AN ASSESSMENT FRAMEWORK OF THE SHOULDER GIRDLE IN PARTICIPANTS WITH TEMPOROMANDIBULAR DISORDERS

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A thesis submitted to the Faculty of Health Sciences, University of the Witwatersrand, in fulfilment of the requirements for the degree of Doctor of Philosophy.
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DECLARATION

I, Micaela Weinberg, declare that this research report is my work. It is being submitted for the degree of Doctor of Philosophy in Physiotherapy at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at this or any other University.

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Signature of candidate

February 2024

DEDICATION

To my husband and biggest fan, Leigh, I cannot thank you enough for your constant support, motivation, and encouragement. I could not have done this without you, thank you for always believing in me and pushing me to achieve my dreams. I couldn't be luckier to have you as my soul mate and best friend.

To my two precious sons, Zev Elad and Uri Rafael, you are both my biggest gifts and blessings. You have both had your turns accompanying me in utero and I couldn't be more grateful to have you both as my children. You were and are my motivation and thank you for keeping me company on the many late nights and long days. I couldn't be luckier to be your mom, this PhD is dedicated to both of you.

To my parents and brother, thank you for your constant encouragement and love. You have always pushed me to do my best and nothing is ever too much for you. I am so blessed to have you in my life, and I love you all.

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SUMMARY

The general population is prone to developing temporomandibular disorders (TMD) due to the complexity of the temporomandibular joint (TMJ), the high number of times the joint is used daily, and the increasing prevalence of parafunctional habits which overload the joint and muscles.

This thesis aimed to develop an assessment framework of the shoulder girdle in participants with TMD, with four original studies emanating from this project.

The first was a scoping review that mapped out the anatomical, neuromuscular and neurophysiological connections between the TMJ and shoulder girdle and included a total of 41 articles.

The second study was a questionnaire that included 186 people with TMD. The result showed that 56% of participants had shoulder pain and 45% had received previous shoulder treatment. A significant positive correlation was found between the level of TMD and pain and disability of the shoulder, with the same findings in the third study.

The third study tested muscle activity of the biceps, medial deltoid, infraspinatus, inferior trapezius and serratus anterior at rest, during active and jaw-resisted movements, and weighted shoulder flexion and abduction. The findings were that participants with TMD, had a lower muscle activity at rest, during jaw and shoulder movements compared to those without TMD. The muscles that showed significant differences between the two groups were the right infraspinatus during shoulder flexion ($p = 0.004$) and abduction ($p = 0.049$), and the right biceps ($p = 0.049$) and left infraspinatus ($p = 0.022$) during shoulder abduction.

The results from these and other studies were taken and a framework was created. Through the use of the Delphi method (Study 4), it was distributed to a panel of international physiotherapy experts to gain consensus on the contents. The final framework included four subjective questions and two objective measures.

The overall findings showed that there are associations between pain, disability, and dysfunction of the TMJ and shoulder girdle in participants with TMD. Furthermore, there are differences in the activity of the shoulder girdle muscles during jaw and shoulder movements in those with and without TMD, with variances among the different muscles.

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As part of my declaration for this thesis, I acknowledge the following individuals for their contributions:

- The planning and design of the studies in this thesis were done by myself and my supervisors, Professor Benita Olivier and Dr Siyabonga Kunene.

- The searching of the databases for the scoping review was done by myself and a second reviewer, Mmathapelo Thotse, which formed part of Study 1.

- I was responsible for the drafting of questions used in Study 2 and tests used in Study 3, with input from my two supervisors.

- Alexander Santos from Delsys provided training and gave a lot of input into the use of electromyography in Study 3.

- Talya Gordon, a physiotherapist in private practice, was the research assistant who performed the assessments on participants in Study 3.

- I was responsible for collating the information used in the Delphi study (Study 4), with Professor Olivier and Dr Kunene reviewing the questions before circulation.

- I was responsible for data analysis for the project, with assistance from Professor Libhaber, who provided me with consults on which statistical tests to use.

- I was responsible for drafting of the literature review, with Professor Benita Olivier[1] editing and reviewing the chapter.

PEER-REVIEWED PUBLICATIONS EMANATING FROM THE WORK CONTAINED IN THIS THESIS

Weinberg, M., Olivier, B., Kunene, S., 2023. Shoulder Girdle Disability, Dysfunction, and Pain in Participants with Temporomandibular Joint Disorders: A Cross-Sectional Survey on Prevalence and Associations. *Physiotherapy Canada.* doi:10.3138/ptc-2023-0037 (published online).

Weinberg, M., Thotse, M., Olivier, B., Kunene, S., 2023. The anatomical, neuromuscular and neurophysiological connections between the shoulder girdle and temporomandibular joint: A scoping review. *Journal of Manipulative and Physiological Therapeutics* (under review).

Weinberg, M., Olivier, B., Kunene, S., 2024. Shoulder girdle muscle activity at rest and during jaw and shoulder movements in participants with and without temporomandibular disorders: a cross-sectional observational study. *Journal of Bodywork and Movement Therapies* (under review).

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LIST OF ABBREVIATIONS

DC/TMD - The Diagnostic Criteria for TMD
FAI - Fonseca Anamnestic Index
NRS - Numerical Rating Scale
OPPERA - Orofacial Pain: Prospective Evaluation and Risk Assessment
QoL - Quality of life
REDCap - Research Electronic Data Capture
ROM - Range of motion
SCM - Sternocleidomastoid
SDT - Scapular Dyskinesis Test
sEMG - Surface eletromyography
SHR - Scapulohumeral rhythm
SPADI - Shoulder Pain and Disability Index
STMDI - Steigerwald-Maher TMD Disability Index
TMD - Temporomandibular Disorders
TMJ - Temporomandibular Joint
VAS - Visual Analogue Scale

CHAPTER 1

1. INTRODUCTION

1.1 BACKGROUND

Temporomandibular disorders have a high prevalence worldwide and have been found to be the second most common musculoskeletal disorder after lower back pain, with a third of the American population having at least one sign of temporomandibular disorders (TMD) (de Leeuw and Klasser, 2018; Schiffman et al., 2014). The most recent systematic review of the prevalence of TMD in the general population was 31% in adults and 11% in adolescents and children (Valesan et al., 2021). The impact of TMD on quality of life (QoL) has been found to be substantial, with no differences between women and men and a higher impact in patients with more signs and symptoms of TMD (Trize et al., 2018).

The most common impairment associated with TMD is chronic pain which has been shown to lead to social exclusion, loss of income due to high health seeking behaviours, depression and anxiety (Bitiniene et al., 2018). Furthermore, a large portion of people with TMD report sleeping difficulties due to pain and stress relating to their condition. A systematic review showed that from 12 clinical trials, there was a direct relationship between a worse level of TMD and lower QoL and general health. A lower QoL in patients with TMD was supported by 83.3% of the clinical trials in the same systematic review (Bitiniene et al., 2018).

It has been proposed that the activity of the masticatory and cervical muscles is synergic. This is shown as higher levels of activity of the muscles of mastication led to higher cervical activity which resulted in changes in the positioning of the shoulder girdle. This is shown as participants with TMD were found to have a higher prevalence of shoulder elevation compared to those without TMD (Chaves, de Oliviera and Damazio, 2018). These findings are further supported by the higher prevalence of shoulder elevation being on the same side as the symptoms of the TMD (Ritzel, et al., 2007).

The evidence shows that there is a relationship between the cervical spine and shoulder girdle as well as between the cervical spine and temporomandibular joint

(TMJ), but there is limited research on the relationship between the TMJ and shoulder girdle and the changes that occur in the pathology of each of those areas.

The current treatment options for patients with TMD does follow the biopsychosocial approach with clear evidence on the impact TMD has on patients social and psychological status. Management of TMD includes the use of occlusal splints, pharmacotherapy, physiotherapy, psychology, self-care techniques, acupuncture and dry needling. Physiotherapy has been shown to be effective with randomised controlled trials showing that patients with TMD who received joint mobilisations or stretching exercises for muscle pain had greater improvements in range and pain of the TMJ compared to no treatment or occlusal splints only (Kapos et al., 2020).

Therefore, an improvement in the current treatment of these patients is needed to reduce the burden on the healthcare, levels of chronicity and associated comorbidities. This requires further expansion on what is known on the TMJ, past the connection it shares with the cervical spine and an exploration of other potential connections.

1.2 PROBLEM STATEMENT

There is an increase in the number of people complaining of signs and symptoms of TMD, with a lack of consensus on the most effective physiotherapy treatment for these patients (Craciun et al., 2022). This is evident in the results of a survey given to 58 maxillofacial surgeons on the effectiveness of physiotherapy in patients with TMD. The findings showed that three-quarters of the surgeons (76%) found physiotherapy to be ineffective, with 41% saying this is due to a lack of knowledge, thus highlighting the need to improve physiotherapists' knowledge of the TMJ and surrounding areas (Rashid, Matthews and Cowgill, 2013).

1.3 RESEARCH QUESTIONS

1.3.1 **Study 1**

What are the anatomical, neuromuscular and neurophysiological connections between the TMJ and shoulder girdle?

1.3.2 **Study 2**

What is the association between disability, dysfunction and pain of the TMJ and shoulder girdle in participants with TMD

1.3.3 **Study 3**

Is there a difference in activity of the shoulder girdle muscles at rest and during jaw and shoulder movements in participants with and without TMD?

1.3.4 **Study 4**

What should be included in an assessment framework of the shoulder girdle in participants with TMD?

1.4 RESEARCH AIM

To develop an assessment framework of the shoulder girdle in participants with TMD.

1.5 RESEARCH OBJECTIVES

1.5.1 **Study 1**

To map out the literature on the anatomical, neuromuscular and neurophysiological connections between the TMJ and shoulder girdle.

1.5.2 **Study 2**

To determine the association between the disability, dysfunction and pain of the TMJ shoulder girdle in participants with TMD. In addition, to estimate the prevalence of disability, dysfunction and pain in the shoulder girdle in participants with TMD.

1.5.3 **Study 3**

To compare the activity of the shoulder girdle muscles in participants with and without TMD. Furthermore, to determine if there were associations between pain and disability of the TMJ and shoulder girdle in those with and without TMD.

1.5.4 **Study 4**

To develop an assessment framework of the shoulder girdle in participants with TMD, based on the consensus from international experts.

1.6 ETHICAL CONSIDERATIONS

Ethical clearance was obtained from the University of the Witwatersrand Human Research Ethics Committee (Medical) (M2111110) (Appendix 1). Approval of the title for this thesis was obtained from the Faculty of Health Sciences at the University of the Witwatersrand (Appendix 2).

1.6.1 **Study 1**

Study 1 comprised a scoping review and, therefore, a synthesis of existing research was done. No human participants were directly involved in this study.

1.6.2 **Study 2**

An information sheet (Appendix 3) was available for each participant to read before agreeing to be part of the study; it was included in the advertisement and on the landing page of the questionnaire. There was no specific consent form, but it stated that by clicking on the link, the participant gave consent to participate in the study.

There was an option for participants to fill out their email addresses if they wanted to receive more information about being a participant in the observational study. It was stipulated that this was optional and that participants who did not wish to put their email addresses or participate in the next study would not be penalised. A data management plan was drawn up providing details of how data would be collected, stored and shared (Appendix 4).

1.6.3 **Study 3**

Before the examination was performed, participants were given an information sheet (Appendices 5 and 6) and gave written consent to be a part of the study (Appendix 7). The participation did not incur any costs; participants were paid R3.61 per km travelled as well as R100 for each assessment, which took 15 minutes. The setting was in a private room, and patients were comfortably seated during most of the examination. There were no adverse effects of the tools used in the study.

Participants were not penalised if they chose to drop out or if they chose for their information not to be used. Their details were kept confidential, and numbers were assigned to each person to conceal their identity. Participants were given feedback about their results and, therefore, benefited from their participation in the study.

1.6.4 **Study 4**

Each panellist received an information sheet describing what was involved in the Delphi study (Appendix 8). If they agreed to participate, they gave consent by signing electronically before completing the questionnaire (Appendix 9). Responses were anonymous, with no identifying questions. No costs were incurred. Results of the two rounds were securely stored on Research Electronic Data Capture (REDCap), with only the researcher having access to the information.

1.7 OUTLINE OF THE THESIS

1.7.1 **Chapter 1** contains the preface of the thesis, including the problem statement, research questions, aim and objectives, ethical considerations, an overall outline and a conceptual framework.

1.7.2 **Chapter 2** is the literature review on the TMJ, shoulder girdle, scapulohumeral rhythm, TMD, shoulder pain and dyskinesia. The existing relationships between the TMJ, cervical spine and shoulder girdle, and the various outcome measures used throughout the studies, are discussed.

1.7.3 **Chapter 3** includes a scoping review that maps out the literature on the anatomical, neuromuscular and neurophysiological connections between the TMJ and shoulder girdle.

1.7.4 **Chapter 4** contains the published manuscript on the prevalence of pain, disability and dysfunction of the shoulder girdle in participants with TMD.

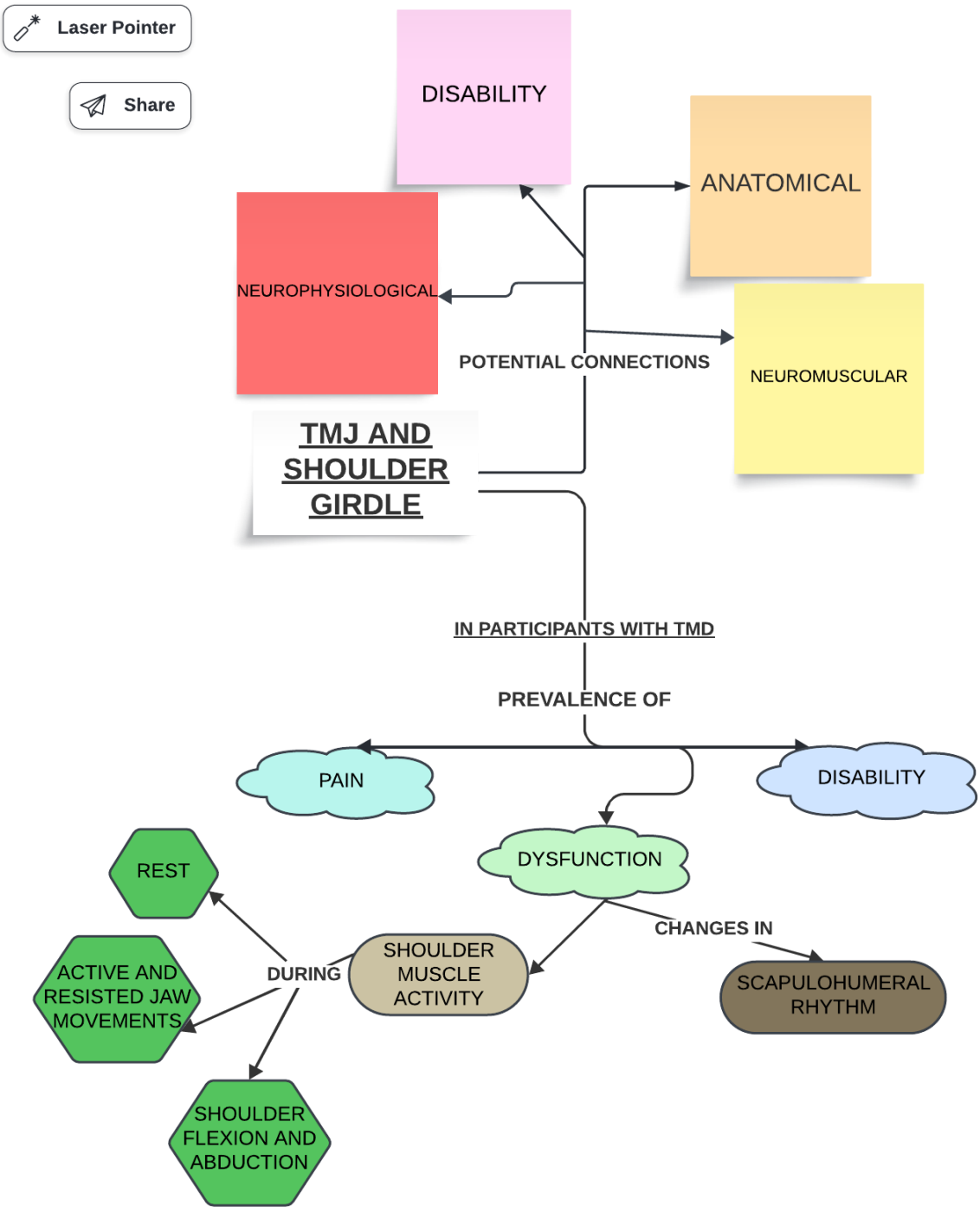
1.7.5 **Chapter 5** includes the observational study on the shoulder girdle muscle activity at rest and during jaw and shoulder movements in participants with and without TMD.

1.7.6 **Chapter 6** contains the manuscript of a two-round Delphi study on establishing an assessment framework of the shoulder girdle in participants with TMD.

1.7.7 **Chapter 7** contains the discussion and limitations.

1.7.8 **Chapter 8** contains the conclusions and future recommendations on this topic.

1.8 CONCEPTUAL FRAMEWORK



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CHAPTER 2

2. LITERATURE REVIEW

2.1 PREFACE TO THE LITERATURE REVIEW

This literature review will discuss the anatomy of the TMJ and go into depth about its pathology, known as TMD. It will explore the anatomy of the shoulder girdle with its biomechanics, scapulohumeral rhythm (SHR), as well as pain and dysfunction of this area. The existing relationships between the cervical spine and TMJ and cervical spine and shoulder girdle will be presented to provide insight into what is known about the existing connections. Furthermore, the evidence on the relationships between the TMJ and shoulder girdle will then be discussed, followed by the various outcome measures used across the studies.

EBSCO Masterfile Premier, MEDLINE, Science Direct and SCOPUS, CINHAL were searched for articles from 2013 – 2023 and all types of articles were included.

2.2 INTRODUCTION TO THE LITERATURE REVIEW

The TMJ is the most commonly used joint in the body, with 2000 to 2500 movements occurring daily. These include talking, chewing, swallowing, breathing, phonation and facial expressions, as well as involuntary actions such as yawning and clenching. These movements show how important the normal functioning of the TMJ is in the performance of vital functions and daily activities (González-Sánchez et al., 2023) and how dysfunction of this area, known as TMD, can impact patients' QoL.

Temporomandibular disorders are an umbrella term for pain and/or dysfunction in the TMJ, masticatory muscles and/or surrounding structures (Kapos et al., 2020). They are the most common type of chronic orofacial pain that is non-odontalgic in origin. Signs and symptoms of TMD include pain in the facial/head region or teeth, pain/tenderness of the masticatory muscles at rest or on palpation, and reduced range of mandibular movements and sounds in the joint during these movements (Bonato et al., 2017; Kapos et al., 2020). They are commonly associated with other conditions or areas of pain. These include headaches, ringing, pain or fullness in the ears, vertigo, cervical pain, and conditions such as irritable bowel syndrome,

depression, chronic fatigue syndrome, and fibromyalgia (Adelizzi et al., 2016; Bonato et al., 2017; Kapos et al., 2020).

2.3 TEMPOROMANDIBULAR JOINT AND DISORDERS

2.3.1 Temporomandibular Joint

The TMJ is a modified hinge, synovial joint, and is located bilaterally. The joint consists of the articulations between the articular eminence and mandibular fossa of the temporal bone and the mandibular condyle of the mandible (Chaves, de Oliviera and Damazio, 2017). Muscles of mastication refer to the chewing muscles of which there are four primary (masseter, temporalis, lateral and medial pterygoids) and three accessory (suprahyoid, infrahyoid and buccinator) (Basit, Tariq and Siccardi, 2023).

The primary muscles attach to the mandible with the main function of moving this bone, whereas the hyoid muscles' roles are to elevate and depress the hyoid and larynx. The buccinator, a muscle of facial expression, assists with mastication by moving and keeping the food backward. These groups of muscles work together to move the TMJ during chewing and other movements of the jaw (Basit, Tariq and Siccardi, 2023).

2.3.2 Temporomandibular Disorders

2.3.2.1 Prevalence of Temporomandibular Disorders

Factors involved in the development of TMD are multifactorial including biological, environmental, physical and psychosocial (González-Sánchez et al., 2023). A large multisite study, *Orofacial Pain: Prospective Evaluation and Risk Assessment* (OPPERA) was done in 2006 and included four observational studies. It also included several thousand participants across the United States, with and without TMD with an aim to determine the prevalence of TMD and its risk factors. In one of the studies, consisting of healthy volunteers, it found an annual incidence rate of 4% for onset of TMD symptoms in individuals between 18 and 44 years old (Slade et al., 2013).

The new onset of TMD was found to rise as age increased, with a prevalence of 2.5% in those between 18-25 years, 3.7% in individuals between 25-34 years and 4.5% in participants in the 35-44-year age group. Of the total group of participants

that developed TMD, almost half of them (49%) had symptoms that persisted after six months (Slade et al., 2013).

Although the studies were large, a systematic review done more recently found a higher prevalence of TMD namely 38.4%, in adults across 40 studies and a higher prevalence of TMD, 24%-56%, in children and adolescents between eight and 19 years old. The potential reasons for such a vast range are children not seeking treatment for TMD and TMD often not being diagnosed in children (Minervini et al., 2023).

Another finding of the OPPERA studies was that women did not have a higher risk of developing TMD but instead were more prone to developing chronic TMD (Ohrbach et al., 2011). However, the majority of other studies have found women to be twice as likely as men to develop TMD with postulated reasons being hormonal differences, higher chances of seeking treatment, and differences in pain sensitivities (Bueno et al., 2018; Gil-Martínez et al., 2016; Minervini et al., 2023). This is evident as 86.6% of people seeking treatment for TMD were women (Trize et al., 2018).

No study has reported on the prevalence of TMD in South Africa, but one study did examine the prevalence of TMD in participants attending an otorhinolaryngological clinic in Sub-Saharan Africa (Adegbiji et al., 2021). They found a prevalence of 1.3% of TMD among the 4 392 patients, with the majority of participants being civil workers. This prevalence was lower than other studies, and contrary to other countries found the most common age of those with TMD (37%) to be in the 51–60-year age group. Similarly to other studies, double the participants with TMD were women. However, these results cannot be generalised to the Sub-Saharan population, as the patients involved were specifically those seeking treatment for earache (Adegbiji et al., 2021).

2.3.2.2 **Types of Temporomandibular Disorders**

A taxonomic summary of the different types of TMD is dysfunction of the muscles, joint, or a combination of both. A much more detailed assessment tool used to detect and differentiate the types further is *The Diagnostic Criteria for TMD* (DC/TMD). According to this tool, there are 12 types of TMD, which are grouped

into painful TMD (joint, muscular and headache-related) and non-painful TMD (degenerative, disc displacement and subluxation) (Schiffman et al., 2014).

The pain-related types of TMD include arthralgia, local myalgia, myofascial pain syndrome with or without referral, and headache attributed to TMD, which occurs in the temple region and is replicated in provoking the masticatory muscular system. The criteria for each type of TMD need to be met through the history and clinical findings for the specific classifications, with each type having subdivisions (Schiffman et al., 2014).

Myalgia is more common than arthralgia, with the prevalence of myofascial pain syndrome varying between studies. The ranges are 50% in Germany, 15.4% among Saudi Arabian children, 48.8% in Ukraine, and 47.4% in Poland, with a review finding an overall global prevalence of 45.3%. Even more common than myalgia is the combination of myalgia and arthralgia, with a prevalence of 73%, compared to 23% in myalgia alone, and 4% in arthralgia alone (Kapos et al., 2020).

The leading causes for muscular types of TMD are pathophysiological and psychological. These include anxiety, depression and other emotional stresses and disturbances, which result in higher activity of the central nervous system. This, in turn, leads to excessive stimuli to the body, resulting in increased masticatory muscle use, commonly known as clenching, which causes the development of trigger points. Pathophysiological causes included certain medications, central nervous system disorders, and genetic predispositions. Other factors involved include dental malocclusions, gender, hypothyroidism, and low levels of vitamin D or B12 (Golanska et al., 2021).

Treatment of TMD focuses on biopsychosocial factors and includes the use of occlusal splints, physiotherapy, botulinum toxin injections, acupuncture, and pharmacological therapy, as well as cognitive behavioural therapy, and other psychological interventions (Golanska et al., 2021).

2.3.2.3 **Associated Conditions of Temporomandibular Disorders**

One of the OPPERA studies examined participants with chronic TMD compared to a control group. They found that those with TMD were more likely to report

headaches, a higher incidence of chronic pain in different regions of the body, more episodes of back pain in the previous year, and a higher amount of irritable bowel syndrome symptoms compared to the control group (Ohrbach et al., 2011).

These results were similar to those of a large descriptive case-controlled study, which found that participants with TMD were 5.5 times more likely to present with pain in other areas compared to controls with a highly significant relationship between TMD and other areas of joint pain ($p < .0001$). Of those with TMD, 90.9% of participants had other areas of pain, with 82.5% being women. Knee pain was the most prevalent out of all the joints, followed by the hip and then the shoulder (Bonato et al., 2017).

The phenomena behind the development of other areas of pain in this population are their predisposition to developing central sensitisation. This occurs through the increased sensitivity of nociceptive receptors, leading to changes in the central neurones' excitability and ultimately influencing pain modulation and causing widespread pain (Gil-Martínez et al., 2016).

2.3.2.4 **Temporomandibular Disorders and Quality of Life**

The disorder has also been shown to impact QoL negatively and places a significant burden on the healthcare system, as TMD pain is a big driver of health seeking treatment (Kapos et al., 2020). A study showed the negative impact of TMD on QoL and found a positive association between pain and mental health according to the Short Form-36 in those with TMD compared to those without. They also found a correlation between anxiety and depression and signs and symptoms of TMD. However, the authors did not provide levels of statistical significance nor correlation coefficients (Trize et al., 2018).

The OPPERA study showed similar findings of lower QoL, including participants with chronic TMD having poorer health statuses and higher amounts of neural and respiratory conditions and usage of medication than those without TMD (Ohrbach et al., 2011).

2.4 SHOULDER GIRDLE

2.4.1 Anatomy of the Shoulder Girdle

The shoulder girdle complex consists of four joints and four bones: the acromioclavicular, glenohumeral, scapulothoracic and sternoclavicular joints and the clavicle, humerus, scapula and sternum bones (Miniato, Anand and Varacallo, 2023). These structures are intricately connected through their articulations and muscular attachments.

The acromioclavicular joint allows additional movement of the scapula, assists in shoulder abduction and flexion and transfers forces from the upper arm to the axial skeleton. The sternoclavicular joint supports the shoulder and connects the arm to the rest of the body. These two joints work synchronously with the scapulothoracic joint through their shared skeletal attachments (Miniato, Anand and Varacallo, 2023).

The glenohumeral joint (GHJ) is a complex ball-and-socket joint which offers a broad range of movement in multiple directions at the expense of stability. The instability is countered by the co-ordination and effort of both contractile and non-contractile tissues around and within the shoulder joint (Gasbarro, Bondow and Debski, 2017).

The contractile tissues include muscles and tendons, which overlap and share attachments throughout the shoulder girdle complex. The dynamic stabilisation of the head of the humerus throughout movement is mainly achieved through the four rotator cuff muscles, namely the infraspinatus, teres minor, subscapularis and supraspinatus, subscapularis. Static stability is provided through the capsule and surrounding ligaments (Gasbarro, Bondow and Debski, 2017).

Other muscles of the shoulder girdle include the latissimus dorsi, levator scapula, rhomboid major and minor, serratus anterior, teres major and trapezius posteriorly; the deltoid laterally and the biceps brachii, coracobrachialis, pectoralis major and minor and the subclavius, anteriorly (Miniato, Anand and Varacallo, 2023).

2.4.2 **Scapulohumeral Rhythm**

One of the main objectives of this thesis is to determine if there is a connection between the TMJ and shoulder girdle. A part of this was to determine if there were changes in scapulohumeral rhythm (SHR) in participants with TMD. Some of the muscles that contribute to the functioning of the TMJ are also scapular stabilisers and therefore this analysis was included.

During arm elevation, the kinematic relationship between the scapula and the humerus is referred to as scapulohumeral rhythm (SHR). The involvement of the scapula in shoulder movements is necessary to obtain the full range of motion (ROM). The first 30° of shoulder movements are mainly from the GHJ, and after that, the contribution from the scapulothoracic joint is half with an overall ratio of 2:1 (glenohumeral to scapulothoracic contribution).

The muscles recruited in moving the scapula during shoulder elevation occur in different phases:

- The upper fibres of both serratus anterior and trapezius are responsible for the first 60° of scapular rotation.
- The upper and lower fibres of trapezius and the lower fibres of serratus anterior are involved in the next 60° of scapular rotation.
- The lower fibres of serratus anterior and trapezius contribute to scapular elevation from 120° and above (Briel, Olivier and Mudzi, 2018).

2.4.3 **Scapular Dyskinesis**

Scapular dyskinesis is the abnormal movement of the scapula during shoulder movements (Christiansen et al., 2017). There is conflicting evidence on the relationship between scapular dyskinesis and shoulder pain in the general population and if changes in the SHR are a risk factor for shoulder pain. However, in those playing overhead sports, a link has been shown between changes in scapular upward rotation, especially at 45° and 90° of shoulder abduction, and the development of painful scapular dyskinesia. Despite the lack of consensus, there is agreement that altered scapula orientation is a risk factor for developing shoulder impingement syndrome (Giuseppe et al., 2020).

A newer study compared the SHR of healthy controls to participants with adhesive capsulitis, glenohumeral osteoarthritis and small and large rotator cuff tears with a total sample size of 121 participants. The results showed a significantly lower SHR in the participants with adhesive capsulitis, glenohumeral osteoarthritis and large rotator cuff tears compared to the control group. A lower SHR indicates a higher amount of scapulothoracic movement, usually compensatory in nature (Xiao et al., 2023).

2.4.4 **Shoulder Pain**

Shoulder pain has a high rate of chronicity, with half of patients experiencing shoulder pain still presenting with symptoms six months later (Lucas et al., 2020). The impact on QoL is seen with poorer pain relief and return to function compared to patients presenting with other types of musculoskeletal pain. Studies utilising functional brain MRIs to assess pain responses found increased central sensitisation in patients with chronic shoulder pain (Walker-Bone and van der Windt, 2021).

There is also a significant financial burden associated with shoulder pain, with a study in Sweden showing the cost to be 4 139 euros per patient, with most of the expense relating to sick leave (Lucas et al., 2020).

2.5 **CERVICAL SPINE AND TEMPOROMANDIBULAR JOINT**

The anatomical, biomechanical and neurophysiological relationships between the cervical spine and TMJ have been well established.

2.5.1 **Anatomical**

Anatomically, the TMJ and upper cervical joints are proximally located with an overlap of the SCM and suprahyoid muscles between the two areas (Grondin et al., 2015).

2.5.2 **Biomechanical**

The quadrant theory describes how the movement of the TMJ centres around the atlas and axis of the cervical spine, and an imbalance of the TMJ causes changes in the positioning of the first two cervical vertebrae and, therefore, the muscles that attach to these joints (Lee et al., 2015).

The close relationship is further shown during maximal mouth opening where it has been found that upper cervical extension occurs simultaneously or even before the mandible moves, highlighting the feed-forward system between the two areas. This also shows that mouth opening is not the depression of the mandible in isolation but a combination of jaw and neck movements (Häggman-Henrikson, Nordh and Eriksson, 2013). The effects of mobilising the upper cervical spine on the ROM of mouth opening have also been shown (Mansilla-Ferragut, et al., 2009).

2.5.3 **Neurophysiological**

The neurophysiological relationship is through the first three cervical nerve roots, which share a neurone pool with the facial, glossopharyngeal, trigeminal and vagus nerves. This leads to changes in occlusion, modulating the input to the cervical muscles, causing changes in the activity of the cervical muscles (Ceneviz et al., 2006; Crăciun et al., 2022).

Other results are an overlap of symptoms between the cervical spine and TMJ with a higher prevalence of TMJ pain in participants with cervicalgia and visa-versa (Häggman-Henrikson, Wiesinger and Wänman, 2018) and a reduced ROM of cervical flexion, extension and rotation, and increased cervical muscular sensitivity in those with TMD compared to without (Crăciun et al., 2022).

2.6 **CERVICAL SPINE AND SHOULDER GIRDLE**

Similarly to the cervical spine and TMJ, there is an overlap of symptoms between the cervical spine and shoulder girdle. Fifty percent of participants with shoulder pathology had cervical pain, and one in every 25 participants who attended the shoulder or spine clinic were found to either have mistaken or overlapping pathology and needed the other clinic's services. It was also found that participants with cervical spine degeneration were predisposed to rotator cuff tears (Kastuura et al., 2020).

The connections of the neck to the clavicle and scapula were shown in a study where right-handed participants with neck pain (whiplash associated disorder and an insidious onset of pain) had significantly reduced right clavicle retraction and left scapular upward rotation in the whiplash group and reduced clavicle elevation in the

gradual neck pain group compared to participants with no cervical pain (Helgadottir et al., 2011).

The reduced clavicular elevation in those with neck pain may be due to the lower fibres of trapezius over-activating compared to the upper fibres of trapezius or that the upper fibres of trapezius were weak in elevating the clavicle against gravity (Helgadottir et al., 2011).

These findings were consistent with other studies that have found participants with neck pain to have increased upper cervical extension, lower cervical flexion and reduced clavicle retraction. This resulted in an increase in compression of the articulations between the cervical and thoracic spine causing changes in muscle activity of the trapezius and serratus anterior as well as increased neural tension of the median nerve (Helgadottir et al., 2011).

The research shows that there is a relationship between the cervical spine and shoulder girdle with pain influencing the activity of the neck and shoulder muscles.

Therefore, it is clear from the research above, although limited, that there are strong connections between both the cervical spine and TMJ and the cervical spine and shoulder girdle.

2.7 TEMPOROMANDIBULAR JOINT AND SHOULDER GIRDLE

The high impact of TMD on QoL and high prevalence of associated co-morbidities highlight the importance of exploring further connections of the TMJ.

2.7.1 Muscles of the Temporomandibular Joint and Shoulder Girdle

The hyoid bone, suprahyoid, infrahyoid, SCM and trapezius muscles are well researched links between the TMJ and shoulder girdle with limited research available on other shoulder girdle muscles and their connections with the TMJ.

2.7.2 Hyoid Bone and Muscles

The hyoid bone is connected to the mandible of the TMJ and the shoulder girdle through the manubrium of the sternum and the notch of the scapula. This is through the mylohyoid, sternohyoid and omohyoid muscles, respectively. The interplay of

the suprahyoid and infrahyoid muscles during swallowing is an example of muscles attached to the mandible and shoulder girdle working together to achieve a function (Auvenshine and Petit, 2020).

The interaction of the two groups of hyoid muscles is also seen during mouth opening, where the mandible is considered the insertion, and the hyoid bone the origin. This action is performed by the infrahyoid muscles contracting to stabilise the hyoid bone and the suprahyoid muscles co-contracting to bring the mandible towards the hyoid bone (Auvenshine and Pettit, 2020). This shows that the scapula and sternum play a role in mouth opening, a movement of the TMJ, through the activity of the hyoid muscles.
One study showed the presence of a greater amount of trigger points in the digastric, a suprahyoid muscle, in those with TMD compared to those without (Inoue et al., 2010). However, more research is needed on how the pathology of both the infrahyoid and suprahyoid muscles will affect the TMJ and action of mouth opening.

2.7.3 **Sternocleidomastoid and Trapezius**

The SCM is a direct anatomical link between the TMJ and shoulder girdle as it originates from the clavicle and manubrium of the sternum and attaches to the superior nuchal line and mastoid process of the temporal bone, which also houses the TMJ (Bordoni and Varacallo, 2022). This muscle is essential in the stomatognathic system, as it provides feedback to the vestibular system through its motor neurons. Changes in activity of the SCM lead to changes in head position, which influences the position of the mandible and the tone of the muscles of mastication (Bae, 2014).

The cervico-trigeminal and trigemino-cervical reflexes are part of the neurophysiological relationship between the SCM and TMJ. The cervico-trigeminal reflex shows the reciprocal relationship between the masseter and SCM muscles during occlusion, with changes in occlusion leading to changes in the functioning of the SCM (Bordoni and Varacallo, 2022). The trigemino-cervical reflex also demonstrates the relationship between the two areas as it is activated during chewing and stimulates the activity of SCM unilaterally when chewing on one side and bilaterally when chewing on both sides. Furthermore, an increase in the SCM's

electrical activity has been associated with a higher occurrence of TMD (Bordoni and Varacallo, 2022).

