
[b] Cohen's d.

temporalis and masseter during prolonged low-level contractions of the muscles of mastication and could give insight into the shoulder girdle muscles facilitating this sustained resisted jaw movements too (Farella et al., 2008).

In the current study, the lower activity of the majority of the shoulder girdle muscles in participants with TMD are aligned with the current research of optimizing TMJ alignment leading to an increase in shoulder girdle muscle activity. This has been shown with higher activity of the anterior deltoid, biceps, pectoralis major, SCM and triceps when participants wore an occlusal splint compared to a placebo splint and no splint (Dias et al., 2019; Lee et al., 2013).

Similarly, this has been shown in the biceps in participants without TMD. The findings showed that participants had significantly higher maximum isometric contraction of the biceps while wearing an occlusal

Table 5
Correlations between shoulder pain and disability using the SPADI pain, disability and total scores with pain and disability of the TMJ using the FAI and STMDI questionnaires (n = 36).

Variables	FAI scores		STMDI scores	
	Spearman correlation coefficient (r) and confidence intervals	p value	Spearman correlation coefficient (r) and confidence intervals	p value
SPADI Pain scores	0.48 95% CI [0.17, 0.71]	0.003	0.46 95% CI [0.15, 0.69]	0.005
SPADI Disability scores	0.46 95% CI [0.15, 0.7]	0.004	0.45 95% CI [0.13, 0.68]	0.006
SPADI Total scores	0.48 95% CI [0.17, 0.7]	0.003	0.46 95% CI [0.14, 0.69]	0.005

FAI, Fonseca Anamnestic Index; SPADI, Shoulder Pain and Disability index; STMDI, Steigerwald Maher TMD Disability Index.

splint compared to no splint (Lee et al., 2013). Similarly, results from Ferrario et al. (2001) showed the ergogenic effects of clenching on the endurance of the biceps muscle on the same side as their hand dominance, which was the highest during clenching and lowest during biting on a cotton wool on the right. This is in agreement with the current results of changes in positioning of the TMJ leading to changes in biceps activity.

The muscle that showed the most significant differences between groups was the right infraspinatus which was significantly higher in the non-TMD group across majority of jaw movements and both shoulder abduction and flexion. This was supported by findings of Dias et al. (2019), who found a significant increase in infraspinatus peak EMG activity in participants who wore an occlusal splint compared to a placebo or no splint, with a significant increase in peak torque of external/internal rotation during the same conditions. Therefore, both of the studies have demonstrated the effects of no pain and optimal alignment of the TMJ on the rotator cuff muscle. Furthermore, shoulder muscles on the participants' hand dominance side had higher activity during jaw and shoulder movements compared to the non-dominant side.

Furthermore, the most significant differences with the right infraspinatus may indicate the potential that hand dominance plays in these participants. The majority, 94% were right hand dominant and therefore the infraspinatus may be sensitive to hand dominance in this population with more research needed.

The muscles that were the exceptions to this were the right inferior trapezius, left serratus anterior and left medial deltoid with a higher activity in participants with TMD. The inferior trapezius and serratus anterior were the only two muscles tested that stabilise the scapula with the serratus anterior protracting and the inferior trapezius depressing the scapula (Paine and Voight, 2013; Park and Lee, 2020). A potential reason for these differences could be the high number of participants (72%) who reported having occupations that are computer based.

Prolonged posture at the computer leads to upper crossed syndrome of increased thoracic kyphosis and a forward head posture. This leads to retraction and elevation of the scapula which has been found to cause weakness of the serratus anterior and inferior trapezius (Katsuura et al., 2020; Park and Lee, 2020). This same forward head posture has been found to be more common in participants with TMD compared to those without (Xiao et al., 2023). This provides an explanation as to why these two muscles had the opposite patterns to the rest of the group at rest and during the jaw movements.

