Universidade de Lisboa
Faculdade de Motricidade Humana

Effects of the use of occlusal splints on the neuromuscular function

Amândio Alberto Pedro Dias

Orientador: Professor Doutor Pedro Luís Camecelha de Pezarat Correia

Tese especialmente elaborada para a obtenção do Grau de Doutor no ramo de Motricidade Humana, na Especialidade de Comportamento Motor

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Declaração de Reprodução da Tese

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Título da Tese: Effects of the use of occlusal splints on the neuromuscular function

Orientador: Professor Doutor Pedro Pezarat Correia

Ano de conclusão: 2018

Ramo de conhecimento do Doutoramento: Motricidade Humana, especialidade de Comportamento Motor

É AUTORIZADA A REPRODUÇÃO INTEGRAL DESTA TESE APENAS PARA EFEITOS DE INVESTIGAÇÃO, MEDIANTE DECLARAÇÃO ESCRITA DO INTERESSADO, QUE A TAL SE COMPROMETE.

Faculdade de Motricidade Humana – Universidade de Lisboa, ____/_____/____

Assinatura: _____________________________
(Amândio Alberto Pedro Dias)

DEDICATÓRIA

Para os meus pais

Para a Tânia e a Catarina, que iluminam os meus dias

AGRADECIMENTOS / ACKNOWLEDGMENTS

O doutoramento é sem dúvida alguma um processo composto por várias etapas, pontos altos e outros não tão bons, como se de uma história de aventuras se tratasse, mas acima de tudo é um processo de aprendizagem. A aprendizagem não se restringe apenas aos métodos laboratoriais, à aprendizagem decorrente do manuseamento de equipamento ou do processamento de dados ou ainda à faculdade que se torna uma casa, pois nela passamos grande parte dos nossos dias. O que temos que reter deste processo acima de tudo são as pessoas que conhecemos, com quem convivemos, que tiveram uma participação nesta história que aqui contamos. Estes agradecimentos que de seguida se apresentam pretendem apenas enaltecer e reconhecer a importância que essas pessoas tiveram para o sucesso deste doutoramento, mesmo que por vezes não tenham tido essa consciência.

Em primeiro lugar quero agradecer aos meus pais pelo apoio dado desde o início desta história, tal como tem sido vosso apanágio em toda a minha vida.

Se esta aventura tem um final feliz, muito se deve à Tânia, companheira, amiga, confidente, que durante todo o tempo do doutoramento nunca deixou de me apoiar, mesmo que isso representasse não me ver ou ficar sobrecarregada.

Tive muita sorte, pois o meu percurso nesta aventura nunca foi solitário. Comigo estiveram colegas, que cedo se tornaram amigos, e que partilharam este processo, que teria de certeza sido ainda mais desgastante se não fossem eles. Um sincero obrigado ao Frederico Lopes, ao Miguel Nery, ao Tiago Neto, à Vanda Guerra, à Joana Reis e no último ano também à Mónica Lopes e ao Ricardo Dinis.

Ao longo do meu doutoramento tive hipótese de colaborar com vários investigadores, dos mais brilhantes e competentes que conheci até hoje, que em muito elevam o trabalho desenvolvido nesta tese. Com todos aprendi muito, bem como o papel por eles desempenhado nesta tese foi fundamental. Os meus sinceros agradecimentos por toda a ajuda e colaboração ao Gonçalo Mendonça, ao Nuno Cordeiro, ao Luís Silva, ao João Vaz, ao Francisco Tavares e ao Frederico Malaquias.

Aos alunos e alunas da licenciatura em Fisioterapia da escola superior de saúde Dr. Lopes Dias, o meu obrigado pela ajuda prestada na recolha dos dados.

A todos os participantes do estudo devo o meu profundo e sincero obrigado, pois sem eles nada tinha sido possível, bem como aos clubes e instituições que participaram. Contudo, alguns pelo seu papel mais participativo nas fases de elaboração e conceção dos estudos, bem como nos testes piloto, merecem um especial destaque, tais como o Luís Martins, o Rui Pires ou o Pedro Moreno. Obrigado pelo vosso interesse, participação e ajuda nesta aventura.

Ao professor Orlando Fernandes um grande obrigado pela boa disposição e constante disponibilidade em ajudar-me, de forma a poder ultrapassar os meus obstáculos.

Os meus agradecimentos a todos o professores e elementos do Laboratório de Comportamento Motor, e em particular aos professores Filipe Melo e Sandro Freitas, que enquanto elementos da CAT, em muito contribuíram para esta tese, com os constantes feedbacks ou questões, sempre de forma construtiva, de forma a que eu pudesse crescer.

Ao doutor Luís Redinha, que foi o pioneiro da ideia por detrás desta tese, por todo o entusiasmo que tem sobre a temática, que acabou por passar para mim, bem como pela constante disponibilidade em ajudar, pelo apoio médico e logístico sem os quais não teria sido possível concluir este doutoramento.