The other muscle extensively researched in relation to the TMJ is the trapezius. The most common findings among studies done on the SCM and trapezius are a higher activity at rest and a lower activity during maximum voluntary contraction in participants with TMD compared to those without (Sforza et al., 2018). A large number of studies have shown the concomitant activity of SCM and trapezius during clenching and even more so during grinding, further highlighting the relationship (Ciuffolo et al., 2005; Giannakopoulos et al., 2013; Giannakopoulos, Schindler and Hellmann, 2018; Häggman-Henrikson, Nordh and Eriksson, 2013).

The effects of occlusal splints on the activity of the SCM and trapezius have also been well researched, with findings of their lower activity at rest and during clenching when using an occlusal splint compared to a placebo or no splint (Ceneviz et al., 2006; Lee et al., 2013).

The other evidence of the relation of the SCM and trapezius to the TMJ is a higher amount of trigger points in the SCM and trapezius in those with TMD, compared to those without, with larger areas of referral including to the temple (Fernandez-des-les-Penas et al., 2010).

2.7.4 **Other Shoulder Girdle Muscles**

The focus of the connections in the literature has been on the SCM and trapezius. Only one study has examined the effects of occlusion on the muscle activity of the anterior deltoid, infraspinatus, lower trapezius and pectoralis major, as well as on the peak torque of shoulder abduction/adduction and internal/external rotation in healthy participants. This study had no control group and consisted of 14 healthy male participants, which does not represent the higher prevalence of TMD in the female population (Dias et al., 2019). The findings showed a higher muscle activity of all four muscles when participants wore an occlusal splint compared to no splint (Dias et al., 2019). However, more research needs to be done on females and in those with TMD.

The biceps and triceps are the only other shoulder girdle muscles tested in relation to changes in the TMJ alignment, and there was only one study done on this. This study included 20 healthy volunteers and did not consist of a comparative group. Maximum voluntary contraction was tested with and without an occlusal splint, and the findings were a significantly higher muscle activity of both the biceps and triceps during isometric movements with the use of an occlusal splint (Lee et al., 2013).The potential reason for this increase in activity of the abovementioned shoulder girdle muscles may be due to the occlusal splint causing changes in the vertical dimensions and positioning of the TMJ. This results in alterations in the information received by the accessory nerve, and as previously mentioned, there is an overlap of signalling between the accessory and trigeminal nerves. Therefore, changes in trigeminal input through the occlusal splint will influence the afferent fibres of the accessory nerve and in turn the SCM and trapezius. Both of these muscles fixate to the clavicle and scapula; these bones support the muscles that showed the changes with the occlusal splint above. Therefore, an improvement in the fixation of the clavicle and scapula through the SCM and trapezius may lead to an increase in support for the other muscles that attach to them and ultimately improve their activation (Dias et al., 2019).

Another theory is that due to no significant differences found when participants wore a placebo splint compared to no splint, the optimisation of occlusal stability by maximising bilateral tooth contact could have potentially led to better stabilisation of the scapula and clavicle and, therefore, better activation of the muscles attaching to them (Dias et al., 2019).

Hence, the change in activity of the anterior deltoid, biceps, infraspinatus, inferior trapezius, pectoralis major and triceps have all been examined in one study each in healthy volunteers only, with the use of an occlusal splint (Dias et al., 2019; Lee et al., 2013). The research has mainly focussed on the hyoid muscles, SCM and trapezius, and more research on the other shoulder girdle muscles is needed.

2.7.5 **Shoulder Girdle Muscles and Range of Motion of the TMJ**

The relationship between the ROM of the TMJ and shoulder girdle muscles has been shown. A randomised controlled trial by Bae (2014) found that participants who received Kinesio Tape on their SCM had a significant improvement ($p < .05$) in

ROM of mouth opening compared to those with no tape. These results further show the connection between the masticatory system and shoulder girdle. The reverse was also shown: correcting occlusal issues led to an improvement in torticollis, which is caused by dysfunction of the SCM (Bordoni and Varacallo, 2022).

The conclusion reached above is similar to the findings of a study that found a positive correlation between the pain pressure threshold of the medial scapular muscles and ROM of mouth opening in 75 participants with scapulocostal syndrome. Therefore, the connections between ROM of the TMJ and the cervical spine and shoulder girdle have been shown (Bae, 2014; Kanhachon and Boonprakob, 2022; Komiyama et al., 2005).

2.7.6 Postural Changes of the Shoulder and Temporomandibular Disorders

The research on changes of the position of the shoulder in participants with TMD is scarce but consistent in its findings of a higher prevalence of shoulder elevation in those with TMD. These results are shown in a study done on children and adolescents, where those with moderate TMD had a higher incidence of shoulder elevation and protrusion compared to those with no and mild TMD (Chaves, de Oliviera and Damazio, 2017). Similarly, another study found that double the number of participants with TMD had elevated shoulders compared to those without TMD (Cox and Klein, 2013). The changes may be due to facial muscle hyperactivity leading to overactivity of the cervical muscles and, therefore, changes in the spinal alignment and shoulder positioning (Chaves, de Oliviera and Damazio, 2017).

2.8 OUTCOME MEASURES AND MEASURING INSTRUMENTS

The outcome measures and measuring tools discussed below are relevant in the remaining chapters of this thesis. A description of each tool used with the related psychometric properties is discussed, and a brief explanation is given of why that specific measure was chosen above others.

2.8.1 Temporomandibular Disorder Pain Screener

The TMD Pain Screener forms part of the DC/TMD and is a simple, reliable and valid tool to screen for patients with pain-related TMD. The TMD Pain Screener was developed due to previous screeners not having all the standards of diagnostic accuracy parameters and being limited in their psychometric properties. This led to

the need for the development of a screening tool that had good psychometric properties and was quick and easy to administer (Gonzalez et al., 2011).

This tool consists of three questions asking participants how long their pain in the jaw/temple lasted, if they had pain/stiffness in their TMJ on awakening and if chewing hard food made their pain worse or better. A score of two or more is indicative of the presence of painful TMD and the need for further assessment (Schiffman et al., 2014).

It has a specificity and sensitivity of ≥ 0.95 and is commonly used to assess patients in a research setting (Schiffman et al., 2014). The internal reliability was found to be excellent, with an alpha value of 0.87 for the short version, which was the type used in the study. The sensitivity was found to be 99% and specificity 97% in differentiating between patients with and without painful TMD. The specificity was at least 95% in determining those with non-painful TMD and headache-associated TMD (Gonzalez et al., 2011).

The three screening questions is another screening questionnaire used to identify participants with TMD. This tool was developed to help dentists identify patients with TMD at their appointments to improve their management. The first two questions were found to have substantial validity in relation to the TMD Pain Screener, whereas the third question only had moderate validity (Lövgren et al., 2016). This tool was thus not chosen due to the lower validity of the third question and the intention for its development being for dentists.

2.8.2 **Numerical Rating Scale**

Pain in the TMJ and/or surrounding structures is a frequent complaint in patients with TMD. It is a common reason that patients will seek treatment; therefore, a valid and reliable tool is needed to measure the level of pain (Kapos et al., 2020).

The Numerical Rating Scale (NRS) is a type of Visual Analogue Scale (VAS) consisting of a 10cm line. Possible options range from a zero, indicating no pain on the left, to 10 on the right indicating the worst possible pain. The tool has a high test-retest reliability (r = 0.96) and convergent reliability with other pain scales such as the VAS (r = 0.95) (Begum and Hossain, 2019). The NRS is also the preferred

tool of choice for children and adolescents, who are common sufferers of TMD (Castarlenas et al., 2017).

A study of TMD participants compared the precision of the Behavioural Rating Scale, NRS, VAS and Verbal Rating Scale. A high tool precision means a large correlation between the initial measurements. The NRS was found to have the highest precision, as the other three tools showed significant differences in scores before treatment occurred (Conti et al., 2001).

2.8.3 Fonseca Anamnestic Index

The Fonseca Anamnestic Index (FAI) is used to classify the level of severity of TMD. It is a self-administered, simple and quick tool that does not require prior training. It is based on the Helkimo Index and assesses function, pain, parafunctional and psychological factors in participants with TMD. The FAI consists of 10 questions with three possible answers of no (0 points), sometimes (5 points) or always (10 points). A total score of 0-15 is indicative of no TMD, 20-45 is mild, 50-65 moderate and 70-100 severe (Rodrigues-Bigaton, de Castro and Paulo, 2017).

The reliability of the FAI has been found to be acceptable with good validity but has mixed reports of accuracy. The intraclass correlation coefficient for test-retest reliability was found to be 0.823, the kappa coefficient for criterion validity 0.63, Cronbach's alpha value 0.699 with a sensitivity of 96% and a specificity of 72% (Zhang et al., 2020). The level of accuracy for the FAI varies across the research, with findings that the two questions on the presence of a stiff neck and headaches are inadequate in the prediction of the level of TMD. Contrarily, another study found a high degree of accuracy of the FAI with area under the curve of 0.94, a sensitivity of 86% and a specificity of 91% (Berni, Dibai-Filho and Rodrigues-Bigaton, 2015).

The best cut off point for the FAI was found to be a score of 47.50, and therefore, according to these findings, a score less than 45 indicates the absence of TMD, and a score of 50 and above indicates the presence of myogenous TMD (Berni, Dibai-Filho and Rodrigues-Bigaton, 2015).

The DC/TMD is the gold standard in the assessment of participants with TMD and has excellent reliability and validity. Despite this, the FAI is more commonly used across clinical and research settings as the DC/TMD requires the assessor to have previous training, needs the patient to be present and is time consuming (Rodrigues-Bigaton, de Castro and Paulo, 2017).

2.8.4 Steigerwald-Maher TMD Disability Index

The Steigerwald-Maher TMD Disability Index (STMDI) is a questionnaire specific to the TMJ and its specialised functions. Although it has not been validated yet, it is based on the Oswestry Back Pain Questionnaire and Neck Disability Index and has been used across various TMJ studies. The participant scores each statement from zero to four, and a total score out of 40 is given with a higher score indicating a higher level of disability (Johnston, Bird and Bright, 2015).

The STMDI is the only questionnaire that focuses on disability specific to participants with TMD. The other scales, such as the Tampa Scale for Kinesiophobia for TMD, is a validated questionnaire but is used to quantify fear of movement in the TMD population, which was not the focus of the current study (Gil-Martínez et al., 2016).

The Craniofacial Pain and Disability Inventory is another commonly used tool to measure disability, function and pain in the craniofacial and mandibular areas. However, the purpose of the current study was to assess participants with TMD, and therefore, this tool was not chosen as it was not specific to that population (Gil-Martínez et al., 2016).

2.8.5 Shoulder Pain and Disability Index

The Shoulder Pain and Disability Index (SPADI) consists of 13 questions, the first five focusing on measuring pain and the latter eight on measuring disability. The SPADI was found to have a good reliability of 90% and above, as well as good construct validity, as it related strongly to other shoulder outcome measures (Breckenridge and McAuley, 2011). It has also shown positive, moderate responsiveness (Thoomes-de Graaf et al., 2017).

A higher SPADI score is indicative of greater shoulder pain and disability, whereas a lower score reflects less pain and disability. A review evaluating the SPADI and three other shoulder disability questionnaires concluded that the measurement properties of all four were acceptable and that no single outcome measure stood out as being superior amongst the outcome measures reviewed (Roy, MacDermid and Woodhouse, 2009). The SPADI was chosen because it is one of the fastest tools to both complete and score. As a comparison, the Disabilities of the Arm, Shoulder and Hand questionnaire takes between 16 and 23 minutes to complete compared to five minutes for the SPADI.

2.8.6 Range of motion of the Temporomandibular Joint

A decrease in ROM of the TMJ on mouth opening is a common complaint in participants with TMD. Of those with chronic TMD, 41% reported difficulty opening their mouth compared to 2.2% of the controls. Their ROM on mouth opening was also 12mm less on average than the control group (Ohrbach et al., 2011).

Measuring ROM of the TMJ is an essential tool in assessing the masticatory system. The gold standard is using a ruler, which forms part of the objective evaluation in the DC/TMD. The normal range is 40-55mm, with a reduction in range on opening termed trismus. A mild form of trismus is a range between 20-30mm, a moderate form is 10-20mm and severe trismus a range less than 10mm (Ohrbach, et al., 2013).

The interrater reliability of measuring ROM using a standard ruler according to the DC/TMD has been shown to be very high, with an intraclass coefficient above 0.75, with examiners obtaining almost the same values across testing (Skeie et al., 2018). The high levels of interrater reliability are due to the clear instructions provided in the guidelines on how to perform the measurement. This involves the use of a standard ruler to measure the distance from the maxillary to mandibular incisor while the participant is seated (Skeie et al., 2018).

The criterion validity for the DC/TMD has also been found to be good, with a sensitivity of 90% and a specificity of 99% for myogenous TMD. Similarly, for arthrogenous TMD, a high sensitivity and specificity were found, at 80% and 97%,

respectively. Therefore, using a ruler to measure the ROM of the TMJ is cost-effective, quick, reliable and valid (Schiffman, et al., 2014).

Another tool commonly used to measure the ROM of the TMJ is the Therabite Range-of-Motion Scale. This tool is specific for assessing the range in participants with TMD and has been found to have excellent psychometric properties. The reliability was found to be 92%, but the standard ruler was chosen as it is easily accessible and the gold standard of measuring range (Saund, Pearson and Dietrich, 2012).

2.8.7 Scapular Dyskinesis Test

It has been recommended that an evaluation and treatment of scapular dyskinesis be done in participants with shoulder pain. The variety of tests available are grouped into visual (static and dynamic) and symptom altering with evidence showing a preference towards the visual tests. The Scapular Dyskinesis Test (SDT) is a visually based, dynamic test where the patient performs shoulder abduction and flexion five times each with weights while the therapist observes for scapular dyskinesis and/or winging (Christiansen et al., 2017).

The presence of dyskinesis is indicated by the scapula moving either prematurely or excessively. Winging is present if the scapula is positioned posteriorly away from the thorax. The therapist will combine the observations during both shoulder abduction and flexion and grade each side as normal, subtle or obvious dyskinesis (Christiansen et al., 2017).

The intra-rater reliability has been found to be moderate (kappa values between 0.48-0.61) with substantial concurrent validity. The interrater reliability was also substantial and almost perfect, with agreement between the two examiners of 88% and 96%. However, the predictive values of the test in participants with subacromial impingement were limited, as those with and without scapular dyskinesis had no differences in impairments at three months post examination (Christiansen et al., 2017). Another common test used to examine scapular dyskinesia is the Kibler 4-Type Classification. However, it has a lower intra-rater (kappa of 0.5) and interrater reliability (kappa of 0.4) compared to the SDT and, therefore, was not chosen for this study (Kibler et al., 2002).

2.8.8 **Electromyography**

2.8.8.1 **Purpose**

Surface electromyography (sEMG) records muscles' electrical signals during activity, giving insight into the contraction, fatigue and tension of the muscle. It is non-invasive and allows multiple electrodes to be used simultaneously. It is commonly used to diagnose musculoskeletal disorders, evaluate muscle activity and for rehabilitation (Choi et al., 2021).

2.8.8.2 **Types**

The other type of commonly used electromyography is fine wire. These indwelling electrodes require prior training and are invasive and more expensive; although they have a higher accuracy due to reduced chances of cross-talk, they may cause pain or cramps in the muscle. They are more common in measuring the activity of deeper muscles, and therefore, for the purpose of the muscles chosen in the current study and the advantages of sEMG, they were not used (Allen et al., 2013)

In sEMG, electrodes are placed on the belly of the muscle and are used to measure the electrical activity of the motor unit action potentials providing an average over a set amount of time. The motor unit action potential occurs when there is a muscle contraction, which happens when motor neurones stimulate muscle fibres of a motor unit (Naik et al., 2016).

2.8.8.3 **Diagnostic accuracy**

The diagnostic accuracy of sEMG in assessing patients with TMD has been established, with two studies finding moderate accuracy in differentiating between patients with and without pain-related TMD. Another study found fair to excellent accuracy in differentiating those with and without myofascial pain syndrome during clenching tasks. On the contrary, a fourth study found little evidence for differentiating participants with and without TMD using sEMG and warned against using this tool to diagnose TMD (Szyszka-Sommerfeld et al., 2023).

The differences in accuracy across the studies may be due to the varying quality of the EMG assessment, as one of the main problems with accuracy is its sensitivity to impedance imbalances. Noise from the EMG, cross-talk and other factors such as subcutaneous fat, proximity to the musculotendinous junctions and alignment of the

electrodes in relation to the muscle fibres may also decrease the validity. Another disadvantage of EMG is that it is time-consuming, needs specific equipment and requires training. The advantages of sEMG are that it is non-invasive, painless, easy to use and easily accessible. Therefore, surface electrodes are the most common type of electromyography used in clinical and research settings (Szyszka-Sommerfeld et al., 2023).

2.8.8.4 **Shoulder girdle muscles**

Surface electromyography is most commonly used on the infraspinatus out of all the rotator cuff muscles due to its superficial location and easy ability to be identified (Allen et al., 2013). Other studies have used sEMG to measure the activity of the biceps, medial deltoid, inferior trapezius and serratus anterior, which are the muscles included in the current study (Cross et al., 2020). These muscles were chosen to give insight into the muscle activity of a combination of the anterior (biceps), medial (medial deltoid) and posterior shoulder (infraspinatus) as well as into two of the scapular muscles involved in SHR (inferior trapezius and serratus anterior). It has also been shown that some of these muscles have a vital role in maintaining the stability of the GHJ during shoulder movements, and their ability to activate adequately is important in preventing injuries (Poitras et al., 2019).

A higher resting activity of SCM and trapezius at rest has been shown to be associated with TMD. Therefore, the activity of shoulder girdle muscles that have not been previously tested was chosen to establish their activity at rest in those with and without TMD and during jaw and shoulder movements.

The Delsys Trigno system, the sEMG system which was the only option available, is a validated and reliable tool to measure activity of the shoulder girdle muscles during shoulder movements and complex tasks which was the system used in the current study (Poitras et al., 2019).

2.8.8.5 **Calculation scripts**

The two main calculations used in EMG are amplitude and frequency scripts. Analysis of amplitude measures the extent of activity within the muscles through the number of motor units that are active and frequency measures the fatigue within the muscle. Therefore, amplitude was chosen as the aim was to measure the

innervation input of each muscle tested. The types of amplitude parameters include the peak, mean and minimum as well as the area and slope. The peak is only used for averaged curves because of its inconsistency and therefore was not chosen for this study. Instead, average amplitude was used as it is the most recommended for comparisons as it gives insight into the amount of muscular activity occurring (Konrad, 2005).

2.9 CONCLUSION TO THE LITERATURE REVIEW

There is a high prevalence and chronicity of TMD in the general population with scarcity of literature in South African patients. The high rates of co-morbidities and impact on QoL highlight the importance of exploring further connections of the TMJ in order to investigate if treating another area may reduce the prevalence and chronicity. The research provides strong evidence of clear relationships between the cervical spine and TMJ with various studies emerging on the connections between the TMJ and shoulder girdle. However, more conclusive research is needed in order to determine the extent of the connections and the impact of one area on another.

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CHAPTER 3

3. STUDY 1

This chapter includes the manuscript of the scoping review and is currently under review with the *Journal of Manipulative and Physiological Therapeutics*.

Title: The anatomical, neuromuscular and neurophysiological connections between the shoulder girdle and temporomandibular joint: A scoping review

Weinberg, M., Thotse, M., Olivier, B and Kunene, S., 2023. The anatomical, neuromuscular and neurophysiological connections between the shoulder girdle and temporomandibular joint: A scoping review. *Journal of Manipulative and Physiological Therapeutics* (under review).

3.1.1 Bibliographical Details of Original Study 1

Authors: Micaela Weinberg, Mmathapelo Thotse, Benita Olivier and Siyabonga Kunene

3.1.2 Journal

Journal of Manipulative and Physiological Therapeutics

The *Journal of Manipulative and Physiological Therapeutics* focuses on improving non-invasive management of health conditions.

The *Journal of Manipulative and Physiological Therapeutics* is indexed in*:*

- BS/CCML Database
- Current Contents - Clinical Medicine
- Embase
- Index to Chiropractic Literature
- PubMed/Medline
- Russian Academy of Sciences
- Scopus

The current impact score of the *Journal of Manipulative and Physiological Therapeutics* is 1.3 (2024).

The formatting and referencing of this study are in line with the current journal it has been submitted to.

ABSTRACT

Background: There is a rising prevalence of temporomandibular disorders and associated co-morbidity. There are clear connections between the cervical spine and temporomandibular joint and the cervical spine and shoulder girdle. Therefore, there is a need to explore if there is a connection between the jaw and shoulder girdle areas. This may provide insight into an improvement and treatment outcomes and chronicity of temporomandibular disorders.

Objective: To map out the literature on the anatomical, neuromuscular and neurophysiological connections between the shoulder girdle and temporomandibular joint.

Method: A scoping review was done from 2000 to July 2023 across the following databases: CINHAL, the Cochrane Controlled Trials Register, EBSCO MasterFile Premier, MEDLINE, ProQuest, Science Direct, SCOPUS and SPORTDiscus. All types of studies on the connections between the temporomandibular joint and shoulder girdle on humans were included. The framework designed by Arksey and O'Malley as well as the PRISMA Extension for Scoping Reviews were used for data synthesis.

Results: Of 6 818 potentially relevant articles, 890 duplicates were identified. Of 5 855 articles screened, 5 817 were excluded as they did not discuss the relationship between the two areas. This led to 38 articles from the main search and three papers from grey literature, totalling 41 articles. Three articles on the anatomical, 29 on the neuromuscular and nine on the neurophysiological connections were analysed. The trapezius and SCM were the main muscles investigated showing changes in their activity in patients with TMD and during different jaw activities.

Conclusion: The exploration of the connections between the shoulder girdle and temporomandibular joint has provided an understanding of the different types of relationships between these two areas with the strongest connections being neuromuscular.

Key Words: *anatomical, neuromuscular, neurophysiological, shoulder girdle, temporomandibular disorder, temporomandibular joint*

INTRODUCTION

Temporomandibular disorders (TMDs) are defined as "a group of disorders that affect the temporomandibular joint (TMJ), the masticatory system, or both, and may even extend to involve the surrounding related structures".[35(p1156)] Signs and symptoms of TMD include spasm of the masticatory muscles, pain or sounds in the TMJ, headaches, aural fullness, tinnitus, cervical spine pain or dysfunction.[35] A consensus study reported a high prevalence of TMD worldwide and found TMD to be the second most common

musculoskeletal disorder after lower back pain.[13] The same study also found that of the American population, 33% had at least one sign of TMD.
This high prevalence of TMD is reported across the globe, with a study in Africa reporting that eight out of 10 patients visit the dentist complaining of signs of TMD or bruxism.[35] The impact of TMD on sufferers is a significant public health concern as it is one of the main causes of chronic orofacial pain. This has been found to have a negative impact on quality of life and activities of daily living. These include higher levels of depression and anxiety, reduced work income and social impairments.[35]

The National Health Information System of the United States of America found that among 42 730 participants, the impact of chronic pain on participants with pain in the TMJ region was four times greater than participants with other musculoskeletal pain.[34]

The rising prevalence, increase in chronicity and associated co-morbidities of TMDs highlight the need to improve the assessment and treatment of these disorders.[13,34] There is evidence of the higher occurrence of TMD in participants with cervical spine disorders compared to participants without, the changes in the cervical spine in those with TMD and the effectiveness of treating the cervical spine in participants with TMD.[26]

A further expansion of this knowledge into the shoulder girdle and the effects of changes in these muscles on the TMJ, along with the effects of changes in the scapulohumeral rhythm on the TMJ movement, may provide further insight into the development and management of TMD. This is possible through the current literature as investigations have been done on the changes in shoulder girdle muscles in participants with TMD. The most well researched of the shoulder girdle muscles include the SCM and trapezius and how their activity changes during various jaw movements and with the use of occlusal splints.

In a systematic review by Chaves, et al,[9] a high prevalence of increased craniocervical extension was found in participants with myogenous TMD. This forward head posture was associated with humeral internal rotation and adduction, leading to a shortening of the internal rotators and weakening of the external rotators, altering the overall mechanics of the shoulder joint. This shows that the type of posture associated with TMD is also more common in participants with shoulder injuries, highlighting a potential link of the cervical spine to both conditions that needs to be explored.[9]

It has been proposed that the activity of the muscles of mastication and cervical spine is synergic, and overactivity of the masticatory muscles causes overactivation of the cervical muscles. This leads to changes in the positioning of the scapula - increased elevation and protraction. Therefore, changes in cervical alignment impact the kinematics and resting position of both the scapula and the TMJ. However, the influence of the TMJ and shoulder girdle on each other is not yet known and needs to be explored.[24]

This review aimed to map out the literature and establish the current state of knowledge on the anatomical, neuromuscular and neurophysiological connections between the shoulder girdle and TMJ.

METHODS

Framework, protocol and registration

A scoping review was chosen to analyse the knowledge gap on the connection between the shoulder girdle and TMJ, and to map out the literature on this broad topic. No review protocol was published. The three-step search strategy and study selection process proposed by Johanna Briggs Institute was undertaken, and their methodology was followed.[3]

Search strategy

The search strategy aimed to locate both published and unpublished primary studies, reviews, text and opinions on available research about the connection between the TMJ and shoulder girdle. For inclusion into the review, the study had to include an investigation of the anatomical, neuromuscular or neurophysiological relationship between the shoulder girdle and TMJ. The shoulder girdle was defined as: the scapula, clavicle and humerus bones, the acromioclavicular, sternoclavicular and glenohumeral joints and the surrounding musculature[38]. All shoulder girdle muscles were included in this review, including the sternocleidomastoid (SCM) and hyoid muscle. These are commonly seen as neck muscles, however the SCM does insert onto the clavicle and the omohyoid onto the scapula which both form part of the shoulder girdle.

In the context of this study, anatomical refers to muscles connecting/overlapping between the two areas. Neuromuscular refers to the relationship in terms of muscles and nerves and includes postural and occlusal factors. The neurophysiological relationship explored

the physiology of the nervous system connecting these areas, including the effects of pain. Research on participants with and without TMD was included as information on the relationships in both sample groups was explored.
Studies published in all languages on humans, from 2000 to July 2023 inclusive, were available for inclusion in this scoping review. The reason for including articles after the year 2000 was due to an improvement in the methodology, technology and assessment tools of the TMJ and a repetition of the same types of studies with improved technology.

An initial limited search of CINAHL (EBSCO) and MEDLINE (PubMed) was undertaken to identify articles on the topic, using preliminary search terms followed by a full search. The second phase of the search strategy was a full search of CINHAL, the Cochrane Controlled Trials Register in the Cochrane Library, EBSCO MasterFile Premier, MEDLINE via Pubmed, Physiotherapy Evidence Database (PEDro), ProQuest Health and Medical Complete, Science Direct, SCOPUS and SPORTDiscus with Full Text using the revised keywords (Appendix 10). The third phase of the review screened the reference lists of all included articles. Grey literature websites were also searched and these included WorldCat, Google Scholar, OpenGrey and Grey Matters.

Study selection

Following the search, all identified records were collated and uploaded into *Zotero* and duplicates removed. Following a pilot test, the titles and abstracts were screened by two independent reviewers for assessment against the inclusion criteria. The full text of selected citations was also assessed in detail against the inclusion criteria by two independent reviewers. Reasons for the exclusion of full-text papers that did not meet the inclusion criteria were recorded and reported in the scoping review.

Any disagreements between the reviewers at any stage of the selection process were resolved through discussion. The results of the search were reported in full in the final scoping review and presented in a Preferred Reporting Items for Systematic Reviews and Meta-analyses for Scoping Reviews (PRISMA-ScR) flow diagram.[31]

Data charting

Data was extracted from papers included in the scoping review by one reviewer, using a data extraction tool developed by the reviewers. The reason for only one reviewer extracting the data was financial constraints. The data extracted included the title, year,

location, aims, participants' characteristics, sample size, methods and results (Table 1). It also described what each article revealed about the relationship between the shoulder girdle and TMJ.

Data synthesis

A technique of deductive thematic analysis was applied, and the themes were determined a priori at the protocol development phase by the three reviewers. The first reviewer organised information according to themes and the allocation of information to themes was reviewed and confirmed by the second reviewer. Although the option was available to create an additional theme if deemed necessary, all information was organized according to the themes of anatomical, neuromuscular and neurophysiological connections, and a further breakdown was done on which shoulder girdle muscles had been studied.

RESULTS

Study selection

A total of 6 316 articles were identified through the databases. Of these, 890 were duplicates and identified through the Zotero reference manager. After screening 5 426 titles and abstracts, 5 234 were excluded as there was no mention of the relationship between the shoulder girdle and TMJ, rather, they just included one of the areas individually. Of the 192 articles sought for full-text retrieval, ten were not retrieved, and of the 182 full-text articles retrieved, 38 were included in the review. The PRISMA flowchart depicts the process of the study selection (Figure 1).[31] In the PRISMA flowchart, new studies refer to studies included from the full search across the different search engines and reports of newly included studies refer to the total amount of studies in the review.[31]

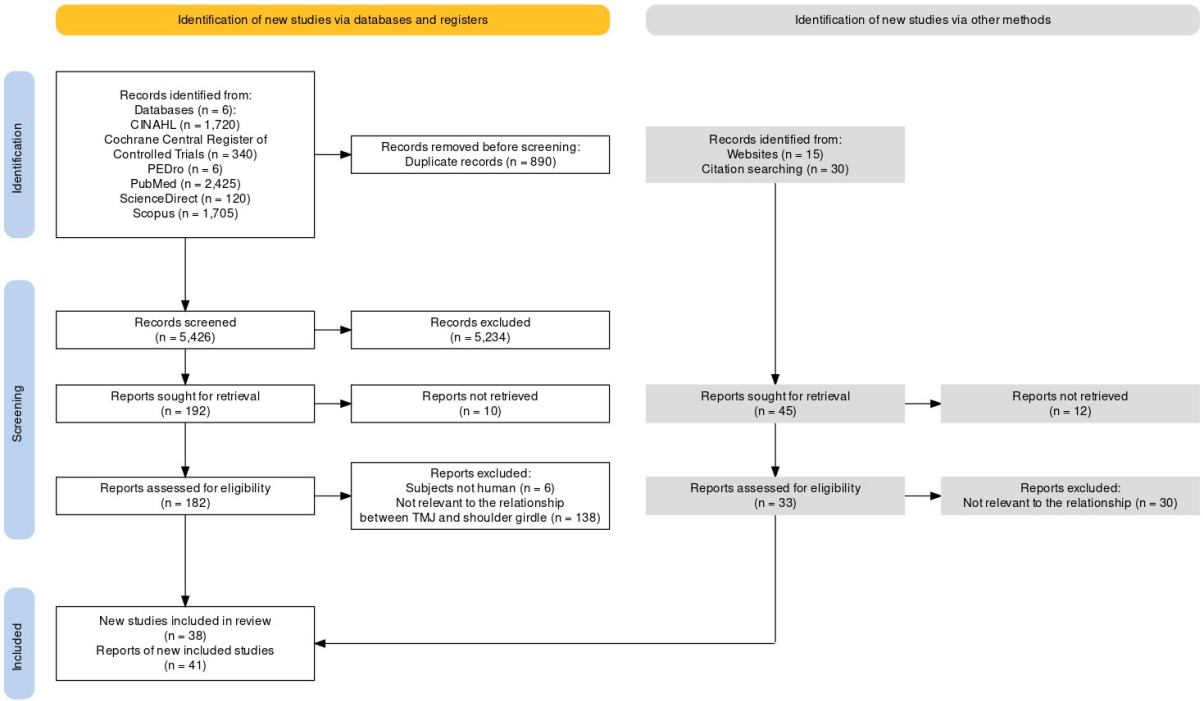

FIGURE 1. PRISMA flow diagram for article selection

Study characteristics

Thirty-one of the included studies were observational designs (15 cross-sectional, two cohort and 14 case-control studies). The other study designs included one randomised controlled trial, five pre-test and post-test studies, two narrative reviews, one preliminary study and one book. Thirty-nine of the studies were in English and two were in German, translated using Google Translate. Figure 2 illustrates the locations of where the studies took place.

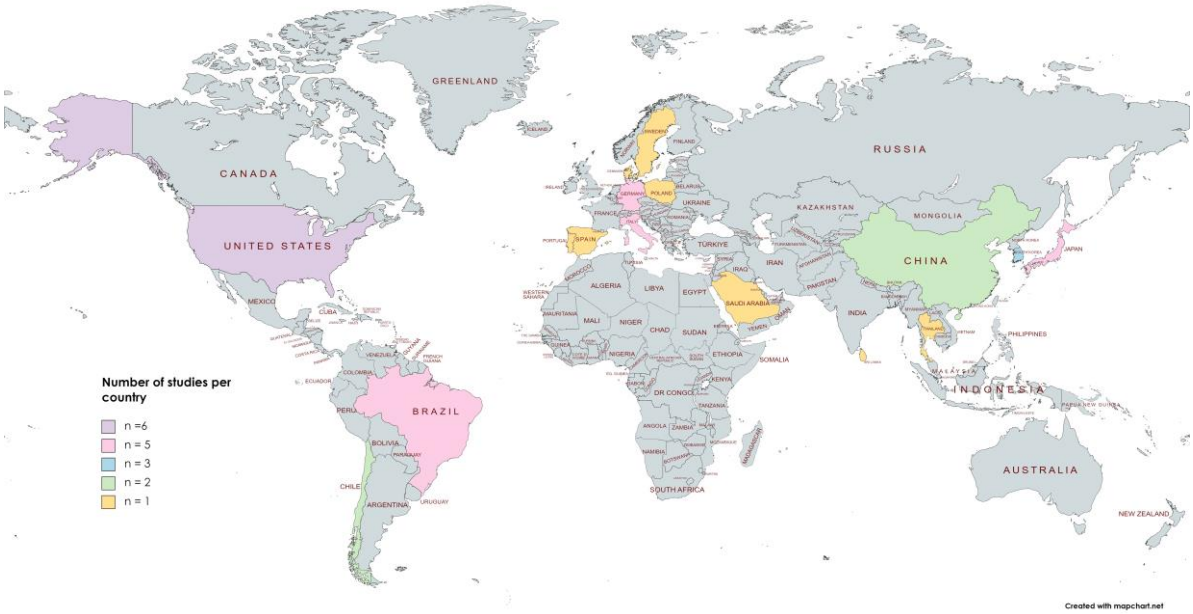

FIGURE 2. GeoMap of the locations where studies were conducted

Table 1 summarises the included studies.

Table 1. Summary of the characteristics of included studies and the relationship discussed between the shoulder girdle and temporomandibular joint

Authors, year of publication, short title	Location of study	Aims	Participant characteristics and sample size	Study methods and results	Relationship between the shoulder girdle and TMJ discussed
Alghadir et al., 2018. Clenching and sitting posture on force of limb muscles	Saudi Arabia	To examine the effects of clenching on the shoulder, elbow and knee flexor, and extensor muscles in slouched versus upright, unsupported sitting	n = 100M, healthy university students Mean age (years): 23.30 (2.8), age range: 18 - 30	MVC of the knee, elbow and shoulder was measured during teeth clenching and no teeth contact in slouched and unsupported upright sitting. Results: - Unsupported upright sitting: sign larger MVC of the shoulder extensors ($p = .0001$) and flexors ($p = .004$) with jaw clenched compared to no teeth contact. -Slouched sitting: increased strength in shoulder flexors ($p = .002$) and extensors (not sign) during no teeth contact compared to clenching.	Higher MVC of the shoulder flexors and extensors during clenching in an upright, unsupported position. The opposite was true for slouched sitting, with a higher MVC during an open mouth position compared to clenching. This shows that the effects of clenching had a greater impact on the shoulder static force in the less stable position (upright sitting) compared to the more stable position of slouched sitting.
Auvenshine and Pettit, 2020. The hyoid bone	USA	To describe the anatomy of the hyoid bone		Book	The hyoid bone is located between the mandible and shoulder girdle. There are four suprahyoid muscles attaching from the mandible to the hyoid and four pairs of infrahyoid muscles attaching from the hyoid bone to the shoulder girdle.
Bae, 2014. Pain and ROM of the TMJ with k-tape of the TPs in SCM	Korea	To determine the effects of using Kinesio tape on latent TPs of the SCM on the ROM and pain of the TMJ	All participants: Latent TPs in the SCM, decreased ROM of the TMJ/crepitus/ disturbance during mastication Age range (years): 20-30 Experimental group: n = 23, 14F, 9M Mean age (years): 23.3 (± 2.7) Control group: n = 19, 11F, 8M Mean age (years): 22.8 (± 3.2)	Participants in the experimental group received taping of the SCM 3X a week for two weeks, control group received no treatment. Results: - Pain and PPT: The pain and PPT on palpation of the TPs in the SCM decreased sign in the experimental group ($p < .01$ and $p < .05$ respectively). - TMJ ROM: improved sign in the experimental group ($p < .05$). No changes in the control group.	These findings show that decreasing the strain on the SCM by taping the TPs leads to an increase in the ROM of the TMJ. This shows that there is a relationship between the SCM and masticatory muscles.