There were no exceptions to the lower activity of the participants with TMD during the two shoulder movements tested. This is similar to the findings of a systematic review that found a lower activity of masseter and temporalis during maximal clenching in those with TMD compared to those without (Szyszka-Sommerfeld et al., 2023). Pain leads to increased pressure intramuscularly due to impaired blood flow and therefore a reduction in muscle activity (Farella et al., 2008) and these findings show that the effects of changes in blood flow due to pain in the TMJ may lead to changes in the strength and endurance of these shoulder muscles.

In accordance with the present results of a significant, positive correlation between the ability to fit three fingers in the mouth and presence of pain in the shoulder girdle, previous studies have also shown the changes in ROM with changes in pain in the SCM, a shoulder girdle muscle attaching to the clavicle. This was seen as reduction in pain and trigger points in the SCM led to an improvement in ROM in participants without TMD compared to a control group of no treatment (Bae, 2014).

The current study found a significant, positive correlation between shoulder and TMJ pain. This was similar to another study that found a higher prevalence of shoulder pain in those with TMD; of 165 participants with TMD, 33.1% had shoulder pain compared to the 11.7% of 172 participants without TMD having shoulder pain (Bonato et al., 2017).

No other studies have examined a potential correlation between shoulder pain and disability and level of TMD. As such, the findings of a positive, significant correlation between SPADI and FAI scores are new and form an important part of our understanding of the connections between the two areas.

This study is the first of its kind to examine these five shoulder girdle muscles in participants with and without TMD and the difference in activity during the various tasks. The main finding of the higher activity of the shoulder girdle muscles at rest and during jaw related movements in participants with TMD, compared to without, shows the impact of TMD on the shoulder. This change in motor recruitment pattern demonstrates the potential of participants with TMD to have higher tension of their shoulder muscles at rest and decreased motor unit recruitment during activation, leading to a decrease in strength.

Further research is needed on more of the shoulder girdle muscles including the use of fine wire electromyography to measure muscle activity of the deeper muscles.

4.1. Limitations

A limitation of the study is the small sample size. A larger sample sizes of different types of participants with varying TMD also need to be explored, along with more shoulder girdle movements such as flexion, extension, internal and external rotations with and without resistance.

The effect sizes and level of significance were small when comparing the two groups and therefore caution needs to be taken with interpreting and generalising the results.

Participants in the non-TMD group still reported pain on the NRS and a low level of disability on the FAI and STMDI, hereby indicating that there was some level of TMD in the non-TMD group. This shows the limitations of the TMD-pain screener used in the study.

Another limitation of this study is that although orthodontic treatment was excluded to control confounding factors, other conditions such as lack of posterior dental support, tooth surface loss, and parafunctional habits were not excluded despite evidence supporting their potential influence on pain and joint function in participants with TMD.

4.2. Strengths

No participants in the non-TMD group had received previous treatment of their TMJ.

4.3. Clinical relevance

- In order to make recommendations on assessing the endurance and strength of the shoulder muscles in participants with TMD, more research is needed
- Practitioners can include the presence of shoulder pain, disability and previous shoulder treatment in the assessment of participants with TMD

5. Conclusion

The main findings of the study were a higher activity of the shoulder girdle muscles at rest, during jaw and shoulder movements in participants without TMD. However, these results need to be interpreted with caution due to the lack of control over confounding variables and small effect sizes.

CRediT authorship contribution statement

Micaela Weinberg: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Benita Olivier:** Writing – review & editing, Supervision, Methodology, Conceptualization. **Siyabonga Kunene:** Writing – review & editing, Conceptualization.

Conflict of interest and financial disclosure

The authors certify that they have no affiliations with or financial involvement in any organisation or entity with a direct financial interest in the subject matter or materials discussed in the article. There were no conflicts of interest in this study.

Patient involvement

Patients involved in this study were able to drop out without consequences, participation was voluntary and participants' data were deidentified.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the author(s) did not use AI in any process.

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Declaration of competing interest

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