Por último, mas não menos importante, ao meu orientador, professor Pedro Pezarat-Correia, sem o qual esta aventura nunca teria passado de um sonho, uma utopia. Muito obrigado por ter acreditado em mim ainda antes de eu acreditar em mim próprio. Estou a terminar uma história que, julgava eu, não tinha capacidade e competência para a contar, mas o professor Pezarat reconheceu em mim algo que eu não sabia existir, logo no final do mestrado. Foi preciso eu crescer e aprender, para ver aquilo que você viu. A si agradeço os conselhos, a calma, a experiência, as portas que me indicou, mas que deixou para eu as abrir, de forma a que pudesse ganhar autonomia e experiência. Acima de tudo agradeço-lhe pelo exemplo que foi, é e sem dúvida continuará a ser, tanto a nível pessoal como profissional.

TÍTULO: Efeito do uso de goteiras na função neuromuscular

RESUMO

Dispositivos orais, tais como as goteiras oclusais, têm sido promovidos como um meio para aumentar a performance desportiva. As goteiras promovem variações na posição do maxilar e por conseguinte criam alterações na articulação temporomandibular (ATM) e nos músculos da mastigação. Estudos têm sido feitos sobre os seus efeitos, a nível neuromuscular e fisiológico, para determinar as mudanças causadas pela sua utilização. Contudo, devido à escassez de estudos nesta área, bem como a lacunas nas metodologias usadas, não é possível dar uma resposta definitiva sobre a possível influência das goteiras na capacidade neuromuscular e na performance desportiva. Deste modo, o objetivo desta tese foi determinar os efeitos agudos da utilização de goteiras oclusais em diferentes aspetos da função neuromuscular. Para tal, cinco estudos foram realizados: 1) Uma revisão sistemática, que revelou evidências do efeito positivo das goteiras em tarefas isométricas do trem superior, para sujeitos destreinados; 2) Um estudo que demonstrou que as goteiras melhoram a força e atividade muscular em tarefas isocinéticas do trem superior, para sujeitos destreinados; 3) Um estudo que determinou que, em jogadores de rugby, as goteiras não aumentaram a força do trem superior num movimento balístico. No entanto, o uso de protetores bocais customizados aumentavam o pico de força e o pico de aceleração, embora outros parâmetros de força e potência não tenham sido afetados; 4) Um estudo que analisou a oscilação do corpo na marcha e corrida através da análise cinemática e não encontrou diferenças em função da utilização de goteiras; e 5) Um estudo que observou a oscilação do centro de pressão, a atividade EMG de músculos do membro superior e a precisão no alvo de atletas do tiro enquanto utilizavam goteiras e não encontrou diferenças em nenhum dos parâmetros. O efeito ergogénico das goteiras, ocorreu de forma clara em ações de força dinâmica do trem superior e em sujeitos destreinados. Protetores bocais customizados, que reposicionam em atletas treinados a ATM numa posição idêntica às goteiras, melhoraram alguns parâmetros de força e aceleração em movimentos balísticos do trem superior, mas não afetaram outros parâmetros. Futuras investigações devem confirmar estas hipóteses, bem como averiguar o efeito a longo prazo da utilização de goteiras.

PALAVRAS-CHAVE: Goteiras; Função Neuromuscular; Eletromiografia; Benefício ergogénico; Força; Equilíbrio corporal

TITLE: Effects of the use of occlusal splint on the neuromuscular function

ABSTRACT

Oral appliances, such as occlusal splints (OS), have been advocated as a mean to improve high-level sports performance. OS promote variations in jaw position and therefore create a change in the temporomandibular joint (TMJ) and on the masticatory muscles. They have been a subject of research, at neuromuscular and physiological level, to determined changes derived from the use of such devices. However, due to a paucity of research studies, and limitations on the used methods in the performed studies, it is not possible to give a correct and definite answer to the possible influence of OS on neuromuscular function and in the human sports performance. Therefore, this thesis aimed to ascertain the acute effects of occlusal splints on neuromuscular function. Five studies were conducted to achieve this purpose: 1) a systematic review, which revealed evidence of the effects of OS in upper body isometric tasks, for untrained healthy subjects; 2) a study that showed that OS enhance strength and muscle activity in upper body isokinetic tasks for untrained subjects; 3) a study which determined that for rugby athletes, OS did not increase strength in an upper body power movement, but a customized mouthguard increased peak force and peak acceleration despite other force and power did not change; 4) a study that analyzed kinematic body oscillation in gait and running and found no changes when using OS; and 5) a study that found no changes in body sway, EMG from upper limb muscles and shooting accuracy in pistol shooters while using OS. The ergogenic effect of OS was found in the dynamic strength performed by untrained subjects. Customized mouthguards, that reposition, for trained athletes, TMJ in an identical position as OS, increased some parameters of strength and acceleration but did not change other parameters. Future research should confirm these findings, while also determining the long-term effect of using OS.