Bonato et al., 2016. TMD and other areas of pain	Brazil	To evaluate the prevalence of pain in the ankle, knee, hip, wrist, elbow and shoulder in participants with and without TMD	n = 337 participants Age range (years): 21 - 65 <u>With TMD:</u> n = 165, n = 150 (90.9%) with other arthralgia Mean age (years): 40.3 (± 16.3) <u>Without TMD:</u> n = 172, n = 111 (64.5%) with other arthralgia Mean age (years): 38.2 (± 14.4)	Descriptive case-controlled study Participants assessed using a standardized TMD screening questionnaire and verbal questions on other joints. <u>Results of presence of shoulder pain:</u> - 13/111 (11.7%) with no TMD - 3/48 (6.2%) with muscular TMD - 2/22 (9%) with arthrogenous TMD - 5/80 (6.2%) with dual diagnoses	The degree of participants' shoulder pain was higher in the group with no TMD compared to those with TMD.
Bordoni and Varacallo, 2018. Anatomy of SCM (Book)	Florida, USA	To describe the anatomy of the SCM		Book	Originates at the sternum and clavicle and attaches to mastoid process of the temporal bone. <u>Cervico-trigeminal reflex</u>: Reciprocal relationship between SCM and masseter during occlusion. Changes in occlusion affecting the function of SCM. Dysfunction of SCM treated by correcting issues of occlusion. <u>Trigeminal-cervical reflex:</u> Reflex activated during chewing stimulating SCM. SCM activated same side during unilateral mastication and both sides during bilateral mastication. Changes in electrical activity of SCM associated with the presence of TMD.
Ceneviz, et al., 2006. Effects of changing the	Boston, USA	To determine the immediate effects of changing the position of the	n = 33, 17F, 16M, volunteers from dental students and staff	Testing occurred in habitual occlusion with a non-repositioning splint (increased vertical dimension but did not realign the mandible) and a repositioning splint (increased vertical dimension and realigned	Trapezius had the greatest response to change in the position of the mandible compared to the other muscles. The trapezius had a sign reduction in activity

position of the mandible on EMG activity of masseter, temporalis, trapezius and SCM		mandible on the electrical activity of the masseter, temporalis, trapezius and SCM muscles	Age range (years): 23 - 52	the mandible) with the mouth relaxed and slightly open as well as during maximal clenching. Results: (changes in muscle activity) **Trapezius:** Effects of non-repositioning splint vs no splint: -Mandible relaxed: sign decrease (R: $p < .001$, L: $p < .002$) -Maximal clenching: sign decrease (R: $p < .022$, L: $p < .003$) Effects of repositioning splint vs no splint: -Mandible relaxed: sign decrease (R: $p < .008$, L: $p < .007$) -Maximal clenching: sign decrease (R: $p < .012$, L: $p < .019$) **SCM:** Effects of non-repositioning splint vs no splint: -Mandible relaxed: sign decrease (R: $p < .006$, L: $p < .018$) -Maximal clenching: sign decrease (L only: $p < .009$) Effects of repositioning splint vs no splint: -Mandible relaxed: no sign differences -Maximal clenching: sign decrease (R: $p < .002$, L: $p < .002$)	during habitual occlusion and maximal clenching with a repositioning splint followed by a non-repositioning splint compared to nothing. The same pattern of activation was found in the masseter and SCM during maximal clenching. This pattern was sign decreases in muscle activity bilaterally with repositioning splints and on the L only with a non-repositioning splint. Mouth opening is associated with cervical extension. Therefore, by increasing the vertical dimension of the mandible by 2mm through the splint, there are changes in the activity of the two shoulder girdle muscles, namely the- SCM and trapezius. The change in input from the differences in occlusion (periodontal, muscular and TMJ receptors) leads to changes in the motor neurons of the SCM and trapezius leading to altered activity.
Chafka et al., 2002. Effect of increasing vertical dimension of occlusion on strength of cervical flexors and deltoid muscles	Boston, USA	To determine the effects of stepwise increases in vertical dimensions of occlusion on the isometric strength of cervical flexors and deltoid muscles in asymptomatic females	n = 20F, healthy with full dentition and an overbite > 10%	Isometric strength of the deltoid and cervical flexors was tested during six conditions: pre-experiment without an occlusal splint, while using an occlusal splint (which had four different bite elevations) and post-experiment. During all these conditions, participants were biting down. Results: Sign differences in the deltoid strength in elevated conditions (R and L = 8.6kg) compared to pre-experimental (R = 6.9kg, L = 6.4kg) and post-experimental (R = 6.5kg, L = 6.3kg) ($p < .001$).	Increasing the vertical dimensions of the TMJ, increases the isometric peak force of the deltoid, showing the strong relationship between the dimensions of occlusion on shoulder strength.

Chaves, de Oliviera and Damazio, 2017. Postural changes and TMD in students	Brazil	To determine the prevalence of postural changes and TMD in students	n = 92 students (11: no TMD, 57: mild TMD, 24: moderate TMD, 1: severe TMD) Mean age (years): 13.9, age range: 10 - 18	Among those with moderate/severe TMD (25/92, 22.7%): - 64% shoulder elevation - 24% shoulder protrusion	In participants with moderate/severe TMD, there is biomechanical adaptation. It is postulated that the muscles of mastication that fixate to the sternum and scapula pull the shoulder anteriorly or superiorly.
Ciuffolo et al., 2005. EMG of neck muscles during maximal clenching	Italy	To assess the activity of SCM, upper and lower trapezius, digastric and cervical muscles during maximal voluntary clenching	n = 20, 6F, 14M, healthy students Mean age (years): 25.3 (± 2.0), age range: 24 - 31	<u>Two groups:</u> Test group: clenching followed by a 1-minute rest, repeated 3X Control group: resting mandible <u>Results:</u> - Sign increases in activity of masseter, anterior temporalis, digastric and SCM during maximal clenching ($p < .05$) and between groups after a 1-minute rest period ($p < .05$). - Root mean square amplitude: doubled during clenching compared to resting in digastric and SCM (10% compared to 5% in resting). No differences in the upper and lower trapezius and cervical muscles between clenching and resting. -No changes in upper and lower trapezius muscle activity during clenching and 1-minute after.	Mean peak increase of SCM during clenching and 1 minute after shows the co-contraction of this muscle during clenching. Similar patterns of SCM and digastric during clenching and post-clenching. No change in lower and upper trapezius muscle activity during clenching and 1 minute after.
Correa and Berzin, 2004. TMD and dysfunctional breathing	USA	To discuss the relationships between the cervical spine, masticatory system and breathing, as well as the factors contributing to TMD			Cervical, respiratory and masticatory muscles: Anterior cervical chain = mandible, tongue, accessory inspiratory muscles (SCM, scalene) Posterior cervical chain = maxilla Hyoid connects the two chains, overactivity of SCM leads to posterior rotation of the jaw and tension in the suprahyoid and infrahyoid muscles. TMD caused by imbalances between the suprahyoid and infrahyoid muscles and the extensor/flexor muscles of the head and masticatory muscles.
Cox and Klein, 2013.	Arizona, USA	To determine the prevalence of	n = 183, 105F, 78M	Three parts: self-administered questionnaire on presence of asymmetry, nurse evaluation of	The higher prevalence of elevation of the shoulder in participants with TMD. The

Craniofacial and shoulder asymmetry: relationship to TMD		asymmetrical craniofacial and shoulder features in TMD	Mean age (years): 53.5, age range: 8 - 92 n (with TMD) = 103/183	asymmetry and physician diagnosing presence of TMD. <u>Results:</u> - Relative risk of 5.89 between the presence of at least 4 asymmetric features and TMD (p = 0.0001; 95% CI: 3.19 to 10.88). - Elevation of the shoulder: 84/103 (82%) with TMD, 34/80 (43%) without TMD. Relative risk: 1.9	relative risk of 1.9 indicates a 90% higher chance of participants with TMD having an elevated shoulder
Dias et al., 2019. Occlusal splint on strength and activation	Portugal	To determine the effects of dental occlusions on shoulder strength	n = 14M, healthy volunteers Mean age (years): 21.67 (± 0.86)	Peak torque and EMG of shoulder girdle muscles during abduction/adduction and internal/external rotation with an occlusal splint, placebo splint and no splint. **Shoulder abduction/adduction:** -Peak torque sign increased (p < .05) in occlusal splint compared to no splint - Sign higher muscle activity of anterior deltoid and pectoralis major (p < .01) with occlusal splint compared to placebo and no splint - No change in muscle activity of medial deltoid in any of the conditions - Lower trapezius had a sign increase in peak EMG in occlusal compared to no splint (p < .05) and no difference between occlusal and placebo **Shoulder external/internal rotation:** - Sign higher peak torque in occlusal splint compared to placebo and no splint (p < .05, ES > 1) - Peak muscle activity sign higher in occlusal splint compared to no splint in every muscle (p < .01, ES ranging from 1.5 -2.9), no difference in occlusal vs placebo splint. -Both groups, no difference in muscle activity between placebo and no splint, therefore showing there is no placebo effect of a splint.	The peak torque and EMG was sign higher in all movements and muscles aside for the medial deltoid when wearing the occlusal splint, compared to placebo and no splint. This shows the ergogenic effect of an occlusal splint on shoulder movements. The occlusal splint was created to position the TMJ in a centric position, increasing occlusal stability through creating bilateral and simultaneous contact of the teeth which maximises the muscle activity of the masseter.
Dong, Wang, Wang and Widmalm, 2008. Muscle	China	To determine if developmental mandibular asymmetry is	<u>With mandibular deformity</u> (diagnosed on x-ray): n = 15, 8F, 7M	Muscle activity of the masseter, upper trapezius, SCM and suprahyoid muscles was recorded during jaw opening-closing-clenching, head-neck flexion-extension, and shoulder elevation-lowering.	Sign changes in the symmetry of SCM and upper trapezius muscle activity in patients with developmental mandibular asymmetry.

function in patients with mandibular developmental asymmetry		associated with asymmetrical muscle activity	Mean age (years): 23.0 (± 4.78) <u>Control:</u> n = 21, 10F, 11M, healthy dental students Mean age (years): 22 (± 0.92)	<u>Results:</u> - The symmetry of all muscles during all movements was sign lower in the mandibular asymmetry group ($p < .01$). No differences in symmetry in any muscle in the control group. - Higher muscle activity of upper trapezius and SCM on hyperplastic side ($p < .01$ for all movements). - Higher frequency distribution of SCM, suprahyoid and upper trapezius in mandibular deformity group.	Higher muscle activity of upper trapezius and SCM on the hyperplastic side on all movements.
Fernandez-des-las-Penas et al., 2010. Referral of TPs in the masticatory and neck-shoulder muscles in participants with myofascial TMD	Spain	To determine the presence, referral and size of TPs in the masticatory and neck-shoulder muscles in women with myofascial TMD compared to controls	<u>With TMD:</u> n = 25F, myofascial TMD, mean duration: 23.1 months, area of pain: n (frontal) = 22, n (occiput) = 18 Mean age (years): 22 (± 3.5), age range: 20 - 28 <u>Without TMD:</u> n = 25F, healthy Mean age (years): 22 (± 3.4), age range: 20 - 28	<u>Results:</u> In all muscles, there were sign differences in presence of TPs in the TMD group vs control ($p < .01$). - **Upper trapezius:** 32 active TPs, 11 latent TPs, 7 no TPs in TMD group compared to seven latent TPs and 43 no TPs in controls (L and R sides combined). - **SCM:** 24 active TPs, 17 latent TPs, nine had no TPs in the TMD group compared to four latent TPs and 46 with no TPs in the control group. - **Referral:** SCM and upper trapezius TPs referred to temple among other areas. Active TPs in the temporalis, masseter, upper trapezius and SCM elicited the participants' pain in the TMD group. More TPs were found in the muscles of mastication compared to SCM, upper trapezius and sub-occipitals. - **Pain and TPs:** the higher the level of the current TMD pain, the greater the area of referral of TPs in the upper trapezius and temporalis on palpation. Upper trapezius: most painful side: $r = .56$, $p < .012$ and less painful side: $r = .44$, $p < .039$.	TPs in the SCM and upper trapezius refer to the temple which is one of the areas of pain in TMD. Participants with TMD had sign greater TPs in the SCM and upper trapezius compared to controls, indicating the shoulder girdle muscles contribution to TMD. Mimicking of the patients TMD symptoms on palpation of the TPs of the SCM and upper trapezius also shows the relationship between the symptoms of TMD and TPs of SCM and upper trapezius.
Ferrario et al., 2001. The effect of the jaw position on muscle activity and endurance	Italy	To determine the effects of different occlusal positions and effects of the position of the jaw on the masticatory	n = 29M, heathy students <u>Normal occlusion</u> n = 14, mean age (years): 21.7 (± 0.9),	Six jaw positions performed randomly: mouth open, open without teeth in contact, closed, closed with teeth lightly touching, maximum clenching and maximum clenching on two cotton balls, maximum clenching on one cotton ball on the R or L. During these, participant sustained dumbbell for as long as	Malocclusion group could perform the exercise for a longer period than the normal occlusion group. It is unclear exactly why but shows that these participants could potentially have compensatory masticatory patterns.

of the biceps brachii		muscle activity during weightlifting	mean dumbbell weight: 26.86kg <u>Malocclusion</u> n = 15, mean age (years): 22.0 (± 1.5), mean dumbbell weight: 24.13kg All had 1/more missing teeth and 6 had a crossbite	possible, with their elbow flexed to 90°. 15 minutes between each trial. <u>Results:</u> **Malocclusion:** - Sign higher endurance of biceps ($p < .005$) - Larger root mean square ($p < .05$), mean median power, median power frequency intercept and slope ($p < .005$) than those with normal occlusion. **Endurance:** - Highest endurance during clenching compared to the lowest on the R side cotton ball position ($p < .005$). - Both groups had higher endurance during clenching (3s at least in occlusion and 4s at least in malocclusion groups) - Lower endurance during clenching on cotton balls and even lower endurance during R side clenching on the cotton ball. - Participants ended their lifting 7s and 10s earlier in the occlusion and malocclusion groups respectively (L wasn't sign).	R sided lower endurance could be due to most of the participants being R handed, therefore showing the importance of questioning handedness in the assessment of TMJ. Biting on an unstable surface, reducing stability led to a decrease in endurance of the biceps.
Ferrario, Sforza, Dellavia and Tartaglia, 2003. Asymetrical occlusion on activity of SCM	Italy	To determine the effects of asymmetrical occlusion on the pattern of contraction of the SCM during clenching	n = 30, 15F, 15M, dental students/staff in good health with symmetrical activity of muscles tested during clenching Mean age (years): 24.4 (± 4.5), age range: 20 - 33	Maximum voluntary clenching for 5s using two cotton rolls put on the molars each side (baseline) and in the intercuspal position with no cotton wool using 200mm artificial paper occlusal interference positioned on the 13^{th}, 16^{th}, 23^{rd} and 26^{th} teeth. EMG of muscles tested: anterior temporalis, masseter and SCM bilaterally. <u>Results:</u> - Intercuspal position: symmetrical muscle activity of SCM during clenching. - Unilateral occlusal interference: changes in symmetry of activation. In 26/30 participants, there was clear asymmetry of the SCM during at least one of the tests, with percentage overlapping co-efficient ranging between 46.82% and 89.75%. In 5/30, all four tests indicated asymmetry.	The effect of occlusal asymmetry caused an immediate change in the symmetry of the SCM muscle in adults without TMD and with normal occlusion, showing the strong coactivation pattern and interlinkage of the SCM and masticatory muscles.

Ferrario et al., 2006. Influence of occlusion on jaw and neck muscle activity	Italy	To determine if there were differences in the neuromuscular balance in the jaw and neck muscles in participants with a complete angle class I compared to partial angle class I	n = 62, students, healthy with no cross bite and 28 teeth Age range (years):18 - 21 <u>Group 1:</u> n = 13M, complete angle Mean age (years): 19.2 (± 5.7) <u>Group 2:</u> n = 13F, complete angle Mean age (years): 19.0 (± 4.2) <u>Group 3:</u> n = 14M, partial angle Mean age (years): 18.9 (± 11.1) <u>Group 4:</u> n = 22F, partial angle Mean age (years): 18.7 (± 9.6)	Complete angle refers to a bilateral, symmetrical relationship between all four canines and molars. Partial angle refers to a relationship between 1 - 3 canines and molars. EMG of SCM, temporalis and masseter were recorded during maximal clenching and head-neck maximal rotation. <u>Results:</u> - Activity of SCM, temporalis and masseter were not influenced by class (molar and canine inter-arch relationship). Type II error was committed on all tests and therefore the null hypothesis cannot be rejected and results must be interpreted with caution.	There was no difference in activation of masticatory and SCM muscles in the different class types (molar – canine relationships), showing that the antero-posterior dental relationship has no effect on SCM activity.
Giannakopoulos et al., 2013. Coactivation of jaw and neck during submaximal clenching	Germany	To test the hypothesis that there is jaw and neck muscle coactivation during force-controlled submaximal biting in supine and that low level tonic activation of neck muscles can be	n = 10, 3F, 7M, symptom-free dental students Mean age (years): 24 (± 2.3)	Baseline EMG recordings taken during maximal biting in intercuspation, against resisted jaw opening and against vertical rods, followed by biting against different forces in different bite positions in supine. <u>Results:</u> - Sign differences in the interaction between direction and amount of intra-oral force and muscle activity of the SCM, suprahyoid and infrahyoid	Previous findings showed SCM, trapezius, infrahyoid and suprahyoid muscle activation during maximal jaw activation. EMG recordings of jaw and neck muscles show that there is coactivation of the muscles during submaximal clenching within the range of sleep bruxism. This highlights the importance of assessing and treating the shoulder girdle muscles in

		induced by clenching in the supine position		muscles ($p < .05$): the direction of force affected the amount of force differently. - Sign increase in muscle activity of trapezius with increasing intra-oral force ($p < .05$). - Low-level-long-lasting tonic activation was apparent for levator scapula as it remained active 30 mins after clenching and was sign longer than other muscles ($p < .05$).	patients with TMD associated with sleep bruxism.
Giannakopoulos, Schindler and Hellmann, 2018.Co-contraction of jaw and neck muscles during grinding	Germany	To analyse the co-contraction of jaw and neck muscles during force-controlled grinding in supine	n = 12, 6F, 6M, healthy volunteers Mean age (years): 25 (± 1.6)	Measurements were taken during simulated grinding in supine and compared to clenching measurements (values from previous study). <u>Results:</u> EMG activity of muscles during grinding in supine: - Levator scapula: 4.5%-12% of MVC - SCM, infrahyoid: 10%-16% of MVC **Clenching compared to grinding:** - Lower activity of neck muscles during clenching compared to grinding, MVC ranging between 1.8% and 9.9%. - Average long-lasting, low-level activation of the neck muscles (in seconds) after grinding was 195 (± 10), maximum of 360, compared to after clenching was 166 (± 30), maximum of 270. **Chewing of food:** - Activity of neck muscles for chewing ranged between 4.2% and 11.7% in sitting. - Sign differences ($p < .05$) between clenching and grinding for SCM ($p < .015$), suprahyoid and infrahyoid ($p < .001$) but not between grinding and chewing ($p > .05$).	During simulated grinding, the co-contraction of jaw and neck-shoulder muscles is much greater than that of clenching. Long-lasting, low-level activation of the neck muscles was longer after grinding than clenching.
Haggman-Henrikson, Nordh and Eriksson, 2013. Increased SCM and not	Sweden	To determine muscle activity of masseter, digastric, SCM and trapezius during chewing of different textures and food sizes	n = 10, 5F, 5M, healthy volunteers Mean age (years): 27, age range: 21-31	Tasks: maximal jaw-opening and closing movements without a bolus and chewing four foods in a randomised order: small and large. <u>Results:</u> - Maximal jaw opening: SCM activity concomitant with digastric.	Higher activity of SCM during chewing larger foods show the increased need for recruiting neck motor neurons during these tasks. The graded recruitment of the SCM during changes in load on the jaw show the dynamic relationship between the two areas.

trapezius muscles activity during increased chewing load				- Chewing (with bolus): jaw closing movement, SCM concomitant with masseter activity (not in jaw opening movement with a bolus). - SCM and masseter activity during all cycles in all participants whereas trapezius activity in all cycles in only three participants and some cycles in the other seven. - Larger boluses: sign higher EMG activity in SCM ($p \leq 0.02$) but not for the trapezius ($p \geq 0.4$). - No differences in activity of any of the muscles with different textures of food.	The higher recruitment might be to increase stability of the head, thus allowing adequate movement of the mandible by the muscles of mastication to prepare the food for swallowing. This also shows that head extension may provide a biomechanical advantage during increased chewing demand.
Hellmann et al., 2012. Neck muscle activation during different biting tasks	Germany	To determine if jaw muscles and a variety of neck muscles co-contract during a variety of submaximal biting tasks	n= 10, 3F, 7M, healthy adults Mean age (years): 24 (± 2.3)	Muscle activity measured during rest, maximum biting in intercuspation and jaw opening against hand resistance, followed by maximum force against vertical rods in eight directions then chewing on the R side silicone rubber. <u>Results</u>: **Maximum biting and chewing:** - Both had sign coactivation of SCM, infrahyoid, suprahyoid, semispinalis and multifidus muscles. - Sign greater activation of above muscles during maximum biting compared to chewing: EMG activity during maximum biting ranged between 7% and 19% compared to 7% and 9% MVC for chewing. - Opposite was true for posterior neck muscles, even though the activity of levator scapula and trapezius wasn't measured. **Intra-oral forces:** - Regardless of direction and amount of force, the neck muscle activity was sign higher than baseline. - SCM had sign differences in EMG activity depending on force level and for infrahyoid and suprahyoid, sign interactions between force direction and level (the direction of force influenced the EMG differently for different force levels).	The higher activity of anterior/lateral neck-shoulder muscles during maximum biting compared to chewing, versus the lower activity of the posterior neck-shoulder muscles during biting compared to chewing, shows the complex relationship between the jaw-neck-shoulder which is needed to provide stability of the head during dynamic movements. These neck-shoulder muscles co-contract during specific jaw tasks, especially at a sub-maximum level mimicking bruxism. Independent of the bite force direction, the greater the bite force the greater the EMG activity of the neck-shoulder muscles.
Inoue et al., 2010. Relationship between jaw,	Japan	To determine the association between TMJ disc pathology and the	n = 171, 124F, 47M, diagnosed with TMD by clinical exam and MRI	Assessment included palpating muscles and assessing tenderness- masseter, temporalis, medial pterygoid, SCM, digastric and trapezius.	No specific details given on which muscles had more TPs.

neck-shoulder muscles tenderness and disc pathology		pattern of neck-shoulder muscle tenderness	Mean age (years): 35.3 (± 18.0) <u>Group 1:</u> n = 58, unilateral painful disc displacement <u>Group 2:</u> n = 51, unilateral, non-painful disc displacement <u>Group 3:</u> n = 21, bilateral, non-painful disc displacement <u>Group 4:</u> n = 41, normal disc position	Palpation using 2kg compression force for 3 seconds and tenderness assessed using a four-point scale from 0-3. <u>Results:</u> Median number of tender points on side of disc displacement sign higher than contralateral side with no disc displacement (p = .019). No sign differences between any other groups.	
Kanhachon and Boonprakob, 2021. Scapulocostal syndrome and myofascial pain syndrome	Thailand	To determine the relationship between myofascial pain syndrome and scapulocostal syndrome in terms of pain intensity, PPT, C-V angle, mouth opening and maximum mouth opening	n = 75, 58F, 17M, pain in at least three locations in the medial scapula, one location in the muscles of mastication, reduced ROM/normal ROM with pain in muscles of mastication as well as pain in both areas > 3 months Mean age (years): 28.23 (± 5.67)	Assessment included pain on palpation of medial scapular and masticatory muscles, PPT of masticatory and medial scapular muscles, cranio-vertebral angle using pictures, mouth opening without pain and maximum mouth opening with pain using Therabite. <u>Results:</u> **Correlation between myofascial masticatory pain syndrome and scapulocostal syndrome:** Pain: r = 0.367 (p < .01) PPT: r = 0.478 (p < .01) **Correlation between PPT of scapulocostal syndrome:** Mouth opening: r = 0.290 (p < .05) Maximal mouth opening: r = 0.282 (p < .05)	Higher levels of PPT in participants with scapulocostal syndrome was associated with a greater ROM on mouth opening without pain, and maximal mouth opening with pain, showing that the sensitivity of shoulder girdle muscles influences the range of the jaw, potentially through influencing the muscles of mastication. Positive correlation between myofascial masticatory pain syndrome and scapulocostal syndrome in terms of pain and PPT also shows the relationship between the myofascial system of the jaw and shoulder girdle.
Kashima et al., 2005. Hardness of	Japan	To determine the relationship between the	n = 22M, healthy volunteers with no pain	Participants assumed five different head positions in a random order:	Simultaneous increase of muscle hardness in upper trapezius and decrease in

the trapezius and masseter muscles in different head positions: pilot study		hardness of the trapezius and masseter muscles in different head positions	from the medical school Age range (years): 21 - 39	L and R 30° axial rotation and lateral flexion as well as 30° anterior flexion. This was followed by a 5-minute holding of the head in 30° anterior flexion. <u>Results:</u> - Compared to baseline, sign increase in hardness of upper trapezius (R: p = .025, L: p = .0082) lower trapezius (R: p = .0002, L: p = .002) sign decrease in R masseter (p = .0008) in 30° anterior flexion. - Sign increase in upper trapezius (R: p = .021, L: p < .0001) in R side bending and sign decrease R masseter during L and R side bending (p = .0008, p = .013) respectively. - Sign increase in upper trapezius (p = .0057) during right axial rotation.	masseter in 30° anterior flexion and R side bending. The decrease in hardness of the masseter could be due to the tightening of the hyoid muscles as the head goes forward, these muscles considered to be the antagonists to the masseter muscles.
Komiyama et al., 2005. Pain patterns and mandibular dysfunction with trapezius pain	Japan	To determine the effects of experimental pain in the trapezius on pain spread and mandibular function	n = 12M, healthy volunteers Mean age (years): 27.9 (± 2.7), age range: 25 – 35	Injection of isotonic and hypertonic saline into the trapezius in a random order four weeks apart. Pain and ROM of mouth opening measured every 30s for 600s post injection. After the 600s, participants drew on a sketch where the pain had referred to. <u>Results:</u> **Area of pain after injection:** - Posterolateral neck (n = 10) - Infra-auricular zone (n = 6) - Submandibular zone (n = 4) - Occipital zone (n = 3) - Anterior temple (n = 3). **Maximal mouth opening:** - Stable after isotonic injection - Reduced sign immediately after hypertonic injection and gradually recovered after 450s. - Reached the lowest value of 47.8 (± 5.1mm). - Sign differences in mouth opening range between isotonic and hypertonic saline (p < .05) from immediately after to 60s after.	Pain in the trapezius muscle caused a reduction in ROM on mouth opening. This could be due to the restriction in neck movement/stability during mouth opening due to pain in the trapezius, but the results show the intimate connection between mouth opening and trapezius muscle pain. Most of the referred pain from the trapezius injection was around the TMJ, also highlighting the possibility of pain in the TMJ being referred from the trapezius muscles.
Lee, Hong, Park and Choi, 2013. Effects of mandibular	Korea	To measure the muscle activity of the trunk and upper limb muscles during	n = 20, 10F, 10M, healthy volunteers	Mandibular orthopaedic repositioning splint was designed for each participant to achieve TMJ alignment. Maximum isometric contractions of each muscle were performed by each participant with	The sign increase in MVC of the shoulder girdle muscles during isometric movements, with a splint, shows how TMJ stability

splint on trunk and upper limb activation		isometric contractions when TMJ alignment is achieved		and without a splint, and the muscle activity was measured using surface electrodes. <u>Results (MVC mean (± SD) without a splint and with a splint:</u> - **SCM:** 111.6 ± 6.0, 125.4 ± 15.6 - **Upper trapezius:** 114.5 ± 7.7, 123.7 ± 9.2 - **Biceps:** 114.7 ± 5.1, 125.2 ± 7.6 - **Triceps:** 111.2 ± 4.9, 120.9 ± 8.6 All were sign increased ($p < .05$)	influences the strength of shoulder girdle muscles.
Lee et al., 2015. The effects of stretching the upper trapezius on bite force	Korea	To determine the effects of stretching the upper trapezius on asymmetric bite force	n = 47F, healthy students n = 16, < 10% asymmetric ratio Mean age (years): 20.4 (± 0.6) <u>< 20% asymmetric ratio:</u> n = 14 Mean age (years): 20.4 (± 0.6) <u>> 20% asymmetric ratio:</u> n = 17 Mean age (years): 20.7 (± 0.8)	Bite force measured pre stretching. Hook lying: upper trapezius stretching 3X, 10s, 3 sets. <u>Results:</u> - Changes in the asymmetric ratio after stretching on the dominant side: **< 10%:** 5.1±2.7 to 10.3±8.1 post stretching **< 20%:** 14.7±2.8 to 14.3±8.7 post stretching **> 20%:** 27.8±5.3 to 12.6±8.8 post stretching - < 10% group had statistically sign increase in asymmetric bite force ($p < .05$) and >20% group had statistically sign decrease in asymmetric bite force ($p < .05$).	The results show that biting force is influenced by the trapezius which attaches to the atlas and axis, and according to the Quantum theory, movement of the TMJ occurs around the atlas and axis. Tenison of the trapezius affects the C1-C2 joint, which in turn affects the tension of the masseter and temporalis and therefore occlusion. The improvement in asymmetric bite when it is high shows that the influence of the cervical muscles and trapezius on the TMJ is greater than when the asymmetric ratio is small, thus showing the importance of including the cervical spine and trapezius in treatment when the asymmetric bite ratio is high.
Munhoz and Marquez, 2009. Body posture evaluation in participants with TMD-internal derangement	Brazil	To determine if there is a relationship between global body posture and internal derangement subtype of TMD	<u>Participants with TMD:</u> n = 30, 27F, 3M participants with internal derangement of the TMJ with/without myogenous involvement Mean age (years): 21.7 (± 3.6) <u>Participants without TMD:</u>	Assessment included evaluation of the TMJ and surrounding musculature using a self-made questionnaire, Helkimo Dysfunction Index and analysis of photography of body posture (six photos – lateral, frontal and dorsal views). Participants with TMD were divided into three groups: mild, moderate or severe TMD according to Helkimo Dysfunction Index. Therapists blinded to participants' group and analysed the muscle chains: respiratory, posterior,	Lifted shoulders were statistically sign more present in those with TMD with internal derangement. This is in line with other research on the overactivity and hardness of trapezius in patients with TMD. The changes in the antero-internal hip chain as the other only sign difference may be linked to the changes in the lifted shoulders.

			n = 20, 14F, 6M Mean age (years): 22.9 (± 5.3)	antero-internal hip, antero-internal shoulder, anterior arm chains. <u>Results between groups:</u> - Non sign differences of rounded shoulders, shoulder abduction and medial rotation, arm abduction - Elevated shoulders: absence (p = .009), presence (p = .04), - Sign higher differences in antero-internal hip muscle chain in those with TMD (p = .02), - Rounded shoulders and forward head posture not statistically sign but higher prevalence in those with more severe TMD. Overall, participants with TMD did not present with sign differences in body posture compared to the control group (p = .12).	
Ohlendorf et al., 2013. Effects of an occlusal splint on upper body posture in participants with cervical spine syndrome	Germany	To determine the changes in the cervical spine, shoulder and pelvis while wearing an occlusal splint in participants with impairments of their cervical spine and shoulder-neck.	n = 34, 22F, 12M, participants with cervical spine syndrome	Participants wore an occlusal splint at night for 6 weeks and measurements of their cervical spine ROM, shoulder and pelvis positions were taken. Changes in shoulder height and rotation were assessed manually and using a 3D back scanner. <u>Results:</u> - Changes in the shoulder position were seen on the manual examination and not on the 3D scan. - These changes included a significant reduction in the scapulae height (p < 0.03) after 6 weeks of an occlusal splint - No significant changes were seen in scapulae distance and rotation of the scapulae.	An occlusal splint has the ability to change the height of the scapula in participants with dysfunction of their cervical spine. This may be through the influence the occlusal splint has on the muscle activity of the trapezius.
Pallegama, Ranasinghe, Weerasinghe and Sitheeque 2004. Influence of masticatory pain on muscle activity of cervical	Sri Lanka	To determine the resting muscle activity of SCM and trapezius in participants with myogenous TMD with and without disc displacement	<u>With TMD:</u> n = 38, 22F, 16M, volunteers at dental clinic Eight with myogenous only and 30 with myogenous and disc displacement, all had tenderness over masseter and/or	Muscle activity measured of SCM and trapezius (L and R) during a resting state. Participants asked to rate their pain, nine patients had pain in the L and/or R SCM and seven in the L and/or R trapezius, six of these seven also had pain in the SCM. <u>Results:</u>	Higher resting muscle activity of the SCM and trapezius in participants with TMD compared to those without. Even more so if the participant had pain in the SCM/trapezius.

muscle in myogenous TMD			temporalis on at least one side Mean age (years): 29 (± 10.3) <u>Without TMD:</u> n = 41, 27F, 14M, healthy participants Mean age (years): 27.3 (± 8.2)	- Both the TMD groups (myogenous only and myogenous and disc displacement) had sign higher resting activity of trapezius and SCM ($p < .01$) but no sign differences between the two groups ($p > .05$). - In the group with masticatory muscle pain only, those with pain in the trapezius (n = 7) or SCM (n = 9) had sign higher resting activity of the respective muscles compared to those without pain in the respective muscles and those in the control group ($p < .001$). - For the nine participants with SCM pain, good correlation between pain and muscle activity ($p < .01$) but not for the seven participants with trapezius pain ($p > .05$).	
Pasinato et al., 2016. Experimentally induced masseter pain changes masseter but not SCM activity during mastication	Brazil	To determine the effects of experimentally induced pain in the masseter on the amplitude and symmetry of muscle activity of the SCM and masseter during mastication	n = 28M, students at Brazil university Mean age (years): 20.6 (± 2.0), age range: 18 - 27	MVC of SCM and masseter measured before experiment. Patients then performed unilateral mastication with a gum candy twice with a 30s interval in three conditions: baseline and after glutamate and isotonic injections into the masseter. <u>Results:</u> - Amplitude of muscle activation on ipsilateral masseter sign reduced after glutamate compared to baseline, no sign differences in SCM. - POC% increase in masseter and no changes in SCM after glutamate injection. - Coactivation of SCM and masseter increased after glutamate on the working side only but small effect size ($d = .26$).	No changes in SCM activity after the glutamate injection shows that the activity of the SCM during submaximal contraction (mastication) is not affected by masseter pain. The increase in coactivation is most likely due to the decrease in masseter activity on the working side, leading to a decrease in the activation of SCM/masseter ratio.
Politti et al., 2009. Effect of maximal clenching on EMG activity of trapezius muscle.	Brazil	To determine if maximal clenching in centric occlusion in participants without TMD influences muscles activity of the upper trapezius on EMG	n = 19, 14F, 5M, healthy volunteers-students and past students at the university F mean age (years): 25.4 (± 4.14) M mean age (years): 24.1 (± 3.28)	Participants performed 40% and 60% of maximum force of shoulder elevation against a load cell 3X for 3s, pre and post maximal clenching with two cotton balls. <u>Results:</u> - Mean RMS and median frequency pre and post maximum clenching showed no sign differences at 40% and 60% max contraction ($p = .32$ and .91	Clenching does not influence muscle activity and fatigue of the trapezius pre and post clenching in participants without TMD.

				mean RMS and p = .16 and .41 for median frequency respectively).	
Rodriguez et al., 2011. Influence of grinding and clenching on SCM activity	Chile	To determine the effect of laterotrusive clenching and grinding on EMG activity of the SCM	n = 28 Participants had to perform their habitual bite then slide their mandible to the R and L Divided into two groups: <u>Group 1:</u> n = 6F, 8M, canines in contact on working side and no contact of teeth on opposite, Mean age (years): 24.0 <u>Group 2:</u> n = 9F, 5M, two/more teeth besides canines in contact on working side and none on opposite side Mean age (years): 23.4	In standing, EMG measured of SCM during: 1. Eccentric grinding from the intercuspal position to lateral edge to edge contact (R) 2. Clenching in the lateral edge to edge contact position (R) 3. Concentric grinding from R lateral edge to edge position to the intercuspal position 4. Maximal clenching in the intercuspal position <u>Results:</u> **Working side:** - Sign higher activity of SCM on the working side during concentric grinding than eccentric grinding ($p < .01$). - No sign differences between other tasks. - Sign lower activity of SCM in Group 1 compared to 2 ($p < .01$). **Opposite side:** - Sign lower activity of SCM during eccentric grinding than clenching and concentric grinding ($p < .01$) - No sign differences between other tasks. - Sign higher activity during clenching compared to the working side ($p < .05$). - Sign lower activity of SCM during clenching ($p < .01$), concentric grinding ($p < .05$). - No sign differences for eccentric grinding ($p > .05$) in group 1 compared to group 2.	The sign lower SCM activity on the working side in group 1 shows that canines have a protective function against excessive forces through inhibitory signals to the SCM from articular and periodontal receptors. Participants in group 1 had a greater anterior occlusion leading to higher activation of the TMJ receptors and higher forces generated by the TMJ, which could have led to inhibition of the SCM.
Shimakazi, Matsubara, Hisano and Soma, 2006. Relationship between masseter and SCM during gum chewing	Japan	To determine the functional relationship between masseter and SCM during gum chewing after maximal clenching as well as its relationship to	n = 12, 2F, 10M, healthy participants Age range (years): 25-28	Participants chewed gum before, immediately after and 3 minutes after maximal clenching. EMG of SCM and masseter and motion capture system for head mandible movements were used. <u>Results:</u> - Time of activity of chewing gum after clenching was sign shorter in masseter and longer in SCM compared to before clenching. Similar activity time	After maximal clenching, the SCM muscles were dominant compared to the masseter. This was seen by the SCM being activated before the masseter and for a longer period of time. This shows that even though SCM also had muscle fatigue, it had a feed forward mechanism by providing head support before the mandibular movement.

		head-mandibular movement		of muscles was seen 3 minutes after clenching as before clenching for both muscles. - No sign differences in 3D distance of mandible immediately and 3 minutes after clenching. However, 3D distance of head movement was sign longer immediately after clenching, but similar 3 minutes after clenching to before clenching.	Coupled with this, the 3D distance of the mandible remained constant even though the head distance increased.
Sojka et al., 2017. Relationships between clinical and neurophysiological findings in participants with TMD	Poland	To investigate the importance of surface electromyography of jaw, shoulder and neck muscles in participants with TMD	<u>Test group:</u> n = 50F, clinically diagnosed TMD (Axis I) – unilateral/bilateral pain in area of TMJ, muscle or joint pain Mean age (years): 31.5, age range: 25-38 <u>Control group:</u> n = 50F, healthy volunteers Mean age (years): 32.5, age range: 26 - 40	<u>Clinical exam:</u> Questionnaire – dental history, medical and psycho-social factors, clenching and grinding. Intra-oral exam, movement range, sounds and deviations. <u>Neurophysiological exam:</u> Surface EMG of muscles at rest, maximal contraction of trapezius and masseter muscles, and electroneuronography of mandibular motor neurone fibres. <u>Results:</u> - **EMG at rest:** higher muscle activity of masseter, temporalis, trapezius and SCM of masseter and trapezius in those with TMD compared to without (on the symptomatic side) ($p < .05$ for all muscles except SCM). - **EMG during maximal contraction:** statistically sign lower muscle activity in all muscles ($p < .05$) and statistically sign lower motor unit action potentials of masseter and temporalis ($p < .05$). - Sign negative correlation between high amplitude of muscle activity at rest and low amplitude during maximal contraction of masseter ($p < .05$).	The higher trapezius and SCM muscle activity at rest and lower activity during MVC shows the increased tension in these muscles in participants with TMD.
Svensson, Wang, Sessle and Arendt-Nielsen 2003. Association between pain and muscle activity in the	Denmark	To determine the effects of experimental pain in the jaw on neck and jaw muscle activity	n = 19M, healthy volunteers Mean age (years): 26.4 (± 1.2)	In one session, a glutamate and isotonic injection was given into either the R masseter or R splenius capitis, and then the opposite was given 1-2 weeks apart. R SCM, R splenius capitis, L and R masseter muscles activity recorded before, 60 - 260s and 15 minutes after the injection in four different positions:	The sign decreases in muscle activity of the SCM when glutamate was injected into the R masseter could be due to the direct inhibition of the muscle. This could be through nociceptive input from the jaw or secondary effects of parallel co-activation of the jaw-neck muscles.

jaw and neck muscles				head and jaw in neutral, maximal jaw clenching, R neck rotation and neck extension. <u>Results (after glutamate injection into R masseter):</u> - **Resting:** sign increase in R SCM muscle activity (p = .002) and R masseter (p = .013) in head neutral position only, no sign changes in muscle activity in other two head positions. - **Maximal clenching:** sign decrease in muscle activity of R masseter (p = .001), L masseter (p = .002) and SCM (p = .047). - No sign changes with isotonic injections.	
Tecco et al., 2008. EMG activity of masticatory, trunk and neck muscles in patients with TMD undergoing splint therapy	Italy	To determine the activity of the neck, trunk and masticatory muscles in participants with internal derangement TMD undergoing anterior splint therapy	<u>Study group:</u> n = 34, 22F, 12M Mean age (years): 30.4, age range: 20 - 48 <u>Control group:</u> n = 34, 20F, 14M Mean age (years): 31.8, age range 18 - 56 Participants in both groups had internal derangement TMD	10 weeks of anterior splint in the study group, no other treatment and no treatment for the control group. EMG measurements of anterior and posterior temporalis, masseter, SCM, upper and lower trapezius and posterior cervicalis muscles. Measurements taken before splinting and after 10 weeks of wearing a mandibular splint in a mandibular rest position and during maximal clenching. <u>Before treatment:</u> Statistically sign lower activity of all muscles in the control group. <u>10 weeks after treatment:</u> - **Mandibular rest:** statistically sign lower activity of cervical muscles, L temporalis, R lower trapezius and R and L masseter and SCM after, but no sign differences between study and control groups. - **Maximal clenching:** statistically sign increase in R and L anterior temporalis and masseter in splint group only. No detectable differences in activity of other muscles after splint therapy.	Anterior mandibular repositioning splints influence the resting muscle activity of SCM and lower trapezius.
Uritani, Kawakami, Inoue and	Japan	To determine the characteristics of upper quadrant	<u>With TMD:</u>	Posture analysed in standing using 3D computer system.	Participants with TMD did not present with more protracted/retracted shoulders.

Kirita 2004. Upper quadrant posture in participants with TMD		postural changes in women with TMD	n = 19F, myogenous and/or arthrogenous TMD Mean age (years): 30.1 (± 8.9) <u>Without TMD:</u> n = 14F, healthy volunteers Mean age (years): 24.6 (± 6.1)	<u>Results:</u> - Sign smaller angle neck inclination in the TMD group ($p < .01$). - Sign less ROM of mouth opening in TMD group ($p < .05$). - No sign differences in angle of the shoulder, cranial rotation angle and shoulder width.	Smaller neck inclination angle in participants with TMD shows a greater anterior forward head posture which has implications on the shoulder girdle, even though no differences in angles were found.
Venegas et al., 2009. Effects of clenching and grinding on muscle activity of SCM and masseter	Chile	To determine the effects of clenching and grinding in different jaw positions on muscle activity of SCM and masseter	n = 34, 18F, 16M healthy volunteers, dental students Mean age (years): 22.6, age range: 19 - 29	<u>Surface EMG measurements taken during:</u> A – maximal habitual clenching B – habitual grinding to maximum contact of teeth in protrusion C - maximal clenching in maximum contact of teeth in protrusion D – grinding from protrusion to habitual occlusion E – grinding from retrusion to habitual occlusion Clenching = isometric contraction Grinding = concentric/eccentric contraction <u>Results:</u> - Sign highest activity of masseter and SCM ($p < .001$) during Task A. - No sign differences in masseter or SCM activity in grinding tasks ($p > .05$) except for the masseter, sign differences between tasks D and E ($p < .05$).	EMG activity of the masseter and SCM was sign lower during eccentric versus isometric contraction in the habitual occlusal position. This may be due to the number of teeth in contact as this forms part of the peripheral mechanism through the trigeminal input from the periodontal receptors.
Von Piekartz and Ruinemans, 2017 Orofacial treatment of overhead athletes with Glenohumeral internal rotation deficit (GIRD) syndrome	Germany	Pilot study To determine the changes in shoulder pain and range through the combination of occlusal splint and orofacial musculoskeletal therapy in participants with GIRD syndrome	n = 11F semi-professional athletes who train at least 10 hours per week and have more than 20° internal rotation restriction on the dominant shoulder compared to the non-dominant compared to the non-dominant shoulder and persistent shoulder	Participants received neuromusculoskeletal treatment 3X over 2 weeks, an individualised exercise programme and a temporary splint. The PEN shoulder score was also administered to participants. <u>Results:</u> 8/11 participants had significant improvements: - Pain on the VAS improved by 4.9 ($p = 0.01$) - ROM of internal rotation improved by 24° ($p = 0.02$) - ROM of external rotation improved by 22.2° ($p = 0.03$)	With caution, as it was a pilot study it can be postulated that there are significant effects of treating the orofacial region in participants with GIRD.

			pain for the past 3 months.	Therefore, those participants were no longer classified as having GIRD. PEN shoulder scores also showed significant improvements: - Pain: p = 0.01 - Function: p = 0.02 - Satisfaction: p = 0.04 Of the three participants who did not show an improvement in pain or range, it could be attributed to previous shoulder girdle fractures with the cause of third participant unknown.	
Zhang et al., 2023. Effects of asymmetrical occlusion on muscle activity in participants with a chewing side preference.	China	To determine the symmetry of muscle activity of the masseter, left and right gastrocnemius and SCM in participants who have a chewing side preference, compared to the control group and during different clenching positions	<u>All participants:</u> Students or staff at the university <u>Chewing side preference group:</u> n = 14, 8F, 6M Mean age (years): 25.9 (± 2.4) <u>Control group:</u> n = 18, 10F, 8M Mean age (years): 26.6 (± 2.7)	Preliminary study The muscle activity was measured with participants clenching in three different placements of a cotton roll: on the posterior teeth on the right only, left only and bilaterally. <u>Results:</u> - **Control group:** significant differences in symmetry of the SCM with biting on left cotton wool compared to right and bilateral compared to the right ($p < 0.05$). - **Chewing side preference group:** significant differences in symmetry of the SCM when biting bilaterally on cotton wool compared to the left side only and left compared to the right ($p < 0.05$).	The effects of asymmetrical occlusion on the changes in symmetry of SCM show the influence of symmetry of the jaw on the symmetry of the SCM.

CI, confidence intervals; EMG, electromyography; F, females; GIRD, glenohumeral internal rotation deficit; M, males; MVC, Maximum voluntary contraction; n, number; ROM, range of motion, RMS, root mean square, SCM, sternocleidomastoid; TMD, temporomandibular disorders; TMJ, temporomandibular joint; TP, trigger points; VAS, Visual Analogue Scale

Thematic synthesis

Of the 41 studies included, the connections were categorised into anatomical, neuromuscular and neurophysiological. Three studies described the anatomical connections, 29 discussed the neuromuscular relationships, and nine reported on the neurophysiological relations. Figure 3 illustrates the number of studies that investigated the various shoulder girdle muscles.

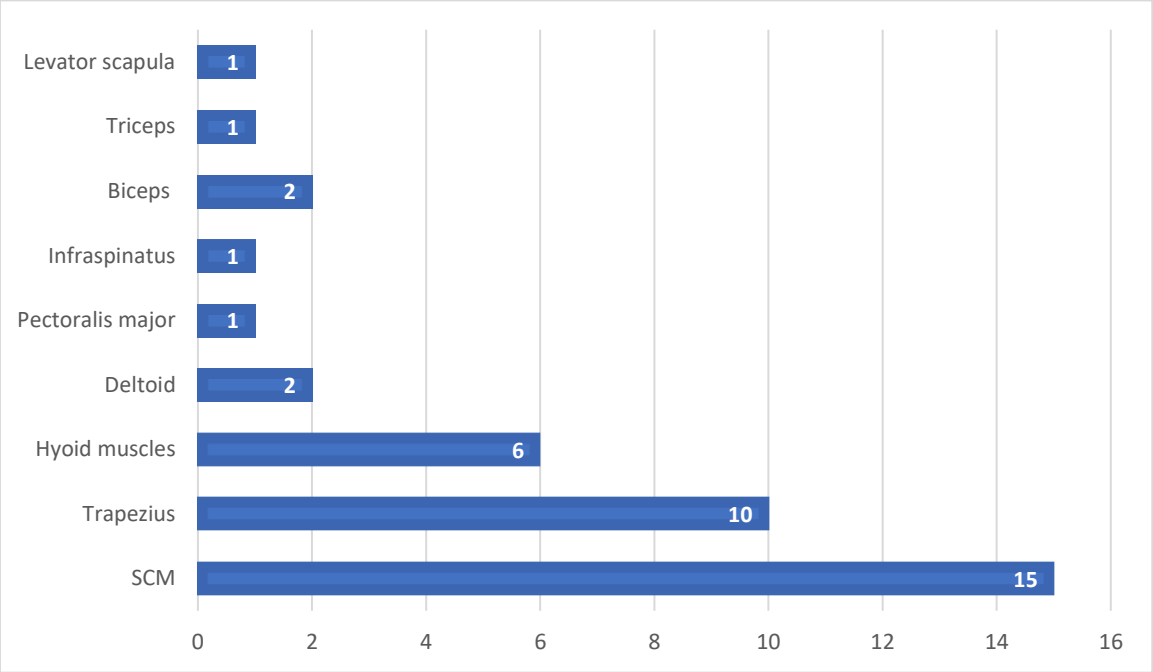

FIGURE 3. The shoulder girdle muscles examined across the included studies

Anatomical

Muscular

In three articles, the SCM and hyoid muscles were discussed as being the two groups of muscles providing a direct muscular connection between the TMJ and shoulder girdle.[4,6,11] For the hyoid muscles, this is through the hyoid bone. It serves as an attachment site for the hyoid muscles, which have origins on the mandible and temporal bones as well as the clavicle and scapula.[4]

The SCM originates from the clavicle and inserts onto temporal bone which is part of the TMJ.[6] Changes in the position of the TMJ is also seen with changes in the activity of the SCM. Overactivity leads to lowering of the tongue, posterior cranial rotation, posterior positioning of the TMJ, and tension in the suprahyoid and infrahyoid muscles.[11]

Myofascial

The myofascial system was found to be a more indirect anatomical connection between the shoulder girdle and TMJ through the presence and treatment of myofascial trigger points. Trigger points are considered pathology of the myofascial system as they are a taut band found in the fascia surrounding the skeletal muscle. The muscular and fascial systems have been shown to be responsible for the development of trigger points and therefore form part of the myofascial system[40]. The results showed that the ROM of the TMJ was influenced by the presence of latent trigger points and pain pressure threshold in the shoulder girdle muscles.[5,23] The other findings were the presence of more active and latent trigger points in the shoulder girdle muscles of participants with TMD compared to those without, coupled with a correlation between a higher level of pain in the TMJ and a larger referral of the trigger points.[16]

<u>Neuromuscular</u>

Muscular activity

Concomitant activation of the shoulder girdle muscles during jaw movements is a neuromuscular strategy to increase stability and movement accuracy of the jaw. The studies reviewed showed that the recruitment of the biceps, hyoid, levator scapula, SCM and trapezius muscles during jaw movements vary depending on the patient's position, activity performed, demand on the jaw and symmetry of occlusion.

The ergogenic effects of jaw clenching on the shoulder girdle muscles were influenced by the position of the participant. This was shown as the maximal voluntary contraction of the shoulder girdle muscles differed when participants changed sitting or lying positions while clenching.[20,42]

The effects of clenching on the shoulder girdle muscles occurred during and after the activity. This included changes in the recruitment patterns and length of time remaining active after clenching. An example of this was the SCM activating before the masseter and for a longer period of time after clenching compared to before.[20,32]

The presence or absence of TMD also influenced the recruitment of the shoulder girdle muscles during various tasks. Participants with TMD had lower activity of SCM and trapezius during jaw clenching[10,15,36] compared to those without TMD.

Postural

The literature showed that participants with TMD are more likely to have elevated shoulders with three studies finding that participants with TMD had a higher risk and prevalence of elevated shoulders compared to those without TMD. [9,29] The evidence of the presence of protracted shoulders in this population was conflicted and not conclusive.[9,41]

Occlusal

Occlusion and occlusal splints were shown to have neuromuscular effects on the shoulder girdle muscles. An occlusal splint encourages equal distribution of contact between all the teeth creating an environment for the mandibular condyle to be in the most unstrained position in the mandibular fossa. By the splint separating the teeth, it prevents patients from achieving maximal intercuspation (maximum contact between teeth) therefore reducing the patient's ability to clench. This reduces the strain on the TMJ and surrounding muscles and creates articular and muscular balance.[1] The splint also causes mechanical changes through altering the position of the TMJ by increasing the vertical height of the TMJ.[35]

The effects of the occlusal splint on the shoulder girdle muscles were seen as it influenced the resting muscle length of the SCM and trapezius[7] with the reverse also being true. The symmetry of occlusion also changed the recruitment pattern and endurance of the shoulder girdle muscles. This was shown during asymmetrical clenching and occlusion: there was asymmetrical contraction of the SCM and lower endurance of the biceps.[17,18]

Significant reductions in muscle activity of the trapezius and SCM were found during clenching with a repositioning splint.[7] The muscle activity differed when a non-repositioning and no splint were used showing the effects of occlusion on the muscle activity of the shoulder girdle. This was different for the deltoid muscles which had a significant increase in isometric strength and activity with the use of occlusal splints.[8,14] Similar results were found in another study, with significant increases in

maximal voluntary contraction of SCM, upper trapezius, biceps and triceps muscles occurring during isometric contractions while wearing an occlusal splint.[27]

Neurophysiological

The neurophysiological relationship between the shoulder girdle (specifically the SCM) and TMJ is described by two reflexes: cervico-trigeminal and trigeminal-cervical. The former reflex is the reciprocal relationship of masseter and SCM during occlusion, how occlusion affects the function of SCM, and how the pathology of SCM can be treated by changing occlusion. The latter reflex is activated during chewing and stimulates the activation of the same side SCM during unilateral mastication, and both sides during bilateral mastication. There are also changes in the electrical activity of SCM in participants with TMD.[6]

This reflex can be further explained by the innervation of SCM by the nerve roots of C1 and C2 which form part of the cervical plexus. These nerve roots converge with the trigeminal afferent fibres in the trigemino-cervical nucleus in the grey matter of the spinal cord at the levels C1-C3. At this level there is convergence of the nociceptive neurones receiving input from the trigeminal and cervical nerves. This neuro-anatomical connection between the trigeminal and upper cervical neurones provides an explanation of referred pain between the two areas.[26]
The cervical plexus's cutaneous branches emerge from the SCM's posterior border. These branches provide innervate the skin superior to the auricle, which is a common area of complaint in participants with TMD.[6]

Pain and muscle activity

In participants with TMD, the SCM and trapezius muscles are more active at rest and less active during jaw movements.[36,39] Participants with myogenous TMD, who had pain in either the SCM or trapezius, had significantly higher resting muscle activity of that muscle compared to those in the group without that specific pain and to those in the control group.[32] Similar results were seen in healthy participants - when they were given a hypertonic injection into the masseter, it led to a significant increase in muscle activity of the SCM at rest and a substantial decrease during clenching.[37] The effects of the hypertonic saline also work in the reverse way, with

the injection into the trapezius causing an immediate reduction in the ROM of the TMJ.[25]

The influence of pain on muscle activity highlights the strong neurophysiological connection between the TMJ and shoulder girdle.

DISCUSSION

The increase in prevalence and chronicity of individuals with TMD emphasises the need to expand on how these conditions are treated, beginning with what other areas of the body the TMJ is linked to. The scoping review aimed to source the research available on the connection between the shoulder girdle and TMJ, which clearly showed the presence of a connection.

The main categories of the types of connections were anatomical, neuromuscular and neurophysiological, and the main muscles that were researched were the SCM, trapezius and hyoid muscles. There was limited research done on the infraspinatus, deltoid, pectoralis major, levator scapula, biceps, and triceps, showing the need for further research on these shoulder girdle muscles.

The main findings of changes in the shoulder girdle muscles in relation to the TMJ were with changes in occlusion and the use of occlusal splints. These changes manifested in muscle activity, strength, peak torque, symmetry of activation and endurance during mastication, clenching and grinding. The changes while wearing occlusal splints were a reduction in resting activity and an increased activity on contraction of the SCM and trapezius muscles. [7,8,14,27,39] These findings suggest that the splint leads to lower recruitment of the shoulder girdle muscles at rest to stabilise the head and an improved ability of the muscles to contract effectively during contraction.

The mechanism of these changes was through the changes in occlusion, which then influenced the input from the periodontal, muscular, and TMJ receptors to the trigeminal nerve. This then affects the motor neurons of the SCM through the cervical plexus.[1,35] Another mechanism is mechanical as the occlusal splint has been found to increase the vertical dimension of the TMJ and increase cranial extension

on the upper cervical spine which is associated with mouth opening which could also contribute to the changes in muscle activity[7].

The effects of symmetry of occlusion also played a role in the recruitment pattern of the shoulder girdle muscles. The SCM contracted symmetrically during habitual occlusion and asymmetrically during clenching on one side.[18] Similar findings were seen with the biceps muscle, with a significantly higher endurance during clenching in habitual occlusion, lower endurance during clenching on cotton balls, and even lower endurance during right sided clenching on cotton balls. This showed that biting on an unstable surface which is a less stable position for the jaw provided the biceps with less proximal stability needed for higher endurance.[17]

The amount of demand on the TMJ also affected the recruitment of the shoulder girdle muscles. This is seen as the activity of the SCM was higher during chewing larger pieces of food compared to smaller ones. Thus, showing the increased need for stability of the head by the shoulder girdle muscles, to allow for adequate movement of the mandible to prepare food for swallowing.[23]

Another main finding between the two areas was the ergogenic effect of clenching on the shoulder girdle muscles and how clenching in healthy participants increased the muscle activity and endurance of shoulder girdle muscles.[2,10,33,42] This is relevant to assess in participants with TMD as they may be clenching to perform exercises of the shoulder girdle due to the improvement in muscle activity and endurance thereby worsening their TMD.

The other areas of interest were the effects of trigger points and pain between the two areas. The trapezius muscle is one of the most common sources of pain in participants with cervicogenic headaches and cervical-shoulder pain. The connection between the jaw and trapezius has been well documented. It varies from palpating the trigger points in the trapezius reproducing patients' pain with TMD[16,] to being the muscle most responsive to changes in the position of the mandible through the use of an occlusal splint.[7,39] The reverse has also been documented with an immediate reduction in ROM of mouth opening after experimental pain into the trapezius[24] and a decrease in the asymmetry of bite force after stretching the trapezius.[28]

The other well-researched muscle is the SCM, which produces findings of muscle activity similar to the trapezius. Participants with TMD have a higher resting activity of the trapezius and a lower activity during maximal voluntary contraction, with the opposite being true for healthy participants.[10,32,36] Just as the trapezius plays a role in the cause and effect of TMD, so the same holds true for the SCM, with treatment of trigger points immediately increasing the ROM of mouth opening, which is a common restriction in participants with TMD.[5]

The effect of malocclusion and the imbalance of clenching highlights another gap in the literature on the influence of the trigeminal nerve through periodontal input on the shoulder girdle muscles. It should be noted that these studies were performed on individuals without TMD, and further research is needed to clarify the impact of TMD on these shoulder girdle muscles. The changes in the shoulder girdle muscles seen while wearing splints during clenching and grinding, and the influence of trigger points on the ROM of the TMJ, highlight the importance of further research to determine the relevance of including the shoulder girdle in the assessment and treatment of participants with TMD. The opposite is also true; an assessment and treatment of the TMJ needs to be researched in order to determine its relevance in inclusion of the management of shoulder girdle dysfunction.

Clinical implications

There is a need to improve the assessment and treatment of patients with TMD, and the review highlights the potential value that assessing and treating the shoulder girdle may add to this population. These include assessing pain and the presence of trigger points in the SCM, trapezius, and medial scapular muscles, as this was shown to improve ROM of the TMJ and, on palpation, caused referral to the temple region, which is a common complaint in participants with TMD. The higher muscle activity of SCM and trapezius at rest and lower activity during jaw activities in participants with TMD show how the recruitment patterns of the muscles needed to support and stabilise the head to allow mandibular movement change with TMD, highlighting the importance of addressing these imbalances to provide better head stability and therefore mandibular movement.

Knowledge gaps and future research

Future studies should be done on the characteristics of shoulder girdle muscles in participants with TMD and how these may relate to changes in the muscles of mastication. Further research is also needed on the effects of occlusal splints, clenching, and changes in all the shoulder girdle muscles. Studies that investigate the impact of movement and changes in the TMJ on the shoulder girdle need to be done without the involvement of the cervical spine.

Limitations

The three articles not translated due to funding restrictions may have contributed to the topic. Due to the exclusion of articles published before 2000, valuable research may also be excluded from this scoping review. Another limitation was the use of only one reviewer to extract the data from the studies. The quality of studies varied with some not having control groups and only small sample sizes.

CONCLUSION

Clear anatomical, neuromuscular and neurophysiological connections exist between the shoulder girdle, cervical spine and TMJ. Further research is needed to determine the role of including an assessment and treatment of the shoulder girdle in the rehabilitation protocol of participants with TMD.

Key points

Findings: The primary connections between the TMJ and shoulder girdle were anatomical, neuromuscular and neurophysiological.

Implications: The results highlight the importance and value of including the shoulder girdle in assessing and treating participants with TMD.

Caution: Inconsistent reporting and focusing only on studies done in English studies only in English may have influenced the results.

Declaration of Generative AI and AI-assisted technologies in the writing process: During the preparation of this work, the authors did not use any artificial intelligence tools.

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CHAPTER 4

4. STUDY 2

This chapter contains the bibliographical details and full manuscript of Study 2

Title: Shoulder Girdle Disability, Dysfunction, and Pain in Participants with Temporomandibular Joint Disorders: A Cross-Sectional Survey on Prevalence and Associations

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4.1.1 Bibliographical Details of Original Study 2

Authors: Micaela Weinberg, Benita Olivier and Siyabonga Kunene

4.1.2 Journal

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The *Physiotherapy Canada* is the official journal of the *Canadian Physiotherapy Association* strongly emphasising patient-centered care and therapeutic skills.

The *Physiotherapy Canada* journal is indexed in*:*

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Title: Shoulder girdle disability, dysfunction and pain in participants with temporomandibular joint disorders: a cross-sectional survey on prevalence and associations

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Patient involvement: study participants were not involved in the design, conduct, interpretation, or translation of the current research.

ABSTRACT

Background: There is a rising prevalence of temporomandibular disorders (TMD) and, therefore a need to improve the management of these conditions. No studies have been done to assess the possible associations between the shoulder girdle and the temporomandibular joint (TMJ) in participants with TMD.

Objective: The aim of the study was to estimate the prevalence of disability, dysfunction and pain in the shoulder girdle in participants with TMD. In addition, the association between the disability, dysfunction and pain in the shoulder girdle and temporomandibular joint in participants with temporomandibular disorders was investigated.

Methods: A cross-sectional study was performed where participants were invited to complete an online survey if they received a score of two or more on the TMD-pain screener. The survey included questions on demographics, the TMJ and the shoulder girdle.

Results: A total of 186 individuals with TMD participated in the study of whom, 56% (n=104) reported having shoulder pain and 45% (n=84) reported having previous shoulder treatment. A positive correlation was found between the level of TMD, as indicated by the mean Fonseca Anamnestic Index score and the pain ($r = 0.29$, $p < 0.001$), disability ($r = 0.24$, $p = 0.001$) and total scores ($r = 0.28$; $p < 0.001$) on the Shoulder Pain and Disability Index and similarly with shoulder pain at its worst ($r = 0.19$, $p = 0.009$).

Conclusion: The associations found between the pain and disability of the shoulder girdle and TMJ give insight into the relationship between the two areas in participants with TMD.

Key words: Fonseca Anamnestic Index; shoulder girdle; Shoulder Pain and Disability Index; temporomandibular joint; temporomandibular disorder

INTRODUCTION

The prevalence of temporomandibular disorders (TMD) is 10-15% in the adult population worldwide (Saczuk et al., 2022). The associated co-morbidity rate is very high with only 0.77% of people with TMD not complaining of associated pain (Kim, Ko, Lee and Jung., 2019). According to

the National Health Interview Analysis in the United States, of the 189 977 participants reviewed, 8 964 (4.6%) had TMD with 83% of these participants having other areas of pain (Byun et al., 2020). The high impact of TMD and associated conditions emphasise the importance of exploring the temporomandibular joint (TMJ) and its possible associations with surrounding structures, such as the shoulder girdle.

Cervical pain is one of the common conditions associated with TMD with anatomical, biomechanical and neurophysiological connections between the two areas. Anatomically, the TMJ and the upper cervical spine are closely located and share myofascial connections (Grondin et al., 2015). Biomechanically, there is simultaneous upper cervical extension during mouth opening and upper cervical flexion during mouth closing (Mansilla-Ferragut et al., 2009). The neurophysiological relationship describes the convergence of the trigeminal and upper cervical afferent fibres in the trigeminocervical nucleus (Castien and De Hertogh, 2019).

Muscular connections between the acromion, clavicle and scapula of the shoulder girdle and the cervical spine have also been well established. This is through the levator scapula, trapezius, cervical flexors and extensors which have proximal attachments to the cervical spine and distal insertions onto the shoulder girdle. Another connection is through the influence of injuries and changes in one area on the other. This is evident as participants with cervical spine degeneration have been found to have a negative impact on the alignment of the cervical spine causing a predisposition to shoulder injuries (Kastuura, et al., 2020).

Changes in the positioning of the shoulder girdle has the potential to create symptomatic dysfunction in the cervical and thoracic spine by causing changes in the length of the trapezius, sternocleidomastoid and scalene muscles. The effects of the cervical spine on the shoulder girdle have also been shown. Participants with neck pain who were right hand dominant had significantly reduced right clavicle retraction, left scapular upward rotation and clavicle elevation compared to participants without cervical pain (Helgadottir, et al., 2011).

These findings are consistent with other studies that have found participants with neck pain to have increased upper cervical extension, reduced cervical flexion and clavicle retraction. This causes an increase in compression of the articulations between the cervical and thoracic spine leading to changes in muscle activity of the trapezius and serratus anterior and neural tension in the median nerve (Yip, Chiu and Poon., 2006).

The high prevalence of TMD and associated disorders as well as the connections between the cervical spine and shoulder and the cervical spine and TMJ highlight the need to establish if there is a connection between the shoulder girdle and TMJ in participants with TMD. As such it was the purpose of the study to estimate the prevalence of disability, dysfunction and pain in the shoulder girdle in participants with TMD. In addition, the correlation between the disability, dysfunction and pain in the shoulder girdle and temporomandibular joint in participants with temporomandibular disorders was investigated.

METHODS

Study design and participants

A cross-sectional study was conducted using a survey from June to September 2022.

Inclusion in the study required participants to score two or more on the TMD-pain screener. This screening questionnaire consists of three questions and is part of the Diagnostic Criteria for Temporomandibular Disorders (DC/TMD), a valid screener for screening of TMD. The questions ask participants about their TMJ symptoms in the past 30 days. A score of two or more is indicative of pain-related TMD (Gonzalez et al., 2011). No exclusion criteria were applied.

Questionnaire

The questionnaire included three sections namely demographics, questions on the TMJ and questions on the shoulder girdle. It took 10 minutes to complete. Section A was designed by the first author and consisted of questions on basic demographics, medical history, occupation and exercise. Demographic questions included age, gender, marital status and highest level of education.

Questions on medical history asked participants about their medical conditions, if they took any medication and any previous surgery. The occupational section included the type of work, amount of time spent in front of the computer/I-pad and amount of heavy lifting required.

Section B consisted of questions on the TMJ and a standardised TMD questionnaire, the Fonseca Anamnestic Index (FAI). The questions on the TMJ were designed by the researcher to determine the range of motion (ROM), previous treatment and history of injuries to the facial region. The FAI consists of 10 questions with possible answers of yes, no or sometimes. The answer yes receives a score of 10, sometimes a score of five and no a score of zero. A total score of 100 can be received. A score of 0 – 15 is classified as no TMD, a score of 20 – 40 is classified as mild TMD, moderate TMD a score of 45 – 65 and severe TMD a score of 70 – 100 (Yaman, Alpaslan and Kalaycioglu, 2021).

Section C consisted of questions on the shoulder girdle and a standardised questionnaire, the Shoulder Pain and Disability Index (SPADI). The questions designed by the researcher included hand dominance, previous shoulder injuries and treatment, presence of pain in the shoulder and popping/clicking. The SPADI questionnaire consists of two parts, the first part is five questions and asks the participants to rate their pain during certain activities from 0 – 10. The second part is eight questions and asks the participant to rate their experience during certain tasks from 0 – 10 with zero being no difficulty and 10 being so difficult it requires help. The total score is out of 130 and is converted to a percentage.

The higher the score the worse the shoulder pain and disability (Breckenridge and McAuley, 2011). The cut-off for SPADI total score is 49.2 for the highest tertile and 39.4 at the lowest, for SPADI pain score is 46.4 for the highest and 36.7 for the lowest and the SPADI disability score is 46.8 compared to 25.1 for the lowest (Tran et al., 2020).

Data collection procedure

Ethical clearance was obtained from the University of the Witwatersrand Human Research Ethics Committee (Medical) (M2111110 MED21-11-098). The questionnaire was designed, and data was collected using the Research Electronic Data Capture (Redcap). This is an online application used to capture data (Patridge and Bardyn, 2018). The link to this questionnaire was attached to the advertisement for qualifying participants.

The invitation to participate in the study, the inclusion criteria and a link to the survey was posted on the main researcher's personal and practice's social media forums. These included Facebook and Instagram posts and WhatsApp statuses. The posts were shared and reposted by other people, which created a local and international reach.

An email was also sent to physiotherapists on the South African Society of Physiotherapy database to complete and share with their patients. The same email was sent to doctors and dentists asking them to share it with their patients. In order for people to qualify to fill out the survey and meet the inclusion criteria, a score of two or more on the TMD-pain screener was required (Gonzalez et al., 2011). There were no other exclusion criteria. Participants were asked for their email addresses if they were willing to receive more information about the third phase of the study but this was not mandatory.

Before the study commenced, a pilot study was conducted involving five participants in order to determine the length of time needed for to complete the questionnaire and if there were any ambiguities in the questionnaire.

Statistical analysis

The raw data was exported from Redcap to IBM SPSS Statistics version 28 and Microsoft Excel for interpretation. Means and standard deviations were used to analyse data that were continuous and descriptive in nature. Frequencies and percentages were used to summarise the remaining demographic data as well as the researcher's questions on the TMJ and shoulder girdle.

Graphical and statistical calculations were used to measure skewness and kurtosis of the SPADI values. The graphical techniques used were histograms and scatter plots. It was found that SPADI pain scores were normally distributed which was supported by the skewness coefficient and kurtosis values. The findings for the SPADI disability and total scores were both skewed on the graphs to the right and had coefficients above one. The mean and standard deviation variables for the individual SPADI questions is depicted in Figure 5.

Correlations between total FAI scores and SPADI pain, disability and total scores, as well as shoulder pain at its worst, were analysed using Pearson's correlation. 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). An independent sample t-test was used to determine the differences between the total FAI scores in those with and without shoulder pain, previous injuries to their shoulder girdle and presence or absence of popping/clicking of their shoulder.

Ethical considerations

An information sheet on the study's objectives, risks, cost of participation, anonymity and storage of data was included before the questionnaire began. This was followed by an informed consent section which stated that participants give consent to participate in the study by continuing to complete the questionnaire.

RESULTS

Demographics, medical history and lifestyle

A total of 186 participants completed the questionnaire, consisting of the researcher's questions, the FAI and SPADI standardised questionnaires. The majority of participants were female with a mean (SD) age of 32.03 (± 11.96) and between the ages of 16 and 79. The full demographics of the sample are represented in Table 1.

A high portion of the sample, 60.2%, had previous surgery, with the most common being wisdom teeth removal (17.2%) and the lowest being shoulder surgeries (2.6%). Over half of the participants

were taking medication, with the most common being selective serotonin reuptake inhibitors. The full information on participants' medical history is shown in Table 2.

Lifestyle questions on exercise, computer work and heavy lifting at work are presented in Table 3. The majority of participants, 80.1%, did exercise with the most common form, aerobic, done by 86% of the sample. This was followed by 34.8% of participants doing resistance training. Despite the analgesic effect of exercising, the results showed a non-significant positive correlation between exercise and total FAI scores ($r = .011$; $p = 0.18$). There was also no significant correlation between the participants' work involving heavy lifting and their total score on the FAI ($r = - .024$; $p = 0.24$).

The most common amount of time spent on the computer was 2-3 hours, reported by 23.6% of the sample. This was followed by 13.9% of participants spending 8-9 hours daily. A positive, significant correlation was found between the total SPADI score and time spent on the computer ($r = -.09$; $p < 0.001$).

Temporomandibular joint disability, dysfunction, history and pain

Specific questions were included by the researcher on the TMJ, such as any previous head and facial injuries and the ability to fit three fingers in their mouth on opening giving an indication of ROM. The answers to these questions and information on the previous management of their TMD are expressed in Table 4.

More than half of the participants, 62.9%, had received previous treatment for their TMD. Exactly half of the participants reported having received physiotherapy, with the majority having received physiotherapy only (41.3%), followed by physiotherapy in conjunction with other therapies.

The highest possible score for each question on the FAI is 10, and the total is 100. This sample had a mean (SD) score of 60.19 (± 21.03), showing that the majority of participants had moderate TMD (42.5%) followed by severe (38.7%) then mild TMD (15.6%). The highest scoring question was asking participants if they clench or grind their teeth, commonly referred to as bruxism. The mean

(SD) score for this question was 8.63 (± 2.83) (Figure 2), with 79% of participants answering yes and 15% answering sometimes (Figure 2).

The next highest scoring question was about participants having pain in the nape of their neck, with a mean (SD) score of 8.20 (± 3.26) (Figure 2). A high percentage of participants reported clicking in their jaw with 65% answering yes and 12.9% answering sometimes (Figure 2). Figures 1 and 2 depict the frequencies of the individual answers, their mean and standard deviation.

Prevalence of shoulder pain in participants with TMD

More than half of the sample, 104 participants (56%), reported having shoulder pain with, 26.3% (n = 49) of participants reporting clicking/popping of their shoulders (Figure 3). Just less than half of the participants, 84 (45%), reported having received previous shoulder treatment. Of these participants, 33.3% (n = 62) had sought physiotherapy, followed by acupuncture at a much lower prevalence of 5.3% (n = 10) (Figure 4). Despite the high rate of shoulder pain and previous shoulder treatment, there was a low prevalence of 16.1% (n = 30) of those with previous shoulder injuries.

The highest scoring question on the SPADI was about participants' shoulder pain at its worst. This mean (SD) score was 4.61 (± 3.33) followed by 3.48 (± 3.11) for pain when lying on the involved arm (Figure 5). The lowest scoring questions were the difficulty associated with putting on pants (0.75 ± 1.38) and putting on a shirt with buttons (0.81 ± 1.55). The mean (SD) for the SPADI pain, disability and total scores were 14.79 (± 11.99), 11.67 (± 13.78) and 26.46 (± 24.10), respectively (Table 4).

Relationships between the TMJ and shoulder girdle

The relationships between the total FAI scores and SPADI pain, disability and total scores as well as shoulder pain at its worst can be found in Table 5. Positive, weak correlations were found between the level of TMD according to the total FAI scores and SPADI pain ($r = 0.29$; $p < 0.001$), disability ($r = 0.24$; $p = 0.001$), and total scores ($r = 0.28$; $p < 0.001$). There was a positive, weak correlation between pain at its worst in the shoulder and total FAI scores ($r = 0.19$; $p = 0.009$).

DISCUSSION

In this study, we investigated the relationships between shoulder and TMJ disability, dysfunction and pain as well as the prevalence of shoulder impairments and previous injuries in participants with TMD. Our results showed that in this population, there is a high prevalence of shoulder impairments and correlation between the shoulder girdle and TMJ pain and disability. More than half of the participants with TMD had shoulder pain and a quarter had shoulder popping or clicking.

There were positive, weak correlations between the total FAI and SPADI pain, disability and total scores, between the amount of time spent on the computer and SPADI scores as well as between shoulder pain at its worst and total FAI score. The weak correlations could be due to the scales used. The FAI measures the level of TMD whereas the SPADI measures pain and disability and therefore, a stronger correlation may have been found with outcome measures that test the same variables. Another reason for the weak correlation could have been the presence of confounding factors that were not included in the questionnaire, such as posture, which could have an impact on the cervical and thoracic spine and, therefore, influence the TMJ and shoulder girdle, creating an indirect relationship.

Another finding of interest was that physiotherapy was the most commonly sought treatment for both participants' TMJ and shoulder complaints. Despite the potential bias of these results due to physiotherapists playing a role in sourcing patients for this study the authors believe the number of participants sourced through this avenue may be negligible. However, further research into the types of treatment sought by patients with TMD is advised. With physiotherapy being the most common therapy, there was still a high prevalence of participants with moderate and severe TMD and shoulder pain. This highlights the need for better management of TMD and shoulder girdle dysfunction by physiotherapists. These findings suggest the inclusion of the shoulder girdle in the assessment of patients with TMD.

Demographics, medical history and lifestyle

The higher prevalence of female participants in the sample is consistent with the findings of two systematic reviews that found TMD was significantly more common in females compared to males (Ryan et al., 2019; Bueno et al., 2018). The reasons for this include hormonal factors, differences in pain sensitivity, higher levels of work stress, depression and anxiety in women (Bueno et al., 2018).

The mean age of the present sample is broadly supported by the research with the prevalence of TMD being the highest in the 20–40-year-old age group and decreasing with increasing age. The proposed reasoning for this is the onset of TMD is directly related to stress and the highest level of stress and productivity occurs during the 20-40-year age period (Mazzetto et al., 2014).

Analysis of the medical results showed that wisdom tooth extraction was the most common surgery reported by participants. The reason for this could be the extensive mouth opening required and considerable lateral forces on the mandible, increasing the risk of TMD. Even though the prevalence of TMD post wisdom extraction varies among different studies from 0.7% to a much higher incidence of 34%, the results are similar in that there is a higher prevalence of TMD after wisdom removal (Chen, Chi and Lee, 2021).

Contrary to previous studies, in the current study no correlation was found between the use of anti-depressants, specifically selective serotonin reuptake inhibitors and bruxism (Garrett and Hawley, 2018). A potential reason for no correlation between this drug and clenching being found in this sample is the effects of bruxism from this class of anti-depressants are seen within four months of starting the drug (Garrett and Hawley, 2018). The TMD- pain screener that was used for inclusion into the current study questioned the presence of participants' symptoms specifically in the past 30 days.

Using a computer for four hours or more a day had a significant contribution to the development of TMD symptoms and a two-hour increase in computer time led to an increase in symptoms by double or triple (Tsukagoshi, Nishiyama and Shimada, 2017). Significant correlations were found between time spent on the computer and SPADI scores in the current population of participants

with TMD. This shows another possible link between disability of the shoulder girdle and TMD as participants who spent more time on the computer were more likely to have higher pain and disability in their shoulders the longer, they spent on the computer.

Temporomandibular joint disability, dysfunction, history and pain

Conservative management of TMD is the first choice for the majority of people with the dysfunction (Paco et al., 2016). Most participants reported having received physiotherapy for their TMD and despite this, there was still such a high prevalence of the presence and severity of TMD. In accordance with the present results, a systematic review found 85-90% of people chose non-invasive treatment options for management of this condition. In the current study, half reported receiving physiotherapy, which has been found to improve ROM of the TMJ more so than dry needling and exercise therapy (Paco et al., 2016). This, among other reasons, could be the reason why the majority of the participants were able to fit three fingers on mouth opening.

Despite most participants having full range of movement of the jaw, the overall FAI scores were higher than previous research. However, in those studies unlike this current study, participants were not included if they had previous head/neck trauma, were undergoing orthodontics or the presence of inflammatory conditions (Xiao et al., 2023). This shows that these changes and conditions may play a role in the worsening of the severity of TMD.

Another reason for the worse severity of TMD in this current study was that majority of participants reported clenching or grinding. This was significantly higher than other studies that reported a prevalence of clenching in 33.9% of participants with TMD and 11.2% in participants without TMD. However, the mean age was higher in that group and as previously discussed, the prevalence of bruxism decreases with age. This study was also done in Germany compared to the current study with majority of participants living in South Africa indicating the potential of a higher prevalence of bruxism in the South African population (Sierwald et al., 2015).

The prevalence of clenching in students without TMD was 36.5% which is higher than the standard non-TMD population (Fluerasu et al., 2022). This study consisted of a high portion of students and health workers. Higher levels of stress have been found in medical/health science students compared to their age-matched peers. Significantly higher levels of stress, anxiety, depression, job-related pressure and anxiety were found in participants who grind and clench compared to those who do not (Sackzuk et al., 2022).

The strong connection between psychological factors and TMD is through the dopaminergic system. This is through cortisol and stress, causing initiation of bruxism in the day and perpetuation of grinding at night. It has also been shown that the majority of people with anxiety adopt the parafunctional habits of clenching and grinding (Alkhudhairy et al., 2018).

The next highest scoring question was the presence of neck pain. The bidirectional relationship between cervical pain and TMD has been well established. The severity of cervical pain has been found to increase with the severity of TMD (Ki et al., 2019; Sanchla et al., 2022). The results of the current study corroborate with these findings as more than three quarters of participants reported neck pain, with the majority having moderate and severe TMD.

The reason for the high levels of cervical pain in these participants is based on the central sensitisation theory. There is an upregulation of the trigeminal nucleus, which causes widespread pain with reduced inhibitory signals and increased sensitisation of nociceptive receptors. This leads to hyperalgesia and allodynia and may be a possible explanation of the association between the pain in the TMJ and shoulder girdle found in this study (Alkhudhairy et al., 2018).

Prevalence of shoulder pain in participants with TMD

Just more than half of the participants with TMD reported having shoulder pain, which is higher than the one-month prevalence of shoulder pain in the general population (18-31%) (Juel and Natvig, 2014). Of these 766 participants, there was a mean age of 49 and therefore was an older sample than the current study. These findings show that participants of a younger age group had a

higher prevalence of shoulder pain compared to another group who were older in age, showing the potentially higher prevalence of shoulder pain in participants with TMD.

Relationships between the TMJ and shoulder girdle

The TMJ and shoulder pain and disability values in the current study were similar to those who were survivors of head/neck cancer, which were also significantly higher than participants without head/neck cancer. In the same study, an increased perception of a swallowing impairment was significantly correlated to a reduction in shoulder strength (Oritz-Comino et al., 2020). It is encouraging that similarly to the current study, Oritz-Comino et al. (2020) found a significant correlation between SPADI pain and disability and FAI scores.

The mean SPADI scores of participants in this study were slightly higher than participants with shoulder pain after seeking treatment and much lower than before seeking treatment (Thoomes-de Graaf et al., 2017). This shows that the intensity of shoulder pain and disability in participants with TMD were lower than those with active shoulder pain. The lowest scoring items on the SPADI were putting on pants and buttoning a shirt. In both of these activities, minimal shoulder range is required. Therefore, higher levels of pain and disability of the shoulder were found as the demand on the shoulder increased in terms of range and strength.

This is seen as the scores increased from questions referring to reaching from their back pocket to washing their hair, with the highest scores being activities that demanded more load, such as carrying a heavy object. This indicates the possibility that the effects of dysfunction of the TMJ on the shoulder girdle are more apparent when the shoulder is under greater load. This hypothesis and the exact mechanism of the greater impact on the greater load required needs to be further explored.

Further research needs to be done on the prevalence of shoulder girdle impairments and their association with the TMJ in participants without TMD. An objective assessment of the shoulder girdle and TMJ needs to be done in participants with and without TMD. This needs to include an assessment of the shoulder girdle in various positions with increasing demand in participants with

TMD. Further research also needs to be done to establish the prevalence of other areas of pain in patients with TMD, and whether the level of shoulder pain and disability is higher than those.

Strengths and limitations

This research was a cross-sectional design using a survey, and participants were invited to participate if they had TMD according to the TMD screening questionnaire. Therefore, participants may not have had an accurate diagnosis of TMD due to the lack of clinical examination. Strengths of this study are the large sample size, the reach to different populations worldwide and the inclusion of previously well-validated standardised questionnaires.

CONCLUSION

The relationships between the level of TMD severity, shoulder girdle pain and disability demonstrate a weak, linear relationship between pain and disability caused by shoulder problems and pain and disability caused by TMD. It is recommended that further research is done to determine if participants with TMD need to be screened for the presence of shoulder pain and an assessment framework of the shoulder girdle in this population is developed.

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Tables

Table 1. Socio-demographic characteristics of participants with TMD (n = 186)

Variable	***n***	**%**
Gender		
Male	19	10.2
Female	167	89.8
Marital status		
Single	75	40.3
Married	84	45.2
Divorced	7	3.8
Widow	1	0.5
Live with partner	15	8.1
Other	2	1
Level of education		
Graduated primary school	8	4.3
Graduated high school	23	12.4
Undergraduate degree	73	39.2
Postgraduate degree	74	39.8
Other	7	3.8
Occupation		
Medical personnel	84	33
Teacher	17	9
Office based job	40	21.5
Other	22	11.8
Student	28	15
Unemployed	7	3.7

Table 2. Medical history of participants with TMD (n = 186)

Medical conditions	***n***	**%**
Yes	32	17.3
No	153	82.7
Type of medical condition		
Autoimmune	14	7.5
Fibromyalgia	2	1.1
Hypothyroidism	10	5.3
Osteoarthritis	2	1.1
Other	4	2.1
Medication		

Antidepressants:		
- SSRI	25	13.4
- SNRI	4	2.1
- Other	5	2.6
Anti-inflammatories	3	1.6
Hypothyroidism	13	6.9
Immune suppressants	6	3.2
Oral contraceptive	10	5.3
Other	11	5.9
Previous surgery		
Yes	112	60.2
No	74	39.8
Type of surgery		
Jaw/facial	11	5.9
Other	79	42.4
Shoulder	5	2.6
Wisdom removal	32	17.2

SSRI, selective serotonin reuptake inhibitors; SNRI, serotonin norepinephrine reuptake inhibitors

Table 3. Exercise and vocation of participants with TMD (n = 186)

Exercise	***n***	**%**
Yes	149	80.1
No	37	19.9
Amount of exercise (per week)		
Once	5	2.7
Twice	34	18.3
Three	51	27.4
Four	31	16.7
Five	19	10.2
Six	8	4.3
Seven	1	0.5
Type of exercise		
Aerobic	129	69.3
Yoga/Pilates	40	21.5
Resistance/weight training	52	27.9
Other	11	5.9
Amount of computer work (hours daily)		
0-1	12	6.4
2-3	44	23.6
4-5	24	12.8
6-7	21	11.2
8-9	26	13.9
≥ 10	8	4.3

Occupation involving heavy lifting		
Yes	69	37.1
No	117	62.9
Amount (kg)		
0-10	24	12.8
11-20	8	4.3
21-50	7	3.8
51-80	2	1
≥ 81	13	6.9

Table 4. Previous history, functional limitations, severity of TMD and SPADI scores in participants with TMD (n = 186)

Previous TMJ treatment	***n***	**%**	**Mean (SD)**
Yes	117	62.9	-
No	69	37	-
Type of treatment			
Acupuncture/needles	9	4.8	-
Bite plate	13	6.9	-
Botox	11	5.9	-
Chiropractor	7	3.7	-
Medication	7	3.7	-
Other	5	2.6	-
Physiotherapy	93	50	-
Surgery to the TMJ	3	1.6	-
Combinations of treatment			
Botox only	2	1	-
Chiropractor	3	1.6	-
Occlusal splint only	3	1.6	-
Physiotherapy only	77	41.3	-
Physiotherapy and botulinum toxin	7	3.7	-
Physiotherapy and chiropractor	5	2.6	-
Previous blow/injury to face/head/chin			
Yes	49	26.3	-
No	133	71.5	-
Insert three fingers with mouth open	3	1.6	
Yes	157	84.4	-
No	29	15.6	-
FAI score	-	-	60.19 (± 21.03)
Severity of TMD			
No TMD	6	3.2	-

Mild TMD	29	15.6	-
Moderate TMD	79	42.5	-
Severe TMD	72	38.7	-
SPADI scores			
SPADI pain score	-	-	14.79 (± 11.99)
SPADI disability score	-	-	11.67 (± 13.78)
SPADI total score	-	-	26.46 (± 24.10)

FAI, Fonseca Anamnestic Index; TMD, temporomandibular disorders; TMJ, temporomandibular joint; SPADI, Shoulder Pain and Disability Index

Table 5. Correlations between SPADI subscales, total scores and shoulder pain at its worst and total FAI scores (n = 186)

Shoulder variables	Pearson correlation co-efficient (r) and confidence intervals	p value
SPADI pain	0.29 95% CI = [0.16, 0.42]	< 0.001
SPADI disability	0.24 95% CI = [0.09, 0.37]	0.001
Total SPADI	0.28 95% CI = [0.14, 0.48]	< 0.001
Pain at its worst	0.19 95% CI = [0.05, 0.33]	0.009

FAI, Fonseca Anamnestic Index; SPADI, Shoulder Pain and Disability Index

Table 6. Comparisons between FAI scores in participants with and without previous shoulder injury, pain or popping/clicking (n = 186)

		Presence of previous shoulder injury, pain or popping/clicking			
Shoulder variables	**Number of responses**	**Yes Mean (SD)**	**No Mean (SD)**	**95% CI[a]**	**p value**
Presence of previous shoulder injury	Yes: 30 No: 155	60.00 (± 24.84)	60.22 (± 20.31)	-6.56, 8.508	0.799
Presence of shoulder pain	Yes: 103 No: 82	61.92 (± 20.59)	57.99 (± 21.500)	-8.882, 2.259	0.242
Presence of shoulder popping/clicking	Yes: 48 No: 137	62.14 (± 22.85)	59.49 (± 20.39)	-8.491, 4.167	0.501

FAI, Fonseca Anamnestic Index; SD, standard deviation

[a]: Independent t test

Figures

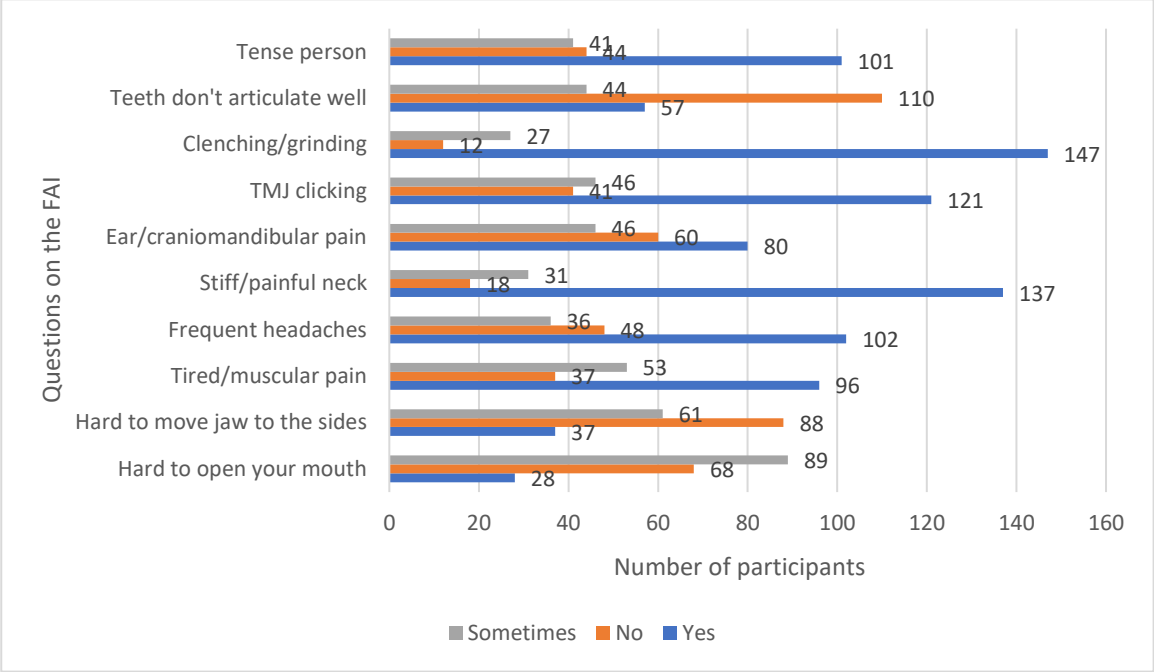

Figure 1. Participants answers to the individual FAI questions

FAI, Fonseca Anamnestic Index; TMJ, temporomandibular joint

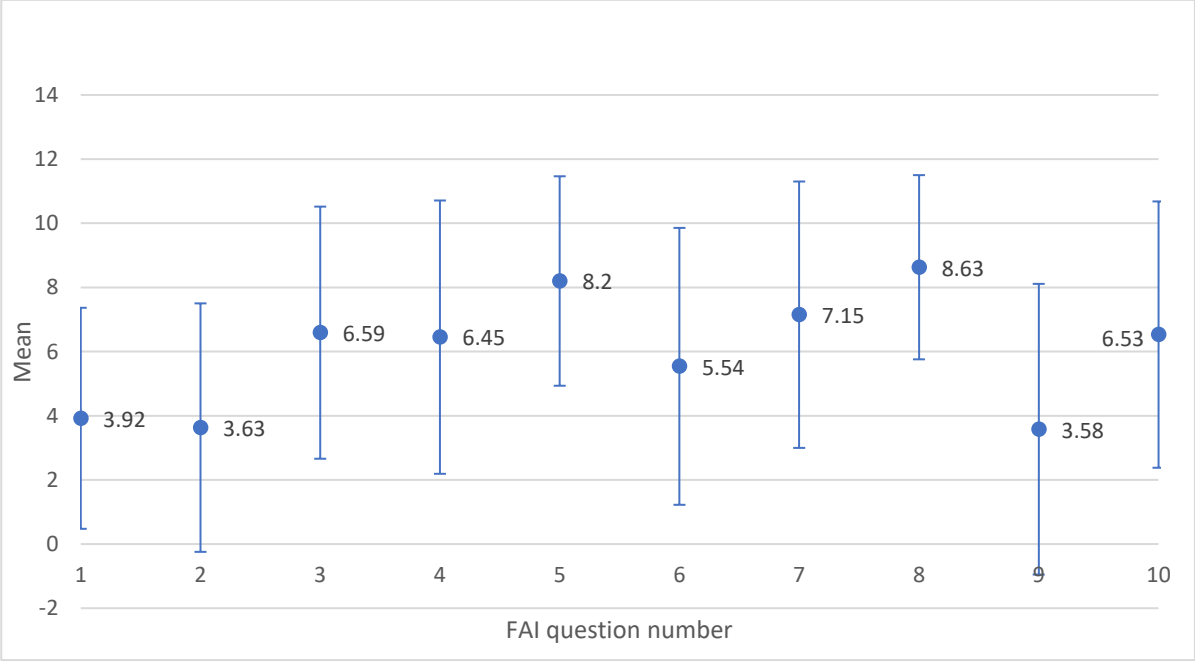

Figure 2. Scatterplot of mean and standard deviations of individual FAI questions.

1. Hard to open your mouth; 2. Hard to move mandible to the sides; 3. Tired/muscular pain when chewing; 4. Frequent headaches; 5. Stiff/painful neck; 6. Earache/pain in the craniomandibular joints; 7. TMJ clicking; 8. Clench/grind; 9. Teeth don't articulate well; 10. Tense person
Vertical bars indicate standard deviation.
FAI, Fonseca Anamnestic Index

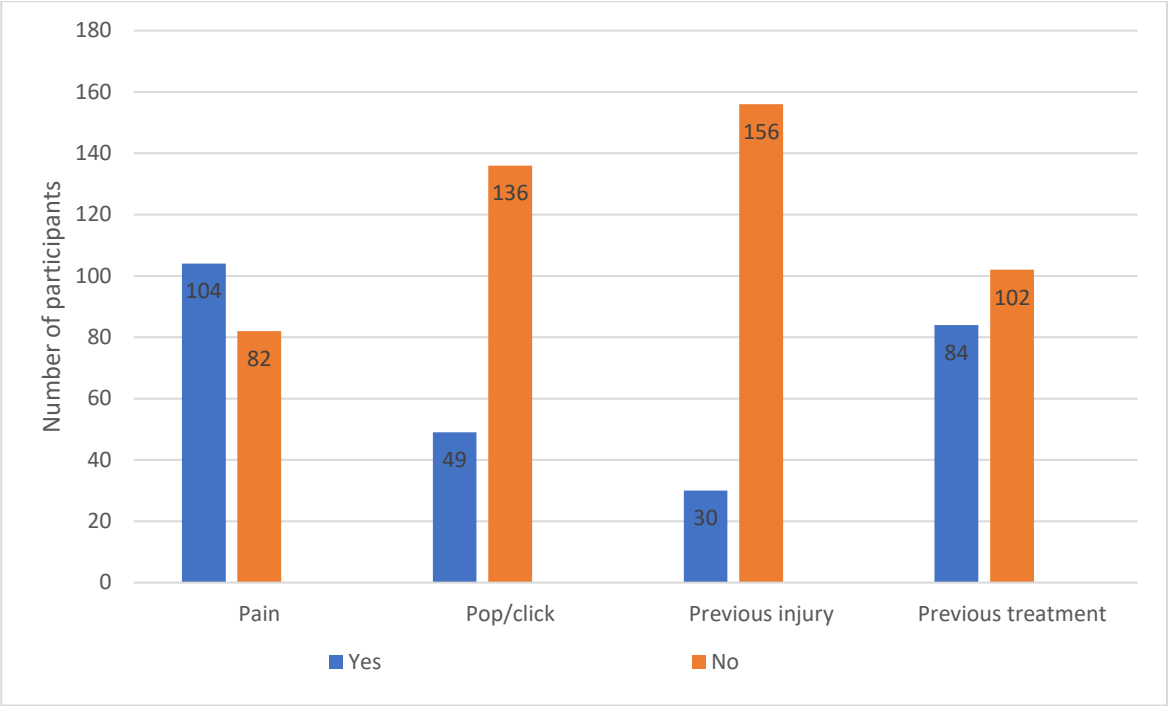

Figure 3. Signs, symptoms and previous history of shoulder function in participants

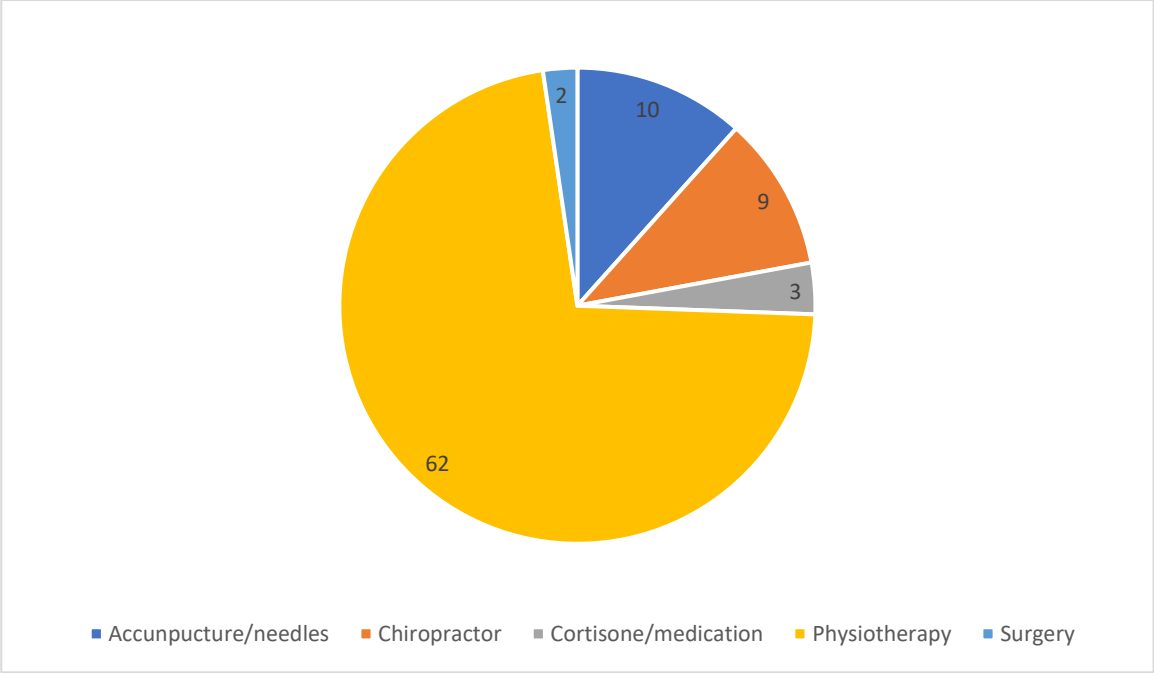

Figure 4. Previous treatment modalities for shoulder dysfunction in participants with TMD (%)

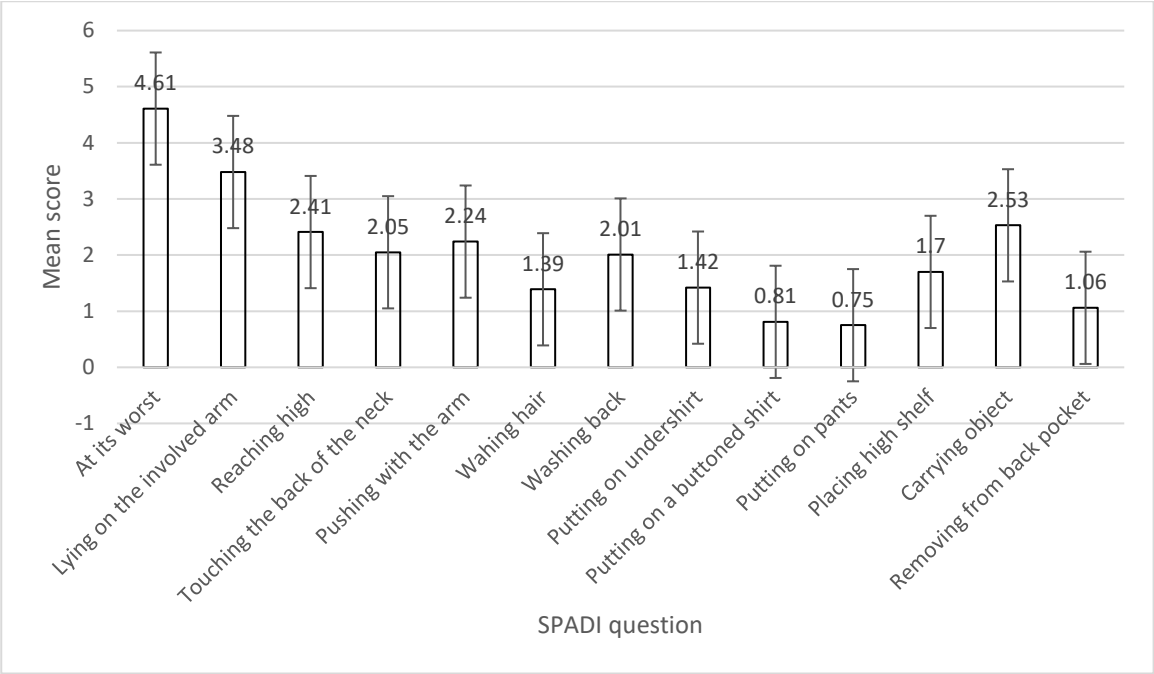

Figure 5. Mean and standard deviations of individual SPADI questions. Vertical bars indicate standard deviation

CHAPTER 5

5. STUDY 3

Title: Shoulder Girdle Muscle Activity at Rest and During Jaw and Shoulder Movements in Participants with and without Temporomandibular Disorders: A Cross-Sectional Observational Study

Weinberg, M., Olivier, B and Kunene, S., 2024. Shoulder girdle muscle activity at rest and during jaw and shoulder movements in participants with and without temporomandibular disorders: a cross-sectional observational study *Journal of Bodywork and Movement Therapies* (under review).

5.1.1 Bibliographical details of Original Study 3

Authors: Micaela Weinberg, Benita Olivier and Siyabonga Kunene

5.1.2 Journal

Journal of Bodywork and Movement Therapies

The *Journal of Bodywork and Movement Therapies* includes various techniques across the varied allied health practices.

The *Journal of Bodywork and Movement Therapies* is indexed in*:*

- Calcium and Calcified Tissue
- Cambridge Scientific Abstracts
- CINAHL
- Cochrane Center
- Embase
- MANTIS
- Neuroscience Abstracts
- PubMed/Medline
- Scopus

The current impact score of the *Journal of Bodywork and Movement Therapies* is 0.394 (2024).

This study's formatting and referencing align with the current journal it has been submitted to.

ABSTRACT

Background: Previous studies have shown the effects of temporomandibular joint (TMJ) alignment on the shoulder girdle muscles. No previous research has investigated the 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, using the Delsys Trigno Wireless EMG System at a frequency of 1000Hz. 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). There were significant, moderate positive correlations between pain in the TMJ and shoulder ($p < 0.001$, Cramer's V = 0.707) as well as between disability of the shoulder and TMD (r = 0.45, p = 0.006).
Conclusion: The majority of the shoulder muscles had lower activity at rest, during jaw and shoulder movements in participants with TMD. There are positive correlations between both shoulder and TMJ pain and disability.

Key words: electromyography; shoulder girdle; temporomandibular joint; temporomandibular disorder.

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. 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 the motivation of 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 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 if it plays a role 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; Sojka 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.

METHODS

Study design

A cross-sectional observational study was done. Ethical approval was obtained by the Human Research Ethics Committee (Medical) at the *(information removed to allow for anonymous peer-review for the purpose of this thesis)* (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.

Participants and sampling

The study included participants between the ages of 18 and 70 years. The first step for inclusion in the TMD group was a score of two or more on the TMD-pain screener, which classifies participants as having TMD (Gonzalez et al 2011). The inclusion criteria for the non-TMD group were the absence of pain anywhere in the body, specifically in the TMJ, cervical spine and shoulder girdle. 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, those who were undergoing orthodontic treatment or were pregnant.

A consecutive sampling method was used for the group of participants with TMD as it included all possible patients as part of the sample. Individuals in the TMD group were invited to participate in the current study if they agreed to be contacted after completing an online questionnaire (Weinberg, Olivier & Kunene, 2023), were new patients at the researcher's private practice referred through other health care practitioners or responded to an advertisement distributed on social media. 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 lower 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.

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 standardised questionnaires. These were the Numerical Rating Scale (NRS), Fonseca Anamnestic Index (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 2018).

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 0-40. The higher the rating, the higher the disability (Johnston, Bird & Bright, 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. 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.

The placement of the electrodes was done according to Criswell & Cram (2011), with the exact placements shown in Table 1.

Table 1. Surface electrode placement of biceps, medial deltoid, infraspinatus, inferior trapezius and serratus anterior muscles (Criswell and Cram, 2011)

Muscle	Position of the electrode	Direction of electrode
Biceps	Two thirds between the acromion and cubital fossa	Vertical, parallel to muscle fibres
Medial deltoid	Lateral arm, 3 cm below the acromion process in a horizontal line.	Parallel to muscle fibres
Infraspinatus	In the infrascapular fossa, 4 cm below the scapular spine	Parallel to the spine of the scapula
Inferior trapezius	Next to the medial edge of the scapula, 5 cm below the scapular spine	55° oblique angle
Serratus anterior	Below the axilla, medial and anterior to latissimus dorsi and posterior to pectoralis major	Parallel to muscle fibres

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 & Cram, 2011).

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 practiced the movements before the activity was measured, and three repetitions were done for each active movement with a one-minute 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 five seconds each (Chafka et al., 2002).

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).

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 to 450Hz and a sampling rate of 1000Hz. 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 the quality of the signal quality remained acceptable throughout the collection.

The mean values of the middle three seconds of the isometric movements and 10 seconds 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.

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.

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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).

RESULTS

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.

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 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)		

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

	TMD group (n = 18)	**Non-TMD group (n = 18)**	**Differences between groups**	
TMJ and shoulder variables	**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

TMD, temporomandibular disorder; TMJ, temporomandibular joint

a: Fisher's exact test

b: Cramer's V

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%).

The results of the individual questions of the FAI, STMDI and SPADI questionnaires are represented graphically in Figures 1, 2 and 3, respectively. Table 4 shows the differences NRS, FAI, SPADI and STMDI scores and ROM between the two groups.

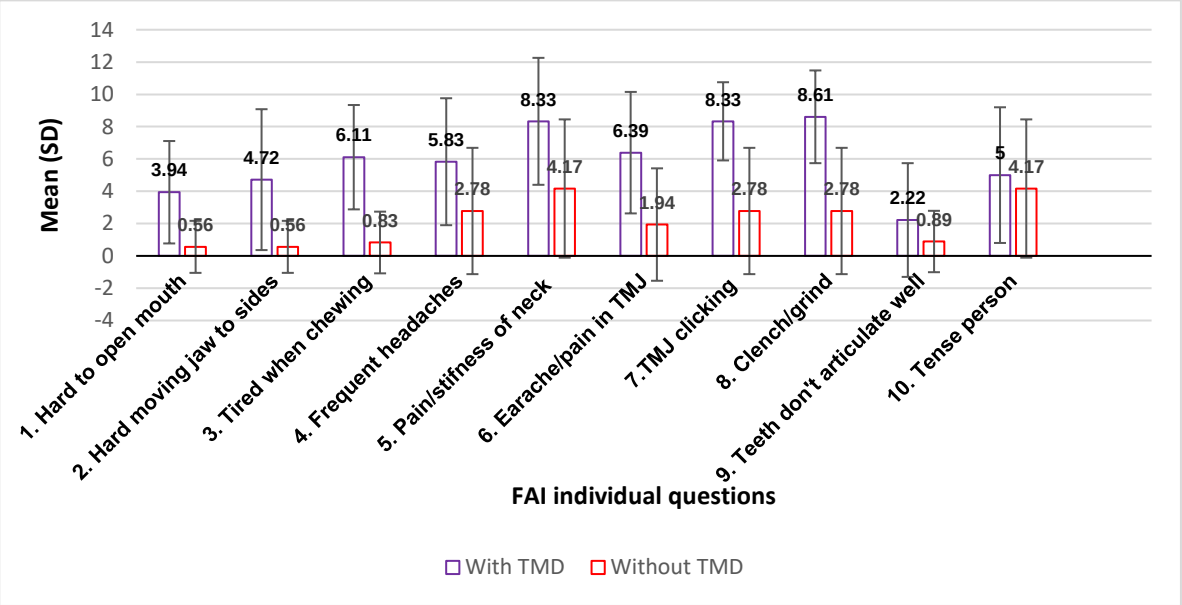

Figure 1. Mean scores and standard deviations of responses to the FAI in participants with TMD (n = 18) and without TMD (n = 18)

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

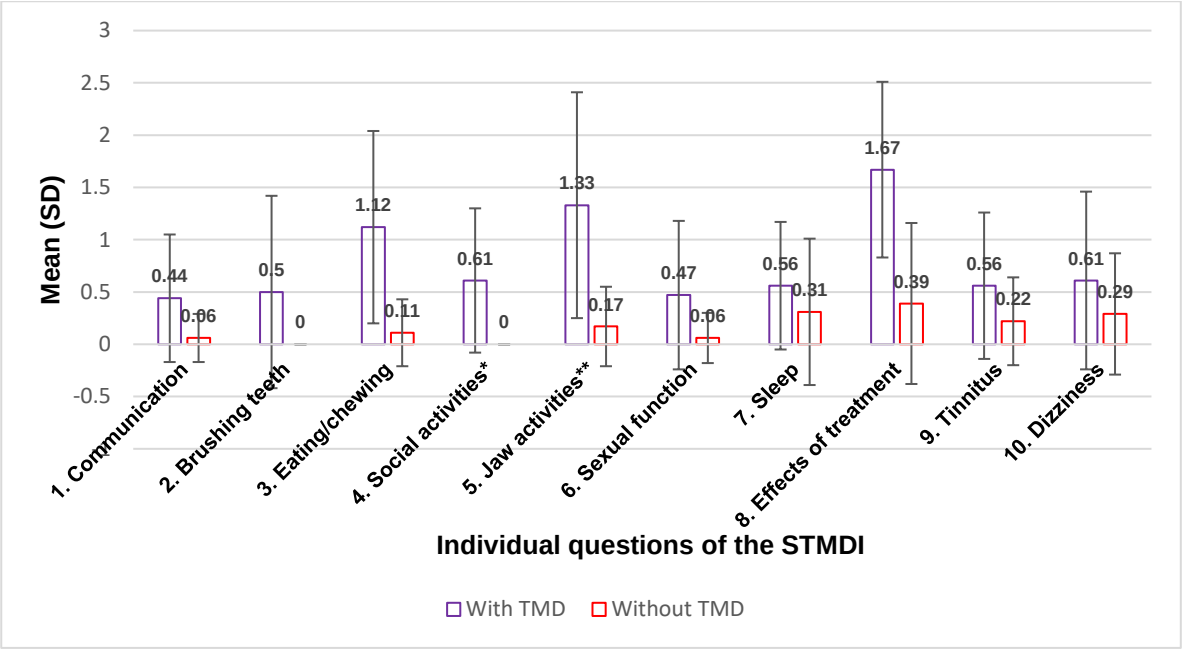

Figure 2. Mean scores and standard deviations of responses to the STMDI in participants with TMD (n = 18) and without TMD (n = 18)

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

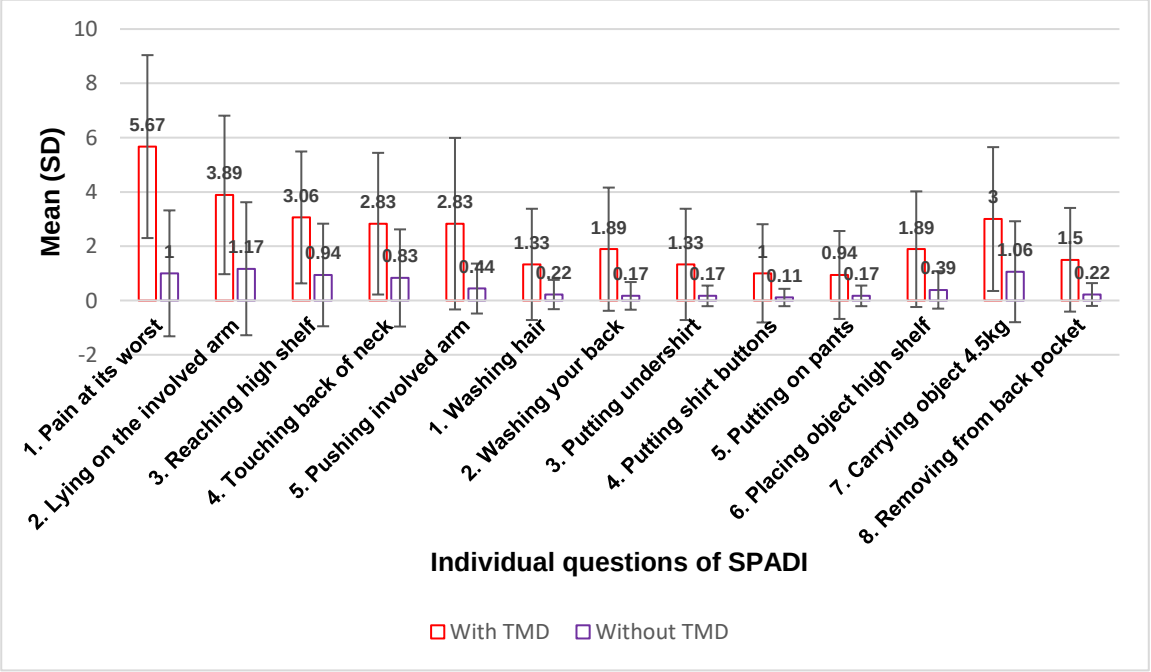

Figure 3. Mean scores and standard deviations of responses to the SPADI in participants with TMD (n = 18) and without TMD (n = 18)

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.

Table 4. Comparisons of levels of pain, function and disability of the TMJ and shoulder girdle between groups (n = 36)

TMJ and shoulder variables	TMD group (n = 18)	Non-TMD group (n = 18)	Differences between groups	
	Mean (SD)	Mean (SD)	*p* value[a]	Effect size[b]
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[c]**	**Effect size[b]**
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: Independent sample's t test

b: Cohen's d

c: Mann Whitney U test

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%).

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).

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

Table 5 shows the differences in muscle activity between the groups.

Table 5. 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

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.

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).

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 6). 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).

Table 6. 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

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 no exceptions to this pattern during the shoulder movements, with some variances observed at rest and during jaw movements.

The TMD pain screener was used to include participants with TMD. Despite participants in the non-TMD group being included as they did not have TMD according to the screener and inclusion criteria, the scores on the FAI showed that some presented with mild TMD. However, no participants in the TMD group received previous treatment of their TMJ and had a median score of zero on the NRS for TMJ pain, which was significantly lower than the TMD group.

It is encouraging to compare the baseline mean pain, ROM and rate of clenching in the current study to that of the findings of 50 participants with TMD by Sojka 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. Of those same participants, 75% had a ROM on mouth opening of less than 40mm which is similar to the current TMD group ROM mean (SD) 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.

In relation to the EMG activity, the majority of the muscles had higher activity at rest and during jaw movements in participants without TMD compared to those with TMD. The exceptions to this were the right inferior trapezius, left serratus anterior, left biceps and left medial deltoid, that had a higher activity during majority of jaw movements in participants with TMD. There were no exceptions during shoulder flexion and abduction, with all shoulder muscles having lower activity in participants with TMD compared to those without.

The right inferior trapezius and left serratus anterior were the only two muscles that had higher activity in the TMD group at rest and during every jaw movement. These were the only two muscles tested that stabilise the scapula with the serratus anterior protracting and the inferior trapezius depressing the scapula (Paine & Voight 2013; Park & Lee 2020). Majority (94%) of participants were right hand dominant and 72% of participants had occupations that involved computer work.

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 lower fibres of trapezius (Kastuura et al 2020; Park & 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). Therefore, the weakening of the inferior trapezius and serratus anterior which is associated with increased computer use and forward head posture, more common in participants with TMD, may explain the reason for these muscles having the opposite patterns to the rest of the group at rest and during the jaw movements.

These findings, however, were in contrast to those of Pallegama et al (2004), who found a higher resting activity of SCM and upper trapezius in participants with TMD compared to those without, as well as a systematic review which found that the masseter and temporalis had higher activity at rest in those with TMD (Szyszka-Sommerfeld et al 2023). However, despite these findings, the majority of the differences between the muscles in the TMD and non-TMD groups had small effect sizes and very low significances between them, and therefore, conclusions on higher activity cannot be drawn. Furthermore, other

confounding factors were present such as participants posture, including the presence of thoracic kyphosis and rounded shoulders which would also have an influence on these muscles.

The left medial deltoid was the other muscle that had higher activity in the TMD group compared to the non TMD group at rest and during all the jaw movements. These findings were not supported by Dias et al (2019), who found no changes in activity in the medial deltoid with the use of an occlusal splint compared to no splint. However, that study only included participants without TMD and therefore these findings may show that, unlike the other muscles tested, the medial deltoid activity is affected by the presence of pain in the TMJ and not by the alignment.

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 muscles. Furthermore, shoulder muscles on the participants' hand dominance side had higher activity during jaw and shoulder movements compared to the non-dominant side.

A pattern that was shown in relation to the movements was that as the demand on the jaw increased from active to resisted movements, the activity of more muscles became higher in the participants with TMD. This is seen as during resisted opening and resisted left laterotrusion, half the muscles had higher activity in the TMD group, and during resisted right laterotrusion, four muscles had higher activity compared to the active jaw movements with between two and three muscles having higher activity in the TMD group with smaller effect sizes.

The potential reason for this could be that as 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 recruitment of the shoulder girdle muscles. This pattern of recruitment of the shoulder girdle muscles has been shown through the ergogenic effects of clenching

leading to an increase in shoulder girdle muscle strength and endurance (Alghadir et al 2018; Ferrario et al 2001).

This was also seen in the left biceps, which had higher activity in the TMD group during all the resisted jaw movements. The effects of the TMJ on the activity of the biceps have been shown by Lee et al (2013), who found that participants without TMD had significantly higher maximum isometric contraction of the biceps while wearing an occlusal splint compared to no splint. 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, agreeing with the current results of changes in positioning of the TMJ leading to changes in biceps activity.

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 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).

The two shoulder movements tested, shoulder flexion and abduction, had no exceptions to all the shoulder muscles having lower activity in participants with TMD compared to those without. 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). These findings show that the potentially, 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 that 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 2016). However, the role of confounding factors cannot be excluded such as the presence of cervical changes, differences in posture and pain perception.

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 potential connection between TMD and the shoulder girdle. 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. However, none of these findings can be generalised as many confounding factors were present such as posture, the cervical spine, type of work, time spent on devices, Body Mass Index and age. Despite all precautions being taken to prevent cross talk from the sEMG, this is another potential confounding factor that could have influenced the results.

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. 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.

LIMITATIONS

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. There were confounding factors that may have played a role in the findings. These include body mass index, gender, age, posture, work related variables and the cervical spine as well as general limitations of using sEMG.

STRENGTHS

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

CLINICAL RELEVANCE

- The presence of shoulder pain and previous shoulder treatment needs to be further investigated before being included in an assessment of participants with TMD
- Further research is needed on the relationship between TMD and shoulder disability before being included in an assessment of participants with TMD
- Further research is needed on the muscle activity of the shoulder girdle muscles in order to determine if an assessment of their strength and endurance during resisted flexion and abduction needs to be done in patients with TMD

CONCLUSION

Majority of the shoulder girdle muscles had higher activity at rest and during jaw movements in participants without TMD. All shoulder muscles had lower activity during shoulder flexion and abduction in participants with TMD. There were positive, significant correlations between SPADI and FAI, and SPADI and STMDI scores. Our findings highlight that there may be a connection between the TMJ and shoulder girdle and more research is needed in this area.

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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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CHAPTER 6

6. STUDY 4

Title: Assessment Framework of the Shoulder Girdle in Participants with Temporomandibular Disorders: Delphi Study

Weinberg, M., Olivier, B and Kunene, S., 2024. Assessment framework of the shoulder girdle in participants with temporomandibular disorders: Delphi study. *Brazilian Journal of Physiotherapy* (under review).

6.1.1 Bibliographical Details of Original Study 4

Authors: Micaela Weinberg, Benita Olivier and Siyabonga Kunene

6.1.2 Journal

Brazilian Journal of Physiotherapy

The *Brazilian Journal of Physiotherapy* publishes original articles relating to various physical therapy topics.

The *Brazilian Journal of Physiotherapy* is indexed in*:*

- CINAHL
- CSA-Cambridge Scientific Abstracts
- MEDLINE (National Library of Medicine)
- Scopus
- Web of Science (WoS)

The current impact score of the *Brazilian Journal of Physiotherapy* is 4.762 (2024).

ABSTRACT

Background: The literature on the most effective physiotherapy techniques in patients with temporomandibular disorders (TMD) is inconclusive. The current protocol for treatment of these conditions is techniques for the temporomandibular joint (TMJ) and cervical spine, with a need for improvement of treatment of these conditions.

Objective: The study aimed to establish an assessment framework of the shoulder girdle in participants with TMD through an international panel of experts using the Delphi technique.

Methods: A survey was sent to 21 physiotherapy experts over two rounds. Each round included 11 statements of subjective and objective assessment tools of the shoulder girdle. Experts were asked to rate the importance of including each statement in the assessment of patients with TMD according to the 5-point Likert scale. The consensus threshold was set at 70% for the first and 60% for the second rounds. Statistical analysis was performed using descriptive statistics and Microsoft Excel.

Results: In the first round 11 experts (52%) responded, and 9 experts (43%) responded in the second round. A consensus of 70% was reached for three statements in the first round and a consensus of 60% for six statements in the second, with one statement being added as a suggestion for inclusion. The final assessment framework included five subjective questions and four objective assessment measures.

Conclusion: A framework assessment of the shoulder girdle in participants with TMD was established, which represented the current literature and knowledge of international experts.

Key words: Delphi; shoulder girdle; temporomandibular joint; temporomandibular disorder

INTRODUCTION

The temporomandibular joint (TMJ) is one of the most complex regions in the body with two joints working simultaneously to achieve movements (Pelicioli et al., 2017). These actions involve input from the dental, neuromuscular and occlusal systems with the interplay of these different systems and the complexities of the joints making them high risk of developing pathology. Dysfunction of the TMJ, the muscles of mastication and/or the surrounding structures are grouped into a common condition, known as temporomandibular disorders (TMD) (Pelicioli et al., 2017).

The prevalence of TMD is high, with an estimated 40-75% of the general population having one sign of TMD and 33% having one symptom. Furthermore, these disorders

have an impact on the body beyond the masticatory system alone. This includes negative effects on breathing and swallowing as well as changes in other areas such as the cervical, thoracic and lumbar spine which ultimately impact the upper and lower limbs (Craciun et al., 2022).

As TMD is a common health seeking disorder it entails a high cost for patients. Physiotherapy emerges as the most sought-after treatment and often requires at least 10 sessions for treating TMD (Craciun et al., 2022). One study found that of 163 participants with TMD, 62.9% reported receiving treatment, with half opting for physiotherapy. Furthermore, the majority of these participants reported receiving physiotherapy alone, followed by physiotherapy in combination with other therapies. Despite the high treatment rate, 38.7% of participants still had severe TMD, 42.5% had moderate TMD, and only 15.6% had mild TMD (Weinberg, Olivier and Kunene, 2023).

Physiotherapy aims to decrease pain and improve ROM and muscle tightness in the cervical spine and TMJ. This includes joint mobilisations and manipulations as well as myofascial release, trigger point and specific soft tissue mobilisations of both the cervical spine and TMJ (Craciun et al., 2022). However, no study has examined the effectiveness of treating the shoulder girdle in these patients despite the findings of changes in the TMJ influencing the muscular activity, endurance, peak torque and pain in the shoulder (Bae 2014; Ceneviz et al., 2016; Dias et al., 2019; von Piekartz and Ruinemans, 2017).

Currently, the clinical assessment of the TMJ commonly includes the cervical spine (Minervini et al., 2023), with still no existing consensus on the best practice treatment for participants with TMD (Pelicioli et al., 2017). No assessment framework on the evaluation of the shoulder girdle in participants with TMD exists and the lack of clarity on the best treatment for TMD and the persistence of symptoms even after physiotherapy highlight the need for further exploration and the development of an assessment framework of the shoulder girdle in participants with TMD.

This study aimed to establish an assessment framework of the shoulder girdle in participants with TMD through consensus from international experts using the Delphi method.

METHODOLOGY

Ethical clearance was obtained from the University of the Witwatersrand Human Research Ethics (Medical) Committee (M2111110). The Delphi technique was chosen as it is a commonly used procedure to collect a group of experts' opinions and ideas on a specific topic through a varying number of rounds (Jünger et al., 2017).

This study consisted of two rounds to achieve a consensus on the content of an assessment framework of the shoulder girdle in participants with TMD. The study took place from November 2023 to January 2024. Data was collected using Research Electronic Data Capture (REDCap), an online tool used to collect and capture information (Patridge and Bardyn, 2018). No identifying questions were asked and only information on participants' age, gender, work environment, and years of work experience was included in the survey. The planning and execution of the study were done based on the Guidance on Conducting and Reporting Delphi Studies (CREDES) (Jünger et al., 2017).

The initial consensus threshold for the inclusion of statements in the overall assessment framework was set at 70%. Statements that did not reach this consensus in the first round, were modified and included in the second round, to gain consensus from the panellists on their opinion on including them in the overall assessment framework. However, results from the first round showed that the statements included, which were based on conclusive findings from the literature, did not reach the 70% level of consensus. This was potentially due to a lack of research on the topic or bias based on their own assessments in clinical practice. Therefore, the consensus for the second round was modified to 60% to ensure that a comprehensive framework assessment was compiled which is both evidence-based, and considers the experts' opinions. Previous TMD related Delphi studies also used a 60% consensus level as their threshold for consensus, further providing support for the use of this level in the current study (von Piekartz et al., 2019).

The statements in the study were designed based on the current literature and findings from the first three studies of this thesis. These were pilot tested among three physiotherapists holding doctorate degrees in neuromusculoskeletal physiotherapy. Each member of the panel was sent an email with an invitation to participate in the study and a link to the survey on the REDCap server.

The landing page included an information sheet which explained the purpose of the study and provided an explanation for each statement. This was followed by an instruction to rate the importance of including each statement in the assessment framework, according to the five-point Likert scale, ranging from 0 to 4 (4 = strongly agree, 3 = agree, 2 = disagree, 1 = strongly disagree and 0 = neutral). Finally, there was a box for panellists to give suggestions and comments.

Participants

When choosing participants, it was found that the most common criteria among studies were the representation of a specific profession, followed by a specific work environment and, lastly, relevant academic achievements (Jünger et al., 2017). In the current study, the criteria used were physiotherapists locally or internationally with more than five years of experience working in the field of the TMJ. The reason for only choosing physiotherapists was that they are the most experienced in treating both the TMJ and shoulder girdle and therefore are equipped to provide the best insight into the framework. They were identified by the primary author through their publications in this field. Furthermore, snowball sampling also took place whereby panellists who agreed to be a part of the study were asked to suggest other physiotherapists who were then contacted and invited to participate.

Number of rounds

In a systematic review that aimed to develop guidelines for the reporting of Delphi studies in palliative care, it was found that among the 30 articles included the number of rounds varied from one to five. The most common amount was two rounds in 14 studies, followed by three rounds in eight.

In terms of duration, most of the studies did not report on the time frames of the surveys, but of the seven that did, the time frames varied between seven days to seven weeks (Jünger et al., 2017). Our study consisted of two rounds which were open for three weeks each. A reminder was sent to each participant in the middle of each round to encourage higher levels of participation.

RESULTS

Round 1

The eleven statements in round one were sent to 20 international experts and one local expert (Table 1).

Table 1. Statements included in Round 1 of the Delphi study

Subjective examination of the shoulder girdle: 1. Presence of current pain in the shoulder girdle 2. Presence of other symptoms of the shoulder girdle 3. Presence of a previous injury of the shoulder girdle 4. Presence of previous treatment of the shoulder girdle 5. Scores of shoulder pain and disability according to the SPADI
Objective examination of the shoulder girdle: 1. Postural evaluation of shoulder elevation 2. A visual assessment of SHR during active shoulder flexion and abduction bilaterally 3. Muscle strength testing of biceps, middle trapezius, inferior trapezius and deltoid, serratus anterior and infraspinatus muscles bilaterally 4. Assess the presence of the clenching and the position of the jaw during shoulder strength testing 5. Muscle length testing of SCM and upper trapezius 6. Evaluate the presence and the area of referral of trigger points in the SCM, upper and middle fibres of trapezius

SCM, sternocleidomastoid; SHR, scapulohumeral rhythm; SPADI, Shoulder Pain and Disability Index

Of the 21 experts invited to participate, 11 (52%) responded. Of the respondents, one was local and the remaining ten were international. The mean age of the respondents was 53.41 years (SD = 13.12) and consisted of six males (54.5%) and five females (45.5%). Most participants (n = 10, 91%) reported having more than 16 years of work experience, with only one participant reporting between 10-15 years. With regards to the work environment, there was diversity among the panellists, with two participants (19%) working in outpatients only, three (27%) in academics only, three (27%) in a combination of outpatients and academics and three (27%) in the combination of outpatients, academics and hospital.

After the first round, three of the 11 statements reached 70% consensus and were excluded for Round 2. The full results for each statement can be found in Table 2.

Table 2. Results of the statements in Round 1 of the Delphi study

Questions on the shoulder	STRONGLY AGREE (5)	AGREE (4)	NEUTRAL (3)	DISAGREE (2)	STRONGLY DISAGREE (1)
Subjective:					
1. Pain	6	4	1	0	0
2. Other symptoms	2	7	2	0	0
3. Previous injury	1	3	4	3	0
4. Previous treatment	0	5	2	2	2
5. SPADI	1	4	2	2	2

Objective:					
1. Elevation	0	4	5	2	0
2. SHR	1	5	4	0	1
3. Strength testing	2	3	6	0	0
4. Clenching/jaw position during strength testing	3	4	3	1	0
5. Muscle length testing	4	3	1	3	0
6. Trigger points	6	2	2	1	0

SHR, scapulohumeral rhythm; SPADI, Shoulder Pain and Disability Index

Round two

Round two included 11 statements, eight from round one that did not reach 70% consensus and three that were added based on comments and suggestions from the panellists. The eight statements included from round one were modified to be clearer, or changed according to the suggestions from the panellists. The full list of statements sent to panellists is shown in Table 3.

Table 3. Statements included in round two of the Delphi study

Subjective examination of the shoulder girdle: 1. A previous injury of the shoulder girdle and if it correlated with the timing of the onset/worsening of TMD symptoms 2. A previous injury of the shoulder girdle and if it was the same side as the current symptoms of the TMD 3. Previous surgery of the shoulder girdle and if that related to the onset/worsening of TMD symptoms 4. A standardised measurement of shoulder pain using the NRS 5. A standardised measurement of shoulder pain and disability using the SPADI
Objective examination of the shoulder girdle: 1. Evaluation of the presence of shoulder elevation and if it correlates to the side of TMD symptoms 2. Observation of SHR during shoulder flexion and if the pattern relates to the mandibular deviation on that side 3. An objective evaluation of SHR according to the SDT and determining if there is an improvement of the score with an improvement of symptoms of TMD 4. Manual strength testing of biceps, deltoid and rotator cuff muscles 5. Observation if the patient is clenching during shoulder strength testing and when corrected to a relaxed jaw position, if there is a change in the shoulder muscle strength 6. Muscle length testing of SCM and upper trapezius

NRS, Numerical Rating Scale; SCM, sternocleidomastoid; SDT, Scapular Dyskinesis Test; SHR, scapulohumeral rhythm; SPADI, Shoulder Pain and Disability Index; TMD, temporomandibular disorders

Of the 21 experts invited to participate in round two, nine (43%) responded. One was local and eight were international. The mean age of the respondents was 52.56 years (SD = 9.44) and included five males (55.5%) and four females (44.5%). The majority of

participants (n = 8, 89%) reported having more than 16 years of work experience, with only one participant having between 10-15 years. With regard to work environment, two participants (22%) worked in outpatients only, three (33%) in academics only, three (33%) in the combination of outpatients and academics and one participant was retired. After round two, six of the 11 statements reached 60%, consensus with the full results for each statement shown in Table 4.

Table 4. Results of the statements in Delphi round two

Questions on the shoulder	STRONGLY AGREE (5)	AGREE (4)	NEUTRAL (3)	DISAGREE (2)	STRONGLY DISAGREE (1)
Subjective:					
1. Previous injury timing	1	6	1	1	0
2. Previous injury side	1	3	2	3	0
3. Previous surgery	1	3	3	1	1
4. NRS	6	2	1	0	0
5. SPADI	1	7	1	0	0
Objective:					
1. Elevation	1	4	3	1	0
2. SHR	3	2	4	0	0
3. SDT	1	3	3	2	0
4. Strength testing	5	1	2	1	0
5. Clenching during strength testing	2	7	0	0	0
6. Muscle length testing	2	4	1	2	0

NRS, Numerical Rating Scale; SDT, Scapular Dyskinesis Test; SHR, scapulohumeral rhythm; SPADI, Shoulder Pain and Disability Index

Of the subjective examination, the majority of participants (> 70%) agreed in the first round to the inclusion of the presence of pain and other symptoms of the shoulder. A suggestion was given by a panellist to add in a standard outcome measure for the shoulder pain, which was implemented in the second round. The use of the Numerical Rating Scale in measuring shoulder pain received consensus and was also included.

After not receiving consensus in round one, the question on the presence of a previous injury of the shoulder girdle was modified to add if it related to the onset/worsening of the symptoms of TMD. This gained consensus among the experts and was included in the final framework.

Table 5 shows the statements included in the final framework after both rounds of the Delphi study. This table illustrates the final assessment framework of the shoulder girdle in patients with TMD.

Table 5. Statements included in the final assessment framework of the shoulder girdle in participants with TMD

Subjective examination of the shoulder girdle: 1. Presence of current pain in the shoulder girdle 2. Measuring current pain in the shoulder girdle using the NRS 3. Presence of other symptoms in the shoulder girdle 4. A previous injury of the shoulder girdle and if it correlated with the timing of the onset/worsening of TMD symptoms 5. A standardised measurement of shoulder pain and disability using the SPADI
Objective examination of the shoulder girdle: 1. Evaluation of the presence and the area of referral of trigger points in the SCM, upper and middle fibres of trapezius 2. Muscle length testing of SCM and upper trapezius 3. Muscle strength testing of the biceps, deltoid and rotator cuff 4. Presence of clenching during the muscle strength testing and when corrected to a rested position, if there is a change in the muscle strength of the shoulder Suggested addition: 1. Evaluation of the presence of shoulder elevation and if it relates to the same side as the TMD symptoms.

NRS, Numerical Rating Scale; SCM, sternocleidomastoid; SPADI, Shoulder Pain and Disability Index; TMD, temporomandibular disorders

DISCUSSION

Due to the emerging evidence of the connections between the TMJ and shoulder girdle and high prevalence of TMD, it is worth developing an assessment framework of the shoulder girdle in patients with TMD. This was done through a two round Delphi study, which included an overall of 20 replies from panellists on their opinion on the importance of each statement in this assessment framework. After the completion of both rounds, there was consensus on four statements in the subjective examination and five in the objective assessment.

The relevance of including the presence of shoulder pain is shown in the findings of two studies. One found that more than double of participants in the TMD group received previous treatment of the shoulder (n = 11, 61%) and had shoulder pain (n = 13, 72%) compared to the non-TMD group (n = 5, 28%) (Weinberg, Olivier and Kunene, 2024). Another finding was that more than half of the 186 participants with TMD had shoulder pain (n = 104, 56%) (Weinberg, Olivier and Kunene, 2023). Similarly, a retrospective study

examining body charts of participants with TMD showed a prevalence of shoulder girdle pain in 33% of participants on the left and 35% on the right (Correira et al., 2015).

Only in the second round was a consensus gained on including the Shoulder Pain and Disability Index (SPADI) in this population. This is an important tool as both studies that investigated if there was a relationship between shoulder pain and disability with the level of severity and disability of the TMJ, found significant correlations (Weinberg, Olivier and Kunene, 2023a, 2024b). The potential reason for panellists only agreeing to include this tool in the second round is the limited evidence available on the connections between the jaw and shoulder disability.

Similarly, panellists disagreed with the inclusion of questioning whether patients had previous shoulder surgery even after this question was modified in the second round to be more specific asking if it related to the onset of their TMD. No study has shown a link between previous shoulder surgery and the onset/worsening of TMD, with only 2.6% of 186 participants with TMD reporting having had shoulder surgery (Weinberg, Olivier and Kunene, 2023). However, more studies are needed to see if there is a potential relationship.

Of the objective examination questions, the only statement that was included after the first round was an assessment of the presence and referral of trigger points from the sternocleidomastoid (SCM), middle and upper fibres of trapezius. The importance of the inclusion of this statement is the finding of significantly higher amounts of trigger points in the SCM and upper trapezius in those with TMD compared to those without. Furthermore, the most common areas of referral of these trigger points were the temples, which elicited participants' TMD related pain (Fernandez-des-las-Penas et al., 2010). Similarly to these findings, in those with TMD a significantly higher amount of trigger points were found in the SCM and trapezius on the side of disc displacement compared to the opposite side (Inoue et al., 2010).

Muscle length testing of the SCM and trapezius was included after the second round, with the research showing that both the SCM and upper trapezius have a higher activity at rest in participants with TMD. This leads to higher tension and decreased flexibility, with one study showing how stretching the upper trapezius improved the symmetry of force in those with asymmetric bite forces. This shows the impact of tightness of the trapezius on the

masticatory system (Sojka et al., 2017). Similarly, treatment of trigger points in the SCM, which cause tightness in a muscle, led to an improvement in ROM of mouth opening (Bae, 2014), showing the effects of muscle length of the SCM on the TMJ.

The next statement included after the second round was strength testing of the biceps, deltoid and rotator cuff muscles, all of which showed changes with alterations in occlusion (Dias et al., 2019) and during clenching (Alghadir et al., 2018). This was further supported by findings of a lower muscle activity of the biceps, medial deltoid, infraspinatus, inferior trapezius and serratus during weighted shoulder abduction and flexion in participants with TMD compared to those without (Weinberg, Olivier and Kunene, 2024).

This was followed through by the inclusion of assessing the presence of clenching during shoulder muscle strength testing. This statement was supported by the findings of the ergogenic effects of clenching on upper limb strength, which has been shown with higher maximum voluntary contraction of the shoulder extensors and flexors during clenching compared to without (Alghadir et al., 2018; Venegas et al., 2009).

An evaluation of the presence of shoulder elevation in those with TMD did not reach consensus to be included in the assessment framework but was added as a suggestion in the final framework. This was done because the research is conclusive and consistent in its findings of a higher prevalence of shoulder elevation in those with TMD compared to those without (Cox and Klein, 2013; Chaves, de Oliviera and Damazio, 2017; Munhoz and Marquez, 2009). The literature has also been consistent in that there is a higher resting activity of the upper trapezius in those with TMD, and this increase in tension is also responsible for higher levels of shoulder elevation (Sojka et al., 2018).

The statements that were not included in the objective assessment of the final framework were relating to the scapulohumeral rhythm (SHR) and the use of the Scapular Dyskinesis Test (SDT) to evaluate the dyskinesia. According to the researcher’s knowledge, no studies have examined the differences in SHR in those with and without TMD and how SHR may relate to the TMJ. Therefore, in both rounds, the inclusion of assessing SHR and whether it relates to the presence of mandibular deviation, and the use of the SDT to assess SHR did not receive consensus.

Even more so, it received the lowest scores in the second round of the Delphi study. This is in agreement with the findings of Weinberg, Olivier and Kunene (2024), who found no significant differences between the SDT scores in those with and without TMD. However, this statement was still included in the Delphi study due to the same study finding differences in muscle activity of the lower trapezius and serratus anterior in those with and without TMD, therefore showing the potential for changes in the SHR (Weinberg, Olivier and Kunene, 2023).

Overall, an assessment framework was developed which can be used as more research on the impairments of the shoulder girdle in participants with TMD emerges.

STRENGTHS AND LIMITATIONS

Despite the information sheet including references and explanations of statements that experts may have been less familiar with, a trend seemed to be the exclusion of statements that had less research supporting its inclusion. Another limitation could have been bias from the explanations and references of the included statements.

The strength of the study was that it was the first of its kind to gain consensus on an assessment framework of the shoulder girdle in the population of those with TMD, which added value to the direction of future research.

CONCLUSION

The statements included in the framework represent international physiotherapy experts' opinions on the role the shoulder girdle plays in participants with TMD. The final framework includes five subjective questions on the presence and history of shoulder pain, other symptoms and previous injuries as well as a standardised shoulder pain and disability questionnaire. Furthermore, it includes four objective tests of trigger points, muscle length and strength as well as assessing the presence of clenching during these tests.

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CHAPTER 7

7. DISCUSSION

7.1 INTRODUCTION TO THE DISCUSSION

The pathophysiology of TMD is based on the biopsychosocial approach with research available on the psychological and social impacts related to TMD. This thesis focused on all three aspects with the biological factors relating to the impairments of the shoulder girdle in participants with TMD and the psychosocial relating to disability of both areas. Chapter 7 is a synthesis of the work done (Chapters 3-6) in light of the literature available (Chapter 2). Four original papers were presented in this thesis. The first study (Chapter 3) was a scoping review to identify what is currently known, as well as the gaps in the literature on the connections between the TMJ and shoulder girdle. The findings were 41 articles between 2000 and 2023 with a focus on the anatomical, neuromuscular and neurophysiological connections between the two areas. This provided a guide for the content and direction of the next three studies.

The second study aimed to determine the associations between disability, dysfunction, and pain in participants with TMD. The main findings were significant, positive correlations between the level of TMD and shoulder pain at its worst, as well as shoulder pain and disability scores according to the SPADI questionnaire. The main objective of the third study was to determine if there were differences in the activity of five shoulder girdle muscles at rest, during active and resisted jaw movements, and weighted shoulder flexion and abduction in those with and without TMD. The results showed that the majority of the muscles had lower activity in those with TMD compared to those without. The fourth study, a Delphi study, established consensus on an assessment framework of the shoulder girdle in participants with TMD, using the results from the first three studies and the literature relating to the topic.

This overall discussion brings the cervical spine into the context of the relationship between the TMJ and shoulder girdle, as part of the author’s inspiration for this thesis was further exploring and understanding the triangle of the jaw, neck, and shoulder. Secondly, due to most of the research being focused on the role of the

cervical spine in TMD, it provides a point of reference for the connections between the TMJ and shoulder.

7.2 RELATIONSHIPS BETWEEN THE TMJ AND SHOULDER GIRDLE WITH THE CERVICAL SPINE

The relationships between the TMJ and cervical spine and cervical spine and shoulder girdle have been well established, with systematic reviews available on both connections (Chisari et al., 2022; Kastuura et al., 2020). Both reviews demonstrated a variety of types of connections and overlapping symptoms between the corresponding areas.

Both the cervical spine and shoulder girdle and TMJ and cervical spine have shown strong anatomical relations with shared muscular attachments and neural pathways. The brachial plexus travels through the intervertebral foramina of the cervical spine into the axilla of the shoulder girdle (Jull et al., 2008). Similarly, the TMJ and cervical spine have a neuroanatomical relation, which is the convergence of the afferent fibres of the upper cervical nerve roots with the trigeminal nerve (Chisari et al., 2022).

A further systematic review was done on the postural connections between the TMJ and cervical spine, with findings showing that a forward head posture is more common in participants with TMD, resulting in shortened cervical extensor and SCM muscles. This posture causes a change in the centre of gravity, resulting in changes in the spinal curvatures influencing the length and function of the axio-scapular muscles (Minervini et al., 2023). This highlights a postural connection between the three areas.

Similar results were seen in a randomised controlled trial where participants with TMD, who wore occlusal splints, had significant improvements in their thoracic kyphosis and lumbar lordosis curvatures compared to those who did not wear splints. Changes in the thoracic curvature specifically will influence the function of the shoulder girdle (De Giorgi et al., 2020).

Therefore, there are anatomical, neuroanatomical, and postural connections between the TMJ, cervical spine and shoulder girdle.

7.3 MAIN CONNECTIONS BETWEEN THE TMJ AND SHOULDER GIRDLE

The first study of the thesis (Chapter 3) was a scoping review that found three main types of connections between the TMJ and shoulder girdle, namely anatomical, neuromuscular, and neurophysiological. The main muscles that had been investigated as the connections between the two areas were the hyoid, SCM, and trapezius, with limited research done on the biceps, deltoid, infraspinatus, levator scapula, pectoralis major, and triceps muscles.

The anatomical connections included direct links between the origins and insertions of SCM and the suprahyoid and infrahyoid muscles (Auvenshine and Pettit, 2020; Bordoni and Varacallo, 2018). The second component of the anatomical connections was myofascial. This included a higher prevalence of trigger points in the muscles of the shoulder girdle in participants with TMD compared to those without. Furthermore, the trigger points had larger areas of referral and referral patterns in the areas commonly affected by patients with TMD (Fernández-de-las-Peñas et al., 2010).

Of the three different types of connection, the neuromuscular was the most researched. The findings consistently showed the concomitant activity of the shoulder girdle muscles during jaw movements, specifically the SCM and trapezius (Haggman-Henrikson, Nordh and Eriksson, 2013; Hellmann et al., 2012.). The factors found to influence the length of activation, patterns and levels of shoulder girdle muscle recruitment were the presence of symptoms of TMD, type of jaw activity and type of shoulder girdle muscle (Helgadottir et al., 2011b; Hellman et al., 2012).

The neuromuscular effects of occlusal splints and occlusion were also seen in the improvements in endurance, peak torque and strength of the shoulder, highlighting the influences of alignment and stability of the TMJ on the shoulder (Dias et al., 2019; Ferrario et al., 2001). Finally, the third component of this category of connection was postural changes. A higher prevalence of shoulder elevation was

found in participants with TMD compared to those without (Chaves, de Oliviera and Damazio, 2017).

The third study examined the concomitant activity of the biceps, medial deltoid, infraspinatus, inferior trapezius and serratus anterior during jaw movements as well as the activity at rest in participants with and without TMD (Chapter 7.7). This was done to compare if, similarly to the SCM and upper trapezius, these shoulder girdle muscles had a higher activity in participants with TMD and if they were recruited in more strenuous tasks of the jaw such as resisted opening and laterotrusion.

The main findings of the first study on the neurophysiological relationship between the two areas were through the cervico-trigeminal and trigemino-cervical reflexes, explaining referred pain between the areas. More details will be described under the topic of shoulder pain (Chapter 7.4).

7.4 SHOULDER PAIN

One study examined the prevalence of headaches and shoulder pain in 120 patients undergoing orthodontic treatment. The results showed that 21.7% of participants (n = 26) had headaches/shoulder pain but did not differentiate the two, nor was it specific to the TMD population (Ohmori et al., 2022). However, it did highlight the need to understand the phenomenon of referred pain between the two areas.

The overlap between pain in the cervical spine and shoulder (Kastuura et al., 2020) and TMJ and cervical spine (Häggman-Henrikson, Wiesinger and Wänman, 2018) are well understood. The reason for referred pain between the cervical spine and the shoulder is the synapsing of their nerve signals onto the same second-order neurons. This occurs as the nerve supplying the shoulder is the brachial plexus, which is formed from the cervical nerve roots. The overlap of pain between the TMJ and cervical spine is through the convergence of the first three cervical nerve roots with the trigeminal nerve (Chisari et al., 2022).

The cervical plexus provides motor innervation to three of the infrahyoid muscles: the sternohyoid, sternothyroid and omohyoid. It also provides sensory innervation to the clavicle, deltoid and trapezius (Waxenbaum, Reddy and Bordoni, 2023).

Therefore, the hypothesis for the potential overlap of pain between the TMJ and shoulder girdle is that because the trigeminal nerve converges with the upper cervical nerve roots, and these roots form part of the innervation to the abovementioned shoulder girdle muscles, there may be an overlap of pain signals. According to the author's knowledge, this was the first study to examine the prevalence of shoulder pain in participants with TMD and get closer to understanding if there is an overlap.

It had been previously reported that patients with chronic spinal pain had a seven times risk of developing pain in the jaw and a five times risk of having signs of TMD. A similar reciprocal relationship was shown in another study of 266 participants, with an increase in the prevalence of spinal pain as the frequency and severity of TMD symptoms rose. This was seen as there was the lowest prevalence of spinal pain in participants without TMD (30%) compared to 52% in those with infrequent TMD, 57% in participants with mild TMD and 68% in those with severe TMD (Wiesenger et al., 2009).

This prevalence of spinal pain in participants with mild and infrequent TMD was similar to the results of the second study in the thesis, which found a prevalence of shoulder pain in 55.9% (n = 104) of participants with TMD. However, the severity of the TMD in these participants was most commonly moderate (42.5%) or severe TMD (38.7%). This highlights that shoulder pain is more common in participants with worse TMD compared to spinal pain. Furthermore, despite no significant correlation being found between the presence of pain in the shoulder and the level of TMD, a positive significant correlation was found between shoulder pain at its worst and the level of TMD.

Similarly, the third study of this thesis found that double of the participants in the TMD group had shoulder pain (n = 13, 72%) compared to the non-TMD group (n = 5, 28%). The results also showed a significant positive correlation between the presence of pain in the shoulder and pain in the TMJ, further supporting the findings of a relationship between the overlap of pain in the TMJ and shoulder girdle.

7.5 SHOULDER DISABILITY

Significant relationships between disability of both the neck and shoulder and the neck and TMJ have been found, with no previous studies on the relationship between TMJ and shoulder disability (Koller et al., 2021; Silveira et al., 2015). One study even showed that participants with high levels of TMD disability had up to a 19-point increase on the Neck Disability Index (Silveira et al., 2015), with both showing a strong interdependence between the disabilities of the corresponding areas, emphasising the importance of evaluating the disability of each region in the respective conditions (Koller et al., 2021).

Higher levels of disability in chronic pain conditions are associated with worsened levels of QoL, depression and levels of pain. This has been shown in participants with TMD and shoulder pain. In participants with acute and chronic TMD, higher levels of depression and somatisation levels were seen in those with higher levels of disability (Dworkin, 2011). The impact of shoulder disability on patients' QoL has also been shown with positive significant correlations between anxiety, depression, quality of sleep and SPADI pain and disability scores (Hwang and Oh, 2022). To the author's knowledge, this is the first study of its kind to explore the correlation between disability of these two conditions.

Both the second (Chapter 4) and third (Chapter 5) studies found a significant positive correlation between SPADI pain, disability total scores and the level of TMD on the FAI. Furthermore, the third study found a positive significant correlation between SPADI pain, disability and total scores with TMD disability according to the STMDI. These results are significant in showing how pain and disability of the shoulder relate to the level of severity of TMD and the associated disability.

7.6 SCAPULAR DYSKINESIA

Scapular dyskinesia describes a combination of dysfunction in the movement and function of the scapula. It consists of two components: changes in the resting position of the scapula and abnormalities in its movement. The most common reasons for these changes are altered activity of the inferior trapezius and serratus anterior, the two main scapular stabilisers. Other causes include alterations in the elasticity and strength of other shoulder girdle muscles (Helgadottir et al., 2011b).

The studies on the role of scapular dyskinesia in shoulder girdle pathology are inconsistent in their findings. However, its connection to chronic neck pain has been established, with these participants having significantly worse scapular dyskinesia scores, according to the SDT, compared to those without (Karaagaç, Aydogan and Keskin, 2023). Similar results were found in a study of 99 office workers who had either neck/shoulder pain. There were significant differences in the presence of scapular dyskinesia on the painful and non-painful sides, with 91% of these participants presenting with scapular dyskinesia (Vongsirinavarat et al., 2023). This led to the question of the prevalence of scapular dyskinesia in participants with TMD and whether there was a difference in SDT scores between those with and without TMD. Therefore, part of the third study included an assessment of SHR using the SDT.

The findings differed from those of the two abovementioned studies on participants with neck pain in that there was no significant difference between the SDT scores of those with and without TMD. The reason for this may be that the one study included participants with chronic neck pain only with a control group that consisted mainly of males (Karaagaç, Aydogan and Keskin, 2023), whereas the current study included participants with TMD symptoms in the last 30 days, therefore more acute and similar number of females in both groups.

The study of office workers included participants with neck and/or shoulder pain and, therefore, does not differentiate between those with and without shoulder pain. The other difference was all the participants had the same occupation, which is linked to increased thoracic kyphosis and forward head posture (Vongsirinavarat et al., 2023) compared to the current study, where less than a quarter of participants with TMD had office jobs.

The differences in chronicity, gender and work-related activities of pain between the studies show that scapular dyskinesia may be more prevalent in chronic musculoskeletal conditions compared to acute and gender may also play a role. This indicates that more research is needed on the presence of scapular dyskinesia in participants with chronic TMD, with and without neck/shoulder pain, in both genders and the effects of work-related activities.

7.7 SHOULDER GIRDLE MUSCLE ACTIVITY

The literature has consistently shown that the resting activity of SCM and upper trapezius is higher in those with TMD compared to those without (Pallegama et al., 2004). Similarly, the findings showed an increase in the activity of SCM and trapezius during clenching, chewing, and grinding. The phenomenon behind the increase in activity of these muscles is to provide greater stability of the head to allow adequate movement of the mandible by the muscles of mastication (Giannakopoulos, Schindler and Hellmann, 2018; Häggman-Henrikson, Nordh and Eriksson, 2013; Rodriguez et al., 2011).

Furthermore, the scapulothoracic muscles are important in transferring load between the upper limbs and spine and changes in their activity and recruitment patterns have been linked to neck pain. The results of a randomised controlled trial showed that the combination of neck strengthening and scapular stabilising exercises resulted in a significant improvement in forward head angle, scapula downward rotation index and neck ROM compared to neck exercises alone (Javdaneh et al., 2021). This connection between the scapulothoracic muscles and the cervical spine highlighted the need to understand further how these muscles influence the TMJ, apart from the SCM and trapezius.

This led to the formation of the third study to examine if more muscles, distally, are being recruited to provide stability proximally at the TMJ. The testing of muscle activity of the anterior (biceps), medial (medial deltoid) and posterior shoulder girdle (infraspinatus) was included in the objective examination. Furthermore, the changes in scapular positioning and movements in participants with neck pain led to the inclusion of testing the muscle activity of the two main shoulder girdle stabilisers, inferior trapezius and serratus anterior, to determine if they had differences in those with and without TMD.

7.7.1 Inferior Trapezius

The inferior trapezius, together with the serratus anterior are the two main stabilisers of the scapula. The activity of the inferior trapezius in participants with and without neck pain is conflicting. One study found a significantly lower strength of the inferior trapezius in those with chronic neck pain compared to the control group (Karaagaç, Aydogan and Keskin, 2023). On the contrary, another study found

significantly higher levels of activity of the inferior trapezius in participants with chronic neck pain with visible scapular dyskinesia during shoulder abduction and not during shoulder flexion (Zakharova-Luneva et al., 2012).

This is also in contrast to another study that included participants with insidious onset of neck pain and whiplash-associated disorders and found no differences in recruitment patterns in terms of onset and length of activation in any of the fibres of trapezius in those with and without neck pain (Helgadottir et al., 2011b).
This contrast in the findings of previous research is aligned with the differences seen in the third study. These included a higher activity of the right inferior trapezius and a lower activity of the left inferior trapezius at rest and during jaw movements in participants with TMD which could be related to hand dominance. However, concerning shoulder abduction and flexion, both sides had lower activity in those with TMD, which matches the findings of lower strength in those with cervical pain.

An explanation for the differences in findings may be that another study included participants with scapular dyskinesia, which was not shown to be a common impairment in the third study (Zakharova-Luneva et al., 2012). This shows that the activity of the inferior trapezius in those with TMD is related to the side of hand dominance and may be influenced by the presence of scapular dyskinesia, with more research needed to compare its activity in participants with TMD, with and without scapular dyskinesia.

7.7.2 Serratus Anterior

The changes in serratus anterior activity in those with and without neck pain are also conflicting. One study found the serratus anterior to have significantly lower strength in participants with chronic neck pain than those without pain (Karaagaç, Aydogan and Keskin, 2023). Similarly, changes in recruitment patterns such as delayed onset and shorter length of activation were shown in those with a gradual onset of neck pain and whiplash-associated disorders compared to the control group (Hegladottir et al., 2011b).

Similarly to the inferior trapezius, in the third study, there were differences in activity of the right and left serratus anterior in those with and without TMD. The left serratus anterior had higher activity at rest and during the majority of the jaw

movements in participants with TMD, with the opposite being true for the right side. Even more so, the differences in activity of the right serratus anterior during mouth opening, right laterotrusion and resisted mouth opening were significant between those with and without TMD. This shows that this muscle had even greater discrepancies between the two sides and the influence of hand dominance in those with TMD.

Similarly to all the other shoulder girdle muscles, there was a consistently lower activity during shoulder abduction and flexion in participants with TMD than in those without. These findings show that the activity of the serratus anterior in participants with TMD at rest and during jaw movements is different on both sides but is consistent in its lower activity during weighted shoulder abduction and flexion.

7.7.3 **Biceps**

According to the author's knowledge, only one study has investigated the changes in the biceps' endurance during different positions of the jaw in those with normal occlusion and malocclusion. The findings showed a significantly higher endurance in those with malocclusion compared to normal occlusion, with the exact reasons being unknown. The highest endurance was seen during clenching, and the lowest during right-sided clenching on a cotton ball. This shows the effects of maximal occlusal stability on the biceps and the lowest stability when biting on an unstable surface and how that causes changes in the biceps (Ferrario et al., 2001).

The other study on the biceps found a significantly higher muscle strength of both the shoulder and elbow flexors during clenching compared to a relaxed jaw position, showing how clenching increases the muscle force of the biceps. The physiology behind these changes is through the potentiation of motor neurons through intercortical communication or the spilling over of motor neurons in the different motor cortices or through an increase in activation of the H-reflex. This was shown in other studies where there was an increase in the H reflex in the flexor carpi radialis and soleus muscles during clenching (Alghadhir et al., 2018). All three hypotheses could form the basis for the reasoning for the increase in endurance and strength of the biceps during clenching demonstrated above.

In the third study, the left biceps had higher activity in those with TMD during active left laterotrusion and during resisted jaw movements compared to the right biceps, which had consistently lower activity in those with TMD at rest and during all jaw movements. Both sides had lower activity during shoulder movements in participants with TMD showing the effects of changes in the TMJ on biceps activity. The biceps muscle is a known dynamic stabiliser of the shoulder, with changes in its kinematics significantly influencing the shoulder's stability (Landin, Thompson and Jackson, 2017). Therefore, the effects of the lower activity of biceps in those with TMD may have implications on the stability of the shoulder, thus predisposing this population to developing shoulder injuries.

7.7.4 **Infraspinatus**

A similar phenomenon of a higher strength in distal muscles is shown with increasing occlusal stability through maximising occlusal contact through the use of an occlusal splint. Significant increases in torque during shoulder internal/external rotation and for the muscle involved, the infraspinatus with the use of an occlusal splint compared to a placebo and no splint (Dias et al., 2019).

The right infraspinatus was the muscle that showed the highest number of significant differences in those with and without TMD during four jaw and two shoulder movements. This corroborates with the above findings of the infraspinatus being sensitive to changes in the TMJ. This was seen as maximising stability of the TMJ through the occlusal splint improved the strength of the infraspinatus. It was also supported by the presence of pain in the TMJ leading to a decrease in the infraspinatus activity during jaw and shoulder movements. In addition, the findings show that the infraspinatus is also sensitive to hand dominance, as most of these participants were right-handed. The previous study only tested the shoulder torque on the dominant side, so it did not have a comparison (Dias et al., 2019).

The infraspinatus was the only rotator cuff muscle tested and the effects of TMD on this muscle are clear. More research is needed on the effects of TMD on the other rotator cuff muscles.

7.7.5 **Medial Deltoid**

One study examined the effects of an occlusal splint and placebo splint on muscle activity of the medial deltoid during shoulder abduction/adduction, with findings showing no significant changes in any of the conditions (Dias et al., 2019). This was

in contrast to the effects of an increase in the strength of the deltoid when participants wore an occlusal splint that had incremental increases in thickness (Chakfa et al., 2002). In contrast, another study found a significantly lower maximal isometric contraction force of shoulder abduction during teeth clenching compared to a relaxed position (Sato et al., 2014).

The findings of the effects of clenching and occlusal splints on the deltoid are, therefore, variable, showing the need for further testing. The medial deltoid was the portion of the deltoid tested, as the variances in strength shown were related to abduction, which is primarily achieved through the activity of the medial deltoid. The anterior and posterior portions of the deltoid play a larger role in the stabilisation of the GHJ (Elzanie and Varacallo., 2024).

The activity of the medial deltoid was similar to that of the other muscles tested, with a lower activity at rest and during jaw movements in those with TMD. The exception was the right medial deltoid, which showed higher activity during resisted mouth opening and significantly so during resisted right laterotrusion. This shows the potential role of hand dominance on the activity of the deltoid specifically relating to the resisted jaw movements, thereby providing insight into the stabilising role the medial deltoid may play during tasks that are more strenuous for the jaw in those with TMD.

7.8 DEVELOPMENT OF AN ASSESSMENT FRAMEWORK

The content of the assessment framework was created from the results of the first three studies in this thesis. The findings from the scoping review provided guidance on the missing gaps in the literature and the need for an assessment framework in participants with TMD. Both the second and third studies found a high prevalence of shoulder pain and previous treatment of the shoulder in those with TMD, with a much lower number of participants reporting clicking/popping and previous shoulder injuries.

All four of these components were included in the framework as one study does not exclude the possibility of an association between previous shoulder injuries and TMD nor between other shoulder symptoms and onset/worsening of TMD. Both studies were conclusive on the relationships between SPADI scores with the FAI

and STMDI scores, therefore, the SPADI questionnaire was also included in the subjective component of the assessment framework.

Some of the statements included in the objective examination were based purely on findings from the first study, as the third study did not include all the different aspects of the shoulder girdle. This included a postural evaluation of shoulder elevation as the results were consistent with findings of higher levels of elevated shoulders in those with TMD. Further statements from the first study measured muscle length and the presence and referral of trigger points in the SCM and trapezius muscles. The literature showed higher activity at rest and prevalence of trigger points of the SCM in those with TMD compared to those without.

Furthermore, the ergogenic effects of clenching on shoulder power and strength that have been previously shown were the reasons for the inclusion of a statement on assessing the presence of clenching during the shoulder strength testing. The recruitment of the TMJ during shoulder exercises could contribute to the overuse of the masticatory muscles and, therefore, the development of TMD. The two components that were included in the findings of the third study were the muscle strength testing of the shoulder girdle muscles examined and the visual assessment of the SHR.

7.9 CONSENSUS ON THE ASSESSMENT FRAMEWORK

In Chapter 6, I used the Delphi method to establish international consensus on the contents of an assessment framework of the shoulder girdle in participants with TMD. Given the challenges in mental and physical aspects that patients with TMD go through, it is essential to perform a thorough assessment of all the areas that contribute to the pathology.

It was clear from the responses of the panellists in the first round that there was potential bias in the statements depending on their clinical assessments and the lack of studies on specific topics. An example of this was the inclusion of SPADI in the assessment framework. After the first round, consensus was not reached on its conclusion, and only after the second round, dropping the level of threshold of consensus needed, was it included in the assessment framework. The relevance of

SPADI in this population was shown in both studies three and four but no previous study had been done to show its importance.

One statement that did not reach consensus after both rounds but was consistently shown in the literature is the presence of shoulder elevation in those with TMD. This was included as a suggestion in the final assessment framework as although it was not included in the third study, the findings of higher activity of upper trapezius at rest and higher levels of shoulder elevation relating to the same side of TMD pathology have been shown.

Therefore, the final framework did reflect assessment tools that were shown to be important in both the literature and the second and third studies, with more research needed on other aspects of the shoulder girdle and further expansion of the framework.

7.10 CONCLUSION TO THE DISCUSSION

The discussion emphasised the extensive research available on the connections between the TMJ and cervical spine and cervical spine and shoulder girdle while highlighting the research that has been done on the connections between the TMJ and shoulder girdle in this thesis as well as in the existing body of literature. A conclusion to this thesis, its significance, future research recommendations and clinical recommendations are shown in Chapter 8.

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CHAPTER 8

8.1 CONCLUSIONS

The high prevalence of TMD, its impact on QoL and the lack of consensus on treatment highlighted the need for a deeper understanding and better management of this condition. The main focus of managing these patients with TMD is through treatment of the cervical spine and TMJ. The research has shown clear connections between the TMJ and the cervical spine, with emerging studies on their relationships with the shoulder girdle.

There are anatomical, neuromuscular and neurophysiological connections between the TMJ and shoulder girdle. Furthermore, it has now been established that there are associations between disability, dysfunction and pain of the TMJ and shoulder girdle, which needs more investigations whether it is due to or via the cervical spine. There are also differences in muscle activity of the shoulder girdle muscles in those with and without TMD, with the majority of muscles having a lower activity at rest, during active and resisted jaw movements and weighted shoulder flexion and abduction.

The objective of study one was to map out the literature on the anatomical, neuromuscular and neurophysiological connections between the TMJ and shoulder girdle. This was achieved through a scoping review, which showed these connections, with the majority of the literature focusing on the neuromuscular relations between the two areas. The most commonly included muscles across the literature were the hyoid, trapezius and SCM muscles. Differences in activity of the shoulder girdle muscles were clearly shown during clenching and with the use of occlusal splints compared to a resting jaw position and placebo or no splints. This was the first study to review the existing literature on the connections between the TMJ and shoulder girdle and provided an overall view of the different types of connections and the future research needed on more muscle groups in different types of populations.

The objective of the study two was to determine the association between the disability, dysfunction and pain of the TMJ shoulder girdle in participants with TMD. In addition, to estimate the prevalence of disability, dysfunction and pain in the shoulder girdle in participants with TMD. Through a cross-sectional study of 186

participants with TMD, a positive correlation was found between the level of TMD and the level of pain and disability of the shoulder, as well as shoulder pain at its worst. Furthermore, more than half of the participants reported shoulder pain and just less than half had previous shoulder treatment. This was the first study of its kind to examine the prevalence of shoulder pain alone in participants with TMD and the first to explore the relationship between the level of TMD and shoulder pain and disability. The presence of associations between the TMJ and shoulder girdle provides insight into the connections between these two areas.

The third study aimed to compare the activity of the shoulder girdle muscles in participants with and without TMD. Furthermore, to determine if there were correlations between pain and disability of the TMJ and shoulder girdle. The main findings were that the majority of the shoulder girdle muscles tested had lower activity in participants with TMD at rest and during active and resisted jaw movements. The exceptions to this were the right inferior trapezius, medial deltoid and serratus anterior which showed higher activity in participants with TMD. However, in participants with TMD, all the shoulder girdle muscles had lower activity during weighted shoulder flexion and abduction compared to those without.

Furthermore, a significant association was found between shoulder pain and disability and the level of TMD as well as with the level of disability of the TMJ. The differences in shoulder girdle muscle activity give insight into the changes in the muscle groups in those with TMD compared to those without. The lower activity during the shoulder movements gives further insight into the changes occurring in the shoulder in participants with TMD.

The objective of the fourth study was to gain consensus from international experts on an assessment framework of the shoulder girdle in participants with TMD. A Delphi technique was used and 11 statements were sent to 21 local and international experts over two rounds. Consensus was reached, and a final assessment framework containing five subjective and four objective statements was established. This is important as a first step towards having a standardized approach to assessing the shoulder girdle in participants with TMD. It is evidence-based, according to the current literature available and the findings of the studies contained in this thesis.

8.2 SIGNIFICANCE OF THE STUDIES CONTAINED IN THIS THESIS

The relevance of these findings lies in the significant, positive associations found between the level of TMD and shoulder pain and disability scores, as well as between disability of the TMD and shoulder pain and disability. Furthermore, the differences in the muscle activity of the shoulder girdle in those with and without TMD was the first study of its kind and provided insight into the role these muscles play in the TMJ.

The assessment framework provides clinicians with guidance on what to include in the assessment of patients with TMD from a shoulder perspective and may lead to improved outcomes through a more thorough evaluation.

8.3 FUTURE RESEARCH RECOMMENDATIONS

The scoping review mapped out the current literature available on the connections between the TMJ and shoulder girdle and is recommended as a precursor to a systematic review on more narrow topics of the different types of connections. This can involve a review of the effects of clenching, different types of TMD, occlusal splints and the level of pain on the shoulder girdle.

More research is needed on the prevalence and type of shoulder injuries and pain in those with TMD. The second study served as a start and showed a high prevalence of shoulder pain and previous shoulder treatment in those with TMD. Similarly, although not significant, there was a higher prevalence of shoulder pain and previous treatment in participants with TMD compared to those without.

8.4 CLINICAL RECOMMENDATIONS

This thesis has shown that there are connections between the TMJ and the shoulder girdle. Practitioners need to explore the influence of the shoulder girdle on participants with TMD. This can be done by using the assessment framework as a guideline and treatment techniques according to the examination findings.

8.5 LIMITATIONS OF THIS THESIS

No conclusive evidence can be drawn due the presence of confounding factors in the studies. The role of the cervical spine and posture in the connection between the TMJ and

shoulder girdle was not explored in these studies and therefore results cannot be generalized.

APPENDIX 1

- **ETHICAL CLEARANCE**

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

R14/49 Mrs Micaela Weinberg

HUMAN RESEARCH ETHICS COMMITTEE (MEDICAL)

CLEARANCE CERTIFICATE NO. M2111110 MED21-11-098

NAME: (Principal Investigator)	Mrs Micaela Weinberg
DEPARTMENT:	Physiotherapy Micaela Weinberg Physiotherapy- 27 Fairmount Avenue Fairmount
PROJECT TITLE:	An assessment framework of the shoulder girdle in participants with temporomandibular disorders
DATE CONSIDERED:	26/11/2021
DECISION:	Approved unconditionally
CONDITIONS:	
SUPERVISOR:	Prof Benita Olivier and Dr Siyabonga Kunene
APPROVED BY:	Dr C Penny, Chairperson, HREC (Medical)
DATE OF APPROVAL:	23/12/2021

This clearance certificate is valid for 5 years from date of approval. Extension may be applied for.

DECLARATION OF INVESTIGATORS

To be completed in duplicate and **ONE COPY** returned to the Research Office Secretary in Room 301, Third floor, Faculty of Health Sciences, Phillip Tobias Building, 29 Princess of Wales Terrace, Parktown, 2193, University of the Witwatersrand. I/we fully understand the conditions under which I am/we are authorized to carry out the above-mentioned research and I/we undertake to ensure compliance with these conditions. Should any departure be contemplated, from the research protocol as approved, I/we undertake to resubmit the application to the Committee. **I agree to submit a yearly progress report**. The date for annual re-certification will be one year after the date of convened meeting where the study was initially reviewed. In this case, the study was initially reviewed November and will therefore be due in the month of November each year. Unreported changes to the application may invalidate the clearance given by the HREC (Medical).

Principal Investigator Signature _____ Date _____

PLEASE QUOTE THE PROTOCOL NUMBER IN ALL ENQUIRIES

APPENDIX 2

- **APPROVAL OF TITLE**

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

Private Bag 3 Wits, 2050
Fax: 027117172119
Tel: 02711 7172076

Reference: Mrs Sandra Benn
E-mail: sandra.benn@wits.ac.za

18 November 2021
Person No: 732828
PAG

Mrs MD Weinberg
Corner Northfield Avenue and Mansion Street
119 Glen Manor
Glenhazel
2192
South Africa

Dear Mrs Micaela Weinberg

Doctor of Philosophy: Approval of Title

We have pleasure in advising that your proposal entitled *An assessment framework of the shoulder girdle in participants with temporomandibular disorders* has been approved. Please note that any amendments to this title have to be endorsed by the Faculty's higher degrees committee and formally approved.

Yours sincerely

Mrs Sandra Benn
Faculty Registrar
Faculty of Health Sciences

APPENDIX 3

- **INFORMATION SHEET FOR STUDY 2**

DEPARTMENT OF PHYSIOTHERAPY: UNIVERSITY OF THE WITWATERSRAND

RESEARCH STUDY INFORMATION LETTER

Good day,

My name is Micaela Weinberg and I am a Physiotherapist with a special interest in the jaw and related conditions. You are invited to participate in this research study for a PhD degree in Physiotherapy at the University of the Witwatersrand. Please take the time to read the information carefully and if anything is unclear or if you would like more information, you are more than welcome to contact the researcher. This study was approved by the Human Ethics Committee (Medical) at the University of the Witwatersrand (M). I would like to invite you to participate in this study.

The purpose of this research is to gather information on the prevalence of shoulder injuries, pain and dysfunction in participants with jaw problems. In order to qualify to participate in this research, you need to get a score of three or more on the following three questions. If you do not get a score of two or more, unfortunately you do not qualify to participate in this study. If you do get a score of three or more, please continue reading this information sheet and answer the questionnaire in the link below.

Scoring is as follows:

- a = 0 points
- b = 1 point
- c = 2 points

1. In the last 30 days, how long did any pain last in your jaw or temple area on either side?
   a. No pain
   b. Pain comes and goes
   c. Pain is always present

2. In the last 30 days, have you had any pain or stiffness in your jaw on awakening?
   a. No
   b. Yes

3. In the last 30 days, did the following activities change any pain (that is, make it better or make it worse) in your jaw or temple are on either side?
   Chewing hard or tough food
   a. No
   b. Yes

Participation in the study is voluntary. Please note by submitting the completed questionnaire, you are providing consent to participate in this research study.

Remuneration: Participation is without remuneration.

Cost of the study: There is no cost to the study but since the questionnaire is online, you will bear internet-related costs.

Risks: There are no risks involved in participating in the study. There are no questions that will identify the participant and therefore your answers are anonymous.

Benefits: The results of this study will provide a greater understanding of the relationship between the jaw and shoulder. This can help improve Physiotherapy treatment of these two areas.

Withdrawal from the study: If you decide to participate, you are free to withdraw from the study at any time before submitting the final response, without giving a reason and with no consequences.
Duration: The questionnaire consists of X parts (). The questionnaire will take X amount of minutes to complete. The questionnaire will be available for X amount of time and you can complete the questionnaire anytime in that period.

Results of the study: The results will be written into a research report that will be assessed. The results will then be published in scientific journals. You will be given access to the results, if you wish to see them by contacting me (732828@students.wits.ac.za).

Confidentiality: All answers obtained from the QuestionPro Survey will be confidential and handled by the main researcher and the supervisors. The data will be secured on QuestionPro and will be only be accessible to the researcher and the supervisors. The data from the survey will be downloaded and stored on a password protected USB for five years and only the main researcher will have access to it.

Please find the link below:

Thank you in advance for your participation in the study, it is greatly appreciated.
Researcher: Micaela Weinberg – 732828@students.wits.ac.za
Research supervisor: Benita Olivier - Benita.olivier@wits.ac.za/ Siyabonga Kunene siyabonga.kunene@wits.ac.za

Health Science Research Ethics Committee:

APPENDIX 4

- **DATA MANAGEMENT PLAN**

0.	Proposal Name
	Data Management Plan for the study titled: “Shoulder Girdle Disability, Dysfunction, and Pain in Participants with Temporomandibular Joint Disorders: A Cross-Sectional Survey on Prevalence and Associations”
1.	**Description of the Data**
1.1	**Type of study** The first study is a quantitative, descriptive, cross-sectional designed questionnaire where qualitative and quantitative data will be collected from participants on different platforms, including social media, email and hard copies with temporomandibular disorders. The second study is a cross-sectional observational study with a comparative cohort where qualitative and quantitative data will be collected from participants with and without temporomandibular disorders in public and private health care settings.
1.2	**Types of data** The questionnaire study will have quantitative and qualitative data generated from participants’ answers on the questionnaire. The observational study will have qualitative data from the interview and quantitative data (clinical measurements) from the objective examination of participants with and without temporomandibular disorders.
1.3	**Format and scale of the data** The questionnaire will be uploaded onto the REDCap secure web platform, and data will be exported and stored as tabular data in a comma-separated values (.csv) file. In the observational study, the principal researcher and research assistants will collect data through a questionnaire and clinical measurements. The findings will be put onto a REDCap form that will then be exported and stored as tabular data in a comma-separated values (.csv) file.
2.	**Data Collection / Generation**
2.1	**Methodologies for data collection/generation** The principal investigator will extract data from the answers on the REDCap questionnaire. The data from the observational study will be put onto a REDCap form. The option of “other” will be provided for the option of gender, and the participant will not be forced to answer any questions that may be sensitive, such as gender or race, and can click the option “prefer to skip.”
2.2	**Data quality and standards** Validated questionnaires were chosen as part of the questionnaire.

To improve the quality of data collection, there will be repeated measurements, and a standardised sheet will be used.

3. Data Management, Documentation and Curation

3.1 Managing, storing and curating data.

Consent will be obtained from the Human Research and Ethics Committee at the University of the Witwatersrand. An information letter will be provided to all potential participants of the questionnaire and observational study where we will explain that the data will be deposited into a research database; If there is a specific topic that the participant would prefer their data not to be used for, they may specify it in the consent form.

Upon completion of the study, raw de-identified data will be stored in REDCap together with the consent form from the chief executive officers, data dictionary, comprehensive protocol with outcome measures and the ethical clearance certificate.

REDCap (Research Electronic Data Capture), hosted at the University of the Witwatersrand, is a secure, web-based software platform designed to support data capture for research studies, providing 1) an intuitive interface for validated data capture; 2) audit trails for tracking data manipulation and export procedures; 3) automated export procedures for seamless data downloads to standard statistical packages; and 4) procedures for data integration and interoperability with external sources (Harris et al 2009; Harris et al 2019). The idea is for the principal investigator to set the project up under his/her own REDCap account from the start of the project, whether the project contains a self-administered questionnaire or data entered by the researcher. In this case, the project will be transferred to the central REDCap database by giving the Data Manager access to the project.

Researchers will send the data and associated documentation to the Data Manager via REDCap's Send-It tool. The Data Manager will review the data and documentation and request changes if needed. Once the Data Manager is satisfied that the data is in the correct format and that all the associated documentation is complete, they will upload the data onto REDCap. The REDCap Data Import tool will be used to import data into REDCap. Each study will have a separate REDCap project created. Data will be stored on the Human Movement Database in the long run.

The participant's name, surname, and contact details will not be asked on the questionnaire nor will these be required in the observational study, and data will be recorded next to a study number only.

If there are any other direct identifiers as well as information that could lead to "deductive disclosure" of participants' identities these will be removed following

the process described in: Hrynaszkiewicz, I., Norton, M. L., Vickers, A. J., & Altman, D. G. (2010). Preparing raw clinical data for publication: guidance for journal editors, authors, and peer reviewers. British Medical Journal, 340, c181. doi:10.1136/bmj.c181.

Researchers who would like to use the data of these studies in future research projects will apply for ethical clearance. Upon completion of the project, the researcher will be required to upload the modified datasheet onto the REDCap system and remove any copies from their computer, whereafter the researcher's access to REDCap will be terminated.

3.2 **Metadata standards and data documentation**

The following information forms part of the meta-data:

- Depositor details (address, contact number, email)
- Creator's (principal investigator's) details (affiliation, ORCID, email)
- Title of dataset
- Data collection timespan
- Date data was created (including versions)
- File format
- Kind of data
- Population
- Context/setting
- Outcome measures used
- Interventions (if applicable)
- Variable list
- Keywords
- MeSH terms
- ICD-10 codes (if applicable)
- Unique identifier
- Associated publications (Full citation for publications, datasets, and other materials associated with the data)
- Potential future research questions (optional)
- Grant/funding agency
- Grant/funding number
- Brief Abstract (Maximum of 100 words)

I will submit the following documentation at the end of a project so that data can be stored on the Human Movement Database (the guidelines of the Wits Cricket Research Hub for Science, Medicine and Rehabilitation's Data Management and Sharing Guide will be followed):

1. Consent form from the Medical Manager in electronic format: collected either via e-consent or hard copy (scanned in).
2. Data dictionary in .csv format: before extraction of the data dictionary, the primary investigator should review the "Data Dictionary Codebook" in REDCap to ensure that each of the variables are clearly explained.

3. Raw de-identified data after it has been cleaned in .csv format: the raw data filed is downloaded from REDCap and then cleaned. However, data should remain in the "raw" format, e.g. where multiple choice options are used, the raw coded value (e.g. 0, 1, 2) should be added to the spreadsheet. Variable names should correspond to the variable names in the data dictionary.
4. Comprehensive protocol in .rtf format.
5. Ethical clearance certificate.

3.3 Data preservation strategy and standards

Data will be stored on the REDCap database hosted on the University of the Witwatersrand servers for an indefinite period. Data will be stored as tabular data in a comma-separated values (.csv) file.

4. Data Security and Confidentiality of Potentially Disclosive Information

4.1 Formal information/data security standards

The University of the Witwatersrand is a public university and is compliant with the International Organisation for Standardisation (ISO) ISO 27001 Information Security. Data will be stored in REDCap in an access-controlled project. REDCap uses encryption to protect traffic between the Web server and the End User as well as to protect REDCap authenticators. Only the research group director will have access to the projects' passwords.

Data will not be destroyed unless required for ethical or legal reasons, in which case the University of the Witwatersrand's Central Records Office will be consulted for expertise advice. For destruction of physical data, the guidance on Biobanks is followed. For destruction of data on the internet, the University of the Witwatersrand follows the guidance of the South African National Research Network: Computer Security Incident Response Team.

4.2 Main risks to data security

No names, surnames or contact details will be captured. Study numbers will be assigned to each participant at the time of data collection. REDCap is a secure database. We therefore do not foresee risks to data security related to this project.

5. Data Sharing and Access

5.1 Suitability for sharing

The data from this project is suitable for sharing since the information captured is not of a sensitive nature.

5.2 Discovery by potential users of the research data

A project description with its meta-data will be shared on the Wits Wired Space platform. Data can be located through the use of a search function. From here, interested researchers will follow a REDCap link where more information (project metadata) can be found.

The DOI of the dataset (if available at the time of publication) on which the publication findings are based will feature in the associated publication.

5.3 Governance of access

The Recipient (the researcher who would like to reuse the data) will complete an online data request form via the link https://redcap.link/datarequestform. The REDCap form will request the following details: name, surname, contact number, email address, affiliation, detailed description of the study's objectives, data needed, intended use of the data and a study protocol. A Recipient may be internal or external to Wits.

The request will be sent to the research group director, who will review the request in relation to the following questions:

- Is the intended use of the data similar to what it has already been used for? If yes, the motivation for the request needs to be made clear.
- Are the scientific methods rigorous and ethical approaches sound as described in the protocol?
- If there are other data available which are more appropriate, these can be suggested.

Recipients are encouraged to submit their requests for data at least six weeks before the start of the intended period of use. The data access committee, research group director and principal investigator who collected the data will review the request and inform the Recipient of the outcome via email within three weeks of the date on which the request was received. Should the request be denied, reasons will be provided, and the Recipient can appeal through the University's Data Access Committee.

The Recipient will sign a Conditions of Use Agreement which can be found in Appendix D. Once the Recipient has obtained ethical clearance and the access agreement has been signed, the data will be released to the Recipient.

The research group director will keep a record of who the data is shared with as well as the intended use of the data. The research group director will share this report with the University or funders as required.

The application, review and approval processes are shown in Figure 1 (based on the MRC UK's suggested processes):

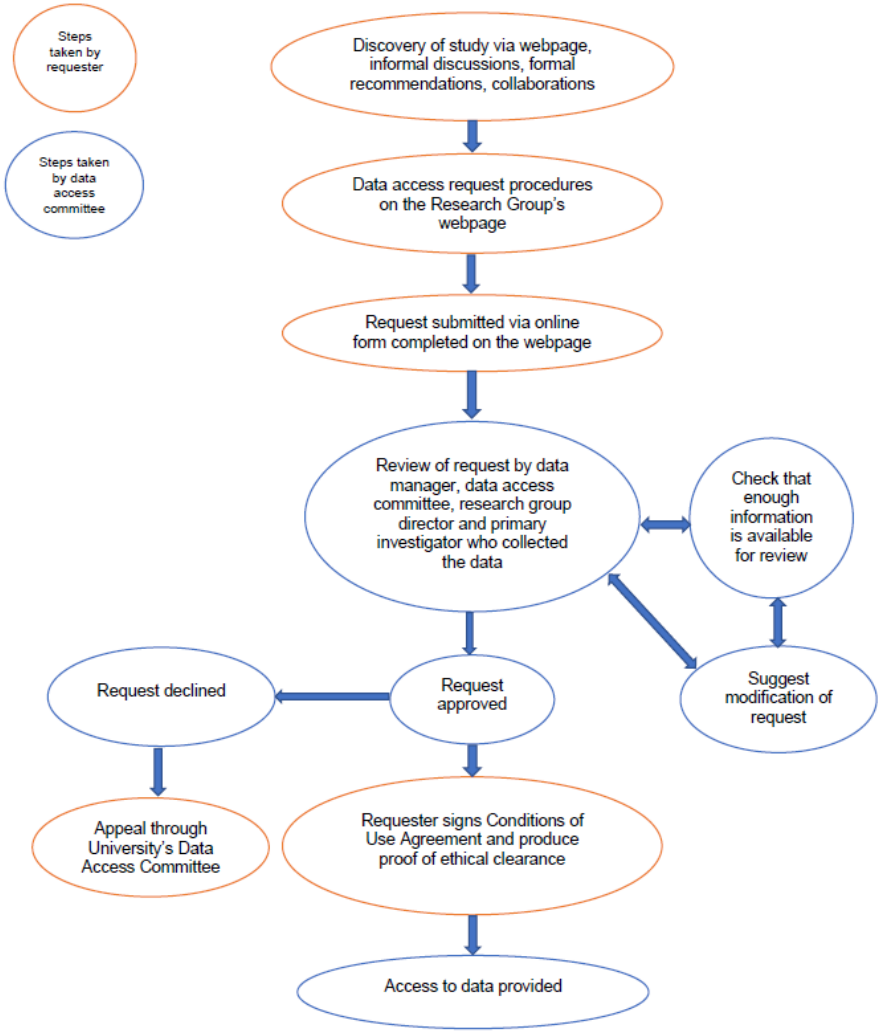


Figure 1. The application, review and approval processes

5.4 The study team's exclusive use of the data

Data will be made available for sharing after acceptance for publication, which will be within 12 months after the end of the data collection period.

5.5 Restrictions or delays to sharing, with planned actions to limit such restrictions.

There are no restrictions or foreseen delays to the sharing of this data.

5.6 Regulation of responsibilities of users

All Recipients, Recipient Institutions and Data Users will be bound by the Conditions of Use Agreement which can be found in the Wits Sport and Health Research Group Data Management and Sharing Guide.

6. Responsibilities

The principal investigator is responsible for the data management, metadata creation, data security and data quality assurance, as no formal, paid data management services are currently available. The data access committee, research group director and principal investigator will review and process

	requests for data reuse.
7.	**Relevant institutional, departmental or study policies on data sharing and data security**
	The following documents were considered in the development of this data management plan: - Wits Data Classification Policy - Wits Data Cloud Policy - Wits Research Data Policy draft 1 (8 July 2020) - Protection of Personal Information Act (POPIA) - Intellectual Property Policy C2012/228
8.	**Author of this Data Management Plan (Name)** and, if different to that of the Principal Investigator, their **telephone & email contact details**
	Micaela Weinberg, 0767882031, micaelaweinberg@gmail.com

APPENDIX 5

- **INFORMATION SHEET FOR PARTICIPANTS IN THE TEST GROUP**

DEPARTMENT OF PHYSIOTHERAPY: UNIVERSITY OF THE WITWATERSRAND
TEST GROUP INFORMATION LETTER

Date:

Study Title: An Assessment Framework of the Shoulder Girdle in Participants with Temporomandibular Disorders

Good day,

My name is Micaela Weinberg and I am a Physiotherapist with a special interest in the jaw and related conditions. You are invited to participate in this research study for a PhD degree in Physiotherapy at the University of the Witwatersrand. Please take the time to read the information carefully and if anything is unclear or if you would like more information, you are more than welcome to contact the researcher. This study was approved by the Human Ethics Committee (Medical) at the University of the Witwatersrand (M).

The purpose of this research is to gather information on the relationship between the shoulder girdle and the jaw in participants with and without jaw problems. This study will compare the activity and thickness of the muscles in the shoulder girdle and jaw in people with and without jaw problems. The study will also look at the movement of the jaw and if the jaw deviates on movement and if this has any connection to the movement of the shoulder. In order to determine who can qualify to be a part of the group with jaw problems, you need to get a score of two or more on the following three questions. If you do not get a score of two or more and have jaw or shoulder unfortunately you do not qualify to participate in this study.

If you do get a score of two or more, please continue reading this information sheet and answer the questionnaire in the link below.
Scoring is as follows:
a = 0 points; b = 1 point; c = 2 points

1. In the last 30 days, how long did any pain last in your jaw or temple area on either side?
   a. No pain
   b. Pain comes and goes
   c. Pain is always present

2. In the last 30 days, have you had any pain or stiffness in your jaw on awakening?
   a. No
   b. Yes

3. In the last 30 days, did the following activities change any pain (that is, make it better or make it worse) in your jaw or temple are on either side?
   Chewing hard or tough food
   a. No
   b. Yes

Participation in the study is voluntary. Please note your participation in the study is completely voluntary and you are able to drop out at any point with no consequences.

Remuneration: Each participant will receive R100 for participation (assessment is 20 minutes in duration) as well as R3.98 per km travelled.

Cost of the study: There is no cost to the study, participants nor their medical aids will be charged for the assessment.

Risks: There are no risks involved in participating in the study.

Benefits: The results of this study will provide a greater understanding of the relationship between the jaw and shoulder. This can help improve Physiotherapy treatment of these two areas.

Withdrawal from the study: If you decide to participate, you are free to withdraw from the study at any time without giving a reason and with no consequences.

What is involved in the study: Each participant will complete an online questionnaire before the testing procedure. The testing procedure will involve five tests: one of them will be using electromyography to measure the muscle activity of the jaw and shoulder girdle muscles during resisted movements of the jaw and shoulder. The next test will use ultrasound to measure muscle thickness of the jaw and shoulder girdle muscles. The other tests will observe the movement of the jaw and shoulder blade during specific movements.

Duration: The questionnaire consists of X parts (). The questionnaire will take X amount of minutes to complete. The questionnaire will be available for X amount of time and you can complete the questionnaire anytime in that period.

Results of the study: The results will be written into a research report that will be assessed. The results will then be published in scientific journals.

Access to information: There will be no identifying information. Each participant will be given a participant number and identities will be concealed.

Information related to the use of your data in future research projects: We would like to get your permission to deposit your data into a research database that will be used for future research. At the moment, we do not know what the future research questions are, but if there is any specific topic that you would prefer your data not to be used for, then you can specify this in the consent form. Researchers who would like to use your data in future research projects will apply for ethical clearance. In addition, these applications will be reviewed by a data access control committee in the light of the intention of your original consent. If the committee is satisfied with the intentions of use, access will be granted to your data. Your data might be linked to other datasets and merged with multiple sources of data. Upon completion of the project, the researcher will be required to upload the modified datasheet onto the REDCap system and remove the copies from his/her computer, whereafter the researcher's access to REDCap will be terminated.

Should you prefer not to allow for your data to be used in either the current or future research projects, or both, you will not lose out on any benefits that you are entitled to in the absence of this research project. If you would like to withdraw your consent for re-use of your data in future research projects you are free to do so by sending an email to the primary investigator, Micaela Weinberg (see email address below).

Storage of data: Your data will be stored on a secure platform called REDCap (Research Electronic Data Capture) which is hosted by the University of the Witwatersrand. This platform is access-controlled, secured on two different servers and only a data manager, data access committee and the research group director will have access to the data.

Thank you in advance for your participation in the study, it is greatly appreciated.
Researcher: Micaela Weinberg – 732828@students.wits.ac.za
Research supervisor: Benita Olivier - Benita.olivier@wits.ac.za/ Siyabonga Kunene siyabonga.kunene@wits.ac.za

Health Science Research Ethics Committee:

APPENDIX 6

- **INFORMATION SHEET FOR PARTICIPANTS IN THE COMPARATIVE GROUP**

DEPARTMENT OF PHYSIOTHERAPY: UNIVERSITY OF THE WITWATERSRAND
PARTICIPANTS IN THE COMPARATIVE GROUP INFORMATION LETTER

Date:

Study Title: An Assessment Framework of the Shoulder Girdle in Participants with Temporomandibular Disorders

Good day,

My name is Micaela Weinberg and I am a Physiotherapist with a special interest in the jaw and related conditions. You are invited to participate in this research study for a PhD degree in Physiotherapy at the University of the Witwatersrand. Please take the time to read the information carefully and if anything is unclear or if you would like more information, you are more than welcome to contact the researcher. This study was approved by the Human Ethics Committee (Medical) at the University of the Witwatersrand (M).

The purpose of this research is to gather information on the relationship between the shoulder girdle and the jaw in participants with and without jaw problems. This study will compare the activity and thickness of the muscles in the shoulder girdle and jaw in people with and without jaw problems. The study will also look at the movement of the jaw and if the jaw deviates on movement and if this has any connection to the movement of the shoulder. Your participation allows us to compare the differences in people with and without jaw problems.

Participation in the study is voluntary. Please note your participation in the study is completely voluntary and you are able to drop out at any point with no consequences.

Remuneration: Each participant will receive R100 for participation (assessment is 20 minutes in duration) as well as R3.98 per km travelled.

Cost of the study: There is no cost to the study, participants nor their medical aids will be charged for the assessment.

Risks: There are no risks involved in participating in the study.

Benefits: The results of this study will provide a greater understanding of the relationship between the jaw and shoulder. This can help improve Physiotherapy treatment of these two areas.

Withdrawal from the study: If you decide to participate, you are free to withdraw from the study at any time without giving a reason and with no consequences.

What is involved in the study: Each participant will complete an online questionnaire before the testing procedure. The testing procedure will involve five tests: one of them will be using electromyography to measure the muscle activity of the jaw and shoulder girdle muscles during resisted movements of the jaw and shoulder. The next test will use ultrasound to measure muscle thickness of the jaw and shoulder girdle muscles. The other tests will observe the movement of the jaw and shoulder blade during specific movements.

Duration: The questionnaire consists of X parts (). The questionnaire will take X amount of minutes to complete. The questionnaire will be available for X amount of time and you can complete the questionnaire anytime in that period.

Results of the study: The results will be written into a research report that will be assessed. The results will then be published in scientific journals.

Access to information: There will be no identifying information. Each participant will be given a participant number and identities will be concealed.

Information related to the use of your data in future research projects: We would like to get your permission to deposit your data into a research database that will be used for future research. At the moment, we do not know what the future research questions are, but if there is any specific topic that you would prefer your data not to be used for, then you can specify this in the consent form. Researchers who would like to use your data in future research projects will apply for ethical clearance. In addition, these applications will be reviewed by a data access control committee in the light of the intention of your original consent. If the committee is satisfied with the intentions of use, access will be granted to your data. Your data might be linked to other datasets and merged with multiple sources of data. Upon completion of the project, the researcher will be required to upload the modified datasheet onto the REDCap system and remove the copies from his/her computer, whereafter the researcher's access to REDCap will be terminated.

Should you prefer not to allow for your data to be used in either the current or future research projects, or both, you will not lose out on any benefits that you are entitled to in the absence of this research project. If you would like to withdraw your consent for re-use of your data in future research projects you are free to do so by sending an email to the primary investigator, Micaela Weinberg (see email address below).

Storage of data: Your data will be stored on a secure platform called REDCap (Research Electronic Data Capture) which is hosted by the University of the Witwatersrand. This

platform is access-controlled, secured on two different servers and only a data manager, data access committee and the research group director will have access to the data.

Thank you in advance for your participation in the study, it is greatly appreciated.
Researcher: Micaela Weinberg – 732828@students.wits.ac.za
Research supervisor: Benita Olivier - Benita.olivier@wits.ac.za/ Siyabonga Kunene siyabonga.kunene@wits.ac.za

Health Science Research Ethics Committee:

APPENDIX 7

- **CONSENT FORM FOR ALL PARTICIPANTS**

DEPARTMENT OF PHYSIOTHERAPY: UNIVERSITY OF THE WITWATERSRAND

INFORMED CONSENT

Study title: An assessment framework of the shoulder girdle in participants with temporomandibular disorders

I, _____ to participate in the study as described to me in the information sheet. I have read the information sheet and fully understand what the study entails. I have had an opportunity to ask questions and understand that my participation is voluntary. I hereby agree to complete the required questionnaires and consent to the video recording of my neck movements.

Participant : _____

Date : _____

APPENDIX 8

- **INFORMATION SHEET FOR PARTICIPANTS OF THE DELPHI STUDY**

DEPARTMENT OF PHYSIOTHERAPY: UNIVERSITY OF THE WITWATERSRAND

INFORMATION SHEET FOR PARTICIPATION IN DELPHI STUDY

Study Title: An Assessment Framework of the Shoulder Girdle in Participants with Temporomandibular Disorders

Good day,

My name is Micaela Weinberg and I am a Physiotherapist with a special interest in the jaw and related conditions. You are invited to participate in this research study for a PhD degree in Physiotherapy at the University of the Witwatersrand. Please take the time to read the information carefully and if anything is unclear or if you would like more information, you are more than welcome to contact the researcher. This study was approved by the Human Ethics Committee (Medical) at the University of the Witwatersrand (M).

The purpose of this research is to gather information on the relationship between the shoulder girdle and the jaw in participants with and without jaw problems. You have been invited to participate in the fourth phase of the study which is a delphi study to obtain the opinions of experts on an assessment framework of the shoulder girdle in participants with temporomandibular disorders.

Participation in the study is voluntary. Please note your participation in the study is completely voluntary and you are able to drop out at any point with no consequences.

Remuneration: There is no remuneration to be a part of the study.

Cost of the study: There is no cost to the study.

Risks: There are no risks involved in participating in the study.

Benefits: The results of this study will provide a greater understanding of the relationship between the jaw and shoulder. This can help improve Physiotherapy treatment of these two areas.

Withdrawal from the study: If you decide to participate, you are free to withdraw from the study at any time without giving a reason and with no consequences.

What is involved in the study: An online questionnaire (REDCap) will be sent via email to experts to develop an evidence-based assessment protocol of the shoulder girdle in participants with TMD. This assessment will be based on the findings of the study and experts will be instructed to comment on each assessment measurement. They will be asked to rate the importance, whether to include/exclude any measure and be invited to make suggestions or comments. After Round 1, consensus will be reached if at least 80% of the panel strongly agreed/disagreed and if consensus is not reached then these items and any new suggested items will be taken to Round 2 together with the aggregated summary from Round 1 responses. The final template will be sent to all members for approval.

Results of the study: The results will be written into a research report that will be assessed. The results will then be published in scientific journals.

Access to information: There will be no identifying information. Each expert will be given a participant number and identities will be concealed.

Information related to the use of your data in future research projects: We would like to get your permission to deposit your data into a research database that will be used for future research. At the moment, we do not know what the future research questions are, but if there is any specific topic that you would prefer your data not to be used for, then you can specify this in the consent form. Researchers who would like to use your data in future research projects will apply for ethical clearance. In addition, these applications will be reviewed by a data access control committee in the light of the intention of your original consent. If the committee is satisfied with the intentions of use, access will be granted to your data. Your data might be linked to other datasets and merged with multiple sources of data. Upon completion of the project, the researcher will be required to upload the modified datasheet onto the REDCap system and remove the copies from his/her computer, whereafter the researcher's access to REDCap will be terminated.

Should you prefer not to allow for your data to be used in either the current or future research projects, or both, you will not lose out on any benefits that you are entitled to in the absence of this research project. If you would like to withdraw your consent for re-use of your data in future research projects you are free to do so by sending an email to the primary investigator, Micaela Weinberg (see email address below).

Storage of data: Your data will be stored on a secure platform called REDCap (Research Electronic Data Capture) which is hosted by the University of the Witwatersrand. This platform is access-controlled, secured on two different servers and only a data manager, data access committee and the research group director will have access to the data.

Thank you in advance for your participation in the study, it is greatly appreciated.
Researcher: Micaela Weinberg – 732828@students.wits.ac.za
Research supervisor: Benita Olivier - Benita.olivier@wits.ac.za/ Siyabonga Kunene siyabonga.kunene@wits.ac.za

Health Science Research Ethics Committee:

APPENDIX 9

- **INFORMED CONSENT FOR PARTICIPATION IN THE DELPHI STUDY**

DEPARTMENT OF PHYSIOTHERAPY: UNIVERSITY OF THE WITWATERSRAND

INFORMED CONSENT FOR PARTICIPATION IN DELPHI STUDY

Study Title: An Assessment Framework of the Shoulder Girdle in Participants with Temporomandibular Disorders

I agree to participate in the Delphi study by the principal researcher, Micaela Weinberg.

The aim of the Delphi study is to achieve an expert consensus on the assessment of the shoulder girdle in participants with temporomandibular disorders. Experts' responses will be anonymous and there will be no repercussions for refusing to participate or dropping out of the study. There are no risks involved in participating in the study.

Signature : _____

Date : _____

APPENDIX 10

- **KEYWORDS AND RESULTS FOR EACH DATABASE**

i) Cochrane Controlled Trials Register in the Cochrane Library

Search conducted on 13/09/22

Search	Query	Records retrieved
#1	[mh temporomandibular joint] OR [mh temporomandibular joint disorders] OR [mh temporomandibular joint dysfunction syndrome] OR [mh temporomandibular joint disc] OR [mh jaw] OR [mh masticatory muscles] OR [mh occlusal splint] OR [mh facial pain] OR [mh craniomandibular disorder] OR [mh stomatognathic system] OR [mh masseter muscle] OR [mh temporal muscle] OR [mh pterygoid muscle] OR temporomandibular* OR jaw* OR masticat* OR “occlusal splint” OR cranio-cervical OR “facial pain” OR craniofacial OR orofacial OR “craniomandibular disorder” OR “stomatognathic system” OR “masseter muscle” OR “temporal muscle” OR “pterygoid muscle” OR TMD OR TMJ	25,197
#2	[mh shoulder] OR [mh shoulder joint] OR [mh clavicle] OR [mh scapula] OR [mh rotator cuff] OR [mh acromioclavicular joint] OR [mh sternoclavicular joint] OR shoulder* OR scapul* OR clavicle OR glenohumeral* OR "sternocleidomastoid muscle” OR "trapezius muscle" OR "scalene muscle" OR "rotator cuff" OR glenoid OR "acromioclavicular joint" OR "sternoclavicular joint"	17,551
#3	#1 AND #2	322
	No language or date limits	

ii) EBSCOHost: Cumulative Index to Nursing and Allied Health Literature complete (CINAHL) and SPORTDiscus with Full Text

Limiters selected: none

Search conducted on 19/08/22

Search	Query	Records retrieved
#1	(MM "Temporomandibular Joint") OR (MH "Temporomandibular Joint Diseases+") OR (MM "Temporomandibular Joint Syndrome") OR (MH "Jaw+") OR (MH "Masticatory Muscles+") OR (MH "Facial Pain+") OR (MH "Craniomandibular Disorders+") OR (MH "Stomatognathic System+") OR (MM "Masseter Muscle") OR (MM "Temporal Muscle") OR (MM "Pterygoid Muscles") OR TX Temporomandibular* OR Jaw OR Masticat* OR “Occlusal splint” OR Cranio-cervical OR “Facial pain” OR Craniofacial OR Orofacial OR “Craniomandibular disorder” OR “Stomatognathic system” OR “Masseter muscle” OR “Temporal muscle” OR “Pterygoid muscle” OR TMD OR TMJ	92, 097

#2	(MM "Shoulder") OR (MH "Shoulder Joint+") OR (MM "Glenohumeral Joint") OR (MM "Clavicle") OR (MH "Scapula+") OR (MM "Trapezius Muscles") OR (MM "Sternocleidomastoid Muscles") OR (MH "Rotator Cuff+") OR (MM "Acromioclavicular Joint") OR (MM "Sternoclavicular Joint") OR TX Shoulder* OR Glenohumeral* OR Clavicle OR Scapul* OR “Trapezius muscle” OR “Sternocleidomastoid muscle” OR “Scalene muscle” OR “Rotator cuff” OR Glenoid OR “Acromioclavicular joint” OR “Sternoclavicular joint”	90,981
#3	#1 AND #2	1, 732
	No language or date limits	

iii) MEDLINE via PubMed

Search conducted on 31/08/22

Filters applied: human

Search	Query	Records retrieved
#1	Temporomandibular joint[MeSH Terms] OR Temporomandibular joint disorder[MeSH Terms] OR Temporomandibular joint dysfunction syndrome[MeSH Terms] OR Temporomandibular joint disease[MeSH Terms] OR Temporomandibular joint disc[MeSH Terms] OR Temporomandibular*[Text Word] OR Jaw[MeSH Terms] OR Jaw[Text Word] OR Masticatory muscles[MeSH Terms] OR Masticat*[Text Word] OR Occlusal splint[MeSH Terms] OR “Occlusal splint”[Text Word] OR Cranio-cervical[Text Word] OR Facial pain[MeSH Terms] OR “Facial pain”[Text Word] OR Craniofacial[Text Word] OR Orofacial[Text Word] OR Craniomandibular disorder[MeSH Terms] OR “Craniomandibular disorder”[Text Word] OR Stomatognathic system[MeSH Terms] OR “Stomatognathic system”[Text Word] OR Masseter muscle[MeSH Terms] OR Temporal muscle[MeSH Terms] OR Pterygoid muscle[MeSH Terms] OR “Masseter muscle”[Text Word] OR “Temporal muscle”[Text Word] OR “Pterygoid muscle”[Text Word] OR TMD[Text Word] OR TMJ[Text Word]	536, 609
#2	"shoulder"[MeSH Terms] OR "shoulder*"[Text Word] OR "shoulder joint"[MeSH Terms] OR "glenohumeral*"[Text Word] OR "Clavicle"[MeSH Terms] OR "Clavicle"[Text Word] OR "scapula"[MeSH Terms] OR "scapul*"[Text Word] OR "Trapezius muscle"[Text Word] OR "Sternocleidomastoid muscle"[Text Word] OR "Scalene muscle"[Text Word] OR "Rotator cuff"[MeSH Terms] OR "Rotator cuff"[Text Word] OR "Acromioclavicular joint"[MeSH Terms] OR "Sternoclavicular joint"[MeSH Terms] OR "Acromioclavicular joint"[Text Word] OR "Sternoclavicular joint"[Text Word]	119,900
#3	#1 AND #2 ("shoulder"[MeSH Terms] OR "shoulder*"[Text Word] OR "shoulder joint"[MeSH Terms] OR "glenohumeral*"[Text Word] OR "Clavicle"[MeSH Terms] OR "Clavicle"[Text Word] OR "scapula"[MeSH Terms] OR "scapul*"[Text Word] OR "Trapezius muscle"[Text Word] OR "Sternocleidomastoid muscle"[Text Word] OR "Scalene muscle"[Text Word] OR "Rotator cuff"[MeSH Terms] OR "Rotator	2,144

	cuff"[Text Word] OR "Acromioclavicular joint"[MeSH Terms] OR "Sternoclavicular joint"[MeSH Terms] OR "Acromioclavicular joint"[Text Word] OR "Sternoclavicular joint"[Text Word]) AND ("temporomandibular joint"[MeSH Terms] OR "temporomandibular joint disorders"[MeSH Terms] OR "temporomandibular joint dysfunction syndrome"[MeSH Terms] OR "temporomandibular joint disorders"[MeSH Terms] OR "temporomandibular joint disc"[MeSH Terms] OR "temporomandibular*"[Text Word] OR "Jaw"[MeSH Terms] OR "Jaw"[Text Word] OR "masticatory muscles"[MeSH Terms] OR "masticat*"[Text Word] OR "occlusal splints"[MeSH Terms] OR "Occlusal splint"[Text Word] OR "Cranio-cervical"[Text Word] OR "Facial pain"[MeSH Terms] OR "Facial pain"[Text Word] OR "Craniofacial"[Text Word] OR "Orofacial"[Text Word] OR "craniomandibular disorders"[MeSH Terms] OR "Craniomandibular disorder"[Text Word] OR "Stomatognathic system"[MeSH Terms] OR "Stomatognathic system"[Text Word] OR "Masseter muscle"[MeSH Terms] OR "Temporal muscle"[MeSH Terms] OR "pterygoid muscles"[MeSH Terms] OR "Masseter muscle"[Text Word] OR "Temporal muscle"[Text Word] OR "Pterygoid muscle"[Text Word])	
	No language or date limits	

iv) ProQuest Health and Medical Complete and Nursing and Allied

Search conducted on 20/08/22

Search	Query	Records retrieved
#1	mainsubject(temporomandibular joint) OR mainsubject(temporomandibular joint disorder) OR mainsubject(temporomandibular joint dysfunction) OR mainsubject(temporomandibular joint dysfunction syndrome) OR mainsubject(temporomandibular joint disease) OR mainsubject(temporomandibular joint disc) OR mainsubject(jaw) OR jaw* OR mainsubject(masticatory muscles) OR mainsubject(occlusal splints) OR mainsubject(facial pain) OR mainsubject(craniofacial) OR mainsubject(orofacial pain) OR mainsubject(craniomandibular disorders) OR mainsubject(stomatognathic system) OR mainsubject(masseter muscle) OR mainsubject(temporal muscle) OR mainsubject(pterygoid muscles) OR mainsubject(tmj disorders) OR mainsubject(tmj syndrome)	164,303
#2	mainsubject(shoulder joint) OR mainsubject(shoulder) OR mainsubject(trapezius muscle) OR mainsubject(sternocleidomastoid muscle) OR mainsubject(clavicle) OR mainsubject(scapula) OR mainsubject(sternoclavicular joint) OR mainsubject(acromioclavicular joint) OR mainsubject(rotator cuff) OR mainsubject(glenoid cavity) OR glenohumeral* OR "scalene muscle"	
#3	#1 AND #2	498

v) Physiotherapy Evidence Database (PEDro)

Search conducted on 31/08/22

	Query	Records retrieved
Abstract and title	Temporomandibular* shoulder*	6

vi) ScienceDirect (Elsevier)

Search conducted on 22/08/22

Search	Query	Records retrieved
#1	Title, abstract, keywords: (Temporomandibular OR jaw OR “masticatory muscles” OR “occlusal splint”) AND (shoulder OR glenohumeral OR “rotator cuff” OR scapula)	181

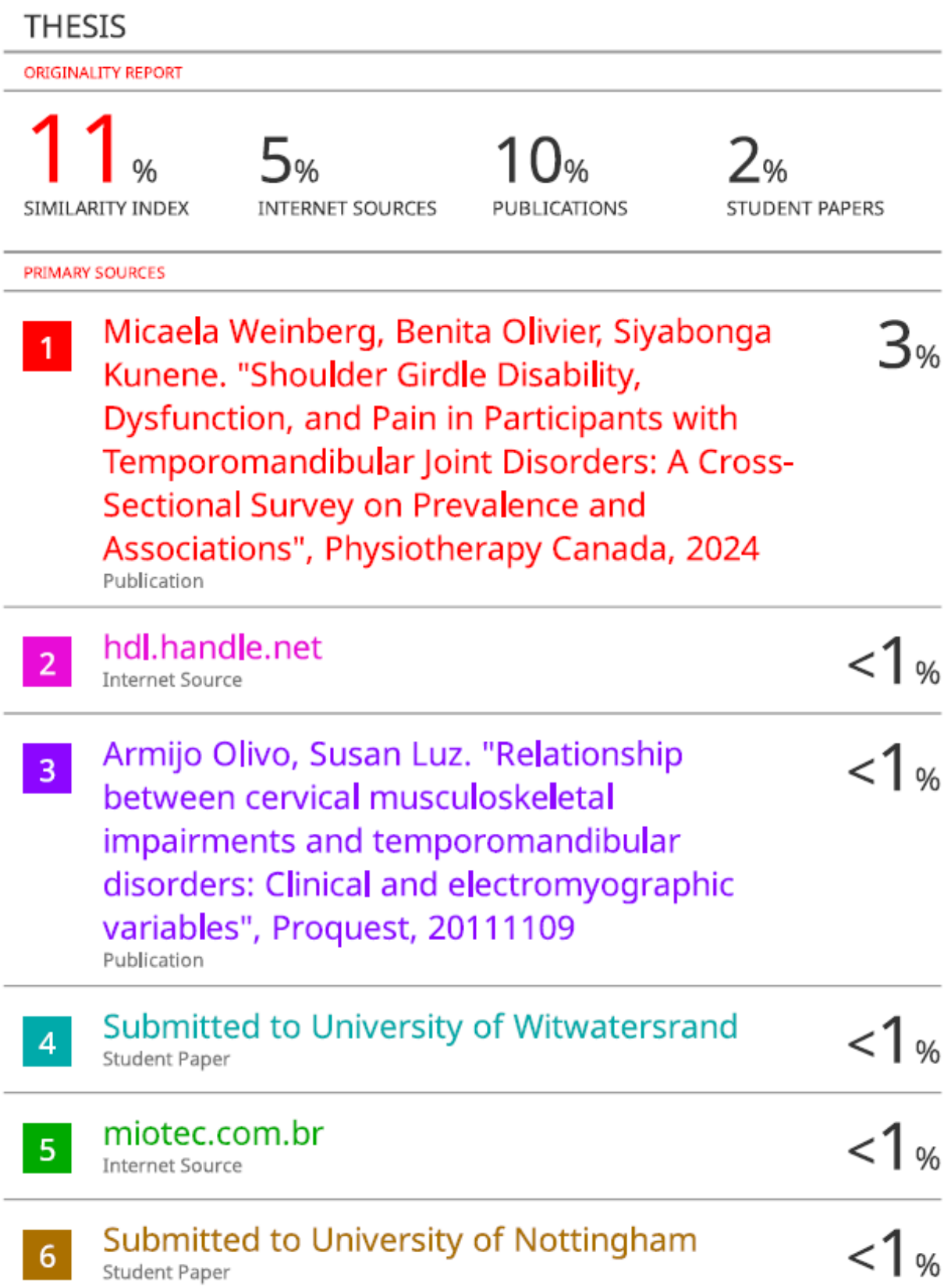
vii) SCOPUS

Search conducted on 23/08/22

Search	Query	Records retrieved
#1	SUBJAREA(HEAL) temporomandibular* OR jaw* OR masticat* OR "facial pain" OR "craniomandibular disorder" OR "stomatognathic system" OR "masseter muscle" OR "temporal muscle" OR "pterygoid muscle" OR "occlusal splint" OR cranio-cervical OR craniofacial OR orofacial	16, 555
#2	SUBJAREA(HEAL) shoulder* OR clavicle OR scapul* OR rotator AND cuff OR "acromioclavicular joint" OR "sternoclavicular joint" OR shoulder* OR glenohumeral* OR "sternocleidomastoid muscle" OR "trapezius muscle" OR "scalene muscle" OR glenoid	33, 328
#3	#1 AND #2	1,698
	No language or date limits	

APPENDIX 11

- **TURN-IT-IN REPORT**



THESIS

ORIGINALITY REPORT

11%	5%	10%	2%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	Micaela Weinberg, Benita Olivier, Siyabonga Kunene. "Shoulder Girdle Disability, Dysfunction, and Pain in Participants with Temporomandibular Joint Disorders: A Cross-Sectional Survey on Prevalence and Associations", Physiotherapy Canada, 2024 Publication	3%
2	hdl.handle.net Internet Source	<1%
3	Armijo Olivo, Susan Luz. "Relationship between cervical musculoskeletal impairments and temporomandibular disorders: Clinical and electromyographic variables", Proquest, 20111109 Publication	<1%
4	Submitted to University of Witwatersrand Student Paper	<1%
5	miotec.com.br Internet Source	<1%
6	Submitted to University of Nottingham Student Paper	<1%