KEYWORDS: Occlusal splints; Neuromuscular Function; Electromyography; Ergogenic aid; Strength; Body Balance;

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BBT – Ballistic bench throw

CAP – Concurrent activation potentiation

CMJ – Counter-movement jump

CMRR – common-mode rejection ratio

CNS – Central nervous system

CON – Control condition

COP – Center of pressure

CR – Centric relation

EMG – Electromyography

LPT – Linear position transducer

MCM – Mandible controlled mouthguard

N – Normal condition

NCM – non-controlled mouthguard

OS – Occlusal splint

PT – Peak torque

PS – Placebo splint

RVC – Remote voluntary contraction

SS – Stomatognathic system

TMJ – Temporomandibular joint

VD – Vertical dimension

VDO -Vertical dimension of occlusion

CHAPTER I – Introduction

Human performance has always been a subject of research. The use of occlusal splints to increase such performance has been a discussion topic for the last years. Occlusal splints (OS) are removable appliances that cover some or all of the occlusal surfaces of the teeth (Yunus, 2009). Occlusal splint therapy may be defined as the art and science of establishing harmony in the neuromuscular system through the correction of temporomandibular joint (TMJ) and the change of functional length of related muscles (Dylina, 2001). Most splints alter the vertical dimension of occlusion. This instantaneous change that occurs in muscle behaviour can be summarized as an increase of postural position of minimal muscles activity or a reduction of activity of postural muscles (Boero, 1989). When a subject wears an OS, it causes an immediate and pronounced relaxation in the masticatory muscles, which will eventually result in the mandible repositioning and the distribution forces across the masticatory system (Yunus, 2009).

From the existing literature, two hypotheses have been put forward as possible explanations for the use of OS and changes in the human body. The first one is based on changes in neuromuscular patterns caused by changes in peripheral proprioceptive input signals in the orofacial region, when using OS (Milani, De Perière, Lapeyre, & Pourreyron, 2000). The second one is based on fascial chains, that appear to possess an ability to contract when stimulated and can distribute tension throughout the body (Schleip, Klingler, & Lehmann-Horn, 2005).

Electromyography (EMG) analysis of muscle activity has been helpful to establish a connection for the relationship between the stomatognathic system muscles and muscles that control posture, as well as muscles involved in the movements of distal segments. The relation between TMJ and human body activity appears to exist (Gangloff & Perrin, 2002; Kibana, Ishijima, & Hirai, 2002) with specific functional correlations (Valentino, Melito, Aldi, Valentino, 2002), but there is still no scientific evidence to support this relationship. However, the above-mentioned studies before, demonstrate that T stomatognathic system muscles and muscles of other body segments are linked.

The effects of OS on muscle strength of upper and lower limbs (Alexander, 1999; Chakfa et al., 2002; Forgione, Mehta, McQquade, Westcott, 1992; Golem, 2012; Jung, Chae, & Lee, 2013; Lee et al., 2014) and trunk (Yates, Koen, Semenick, Kuftinec, 1984) muscles has been one of the great focus of studies in this area. Still, results reveal different effects on muscle strength, which range from significant increases to no differences at all.

Posture also appears to be affected by OS in static condition (Bracco, Deregibus, & Piscetta, 2004a) and during gait. When walking, the mandible moves vertically in relation to the maxilla (Flavel, Nordstrom, & Miles, 2003). If the muscles involved in TMJ are active and contracting during gait, maybe they could have an effect on body stability. Some studies point to this conclusion (Cuccia, 2011).

However, there are gaps in terms of quality and methodology of most studies that address the use of oral appliances on human performance (Hanke, Motschall, & Türp, 2007; Perinetti & Contardo, 2009), whether it is in a sport-related context or not. So, there is a need for further studies that quantify, and characterize neuromuscular patterns associated with motor performance tasks while using OS.

Objectives and Hypothesis

The **main purpose** of this thesis was to investigate the immediate changes and neuromuscular adaptations caused by the use of OS in healthy participants. In order to reach this objective, five studies were carried out, each one with its specific goal, but following a logical sequence.

The **study 1** was conducted with the objectives of:

1) Evaluate the body of evidence available on the efficiency of OS in producing changes in strength in healthy participants;
2) Determine the most used protocols and assessed parameters.

To achieve these objectives, we performed a systematic review, with quality studies analysis, using keywords from the dental medical field as well as from the sports science field. We searched the literature for studies that examined the acute effects of OS on strength, regardless of the assessment protocol or the body part tested. This review was also used to determine some of the parameters assessed in studies 2 and 3.

The **study 2** was performed with the following objectives:

1) Determine the acute effects of using OS on shoulder strength, through isokinetic evaluation;
2) Access how the use of OS affects neuromuscular activation patterns of muscles involved in the evaluated movements.

This second study was conducted with healthy participants. Considering the lack of unanimity and also the methodological limitations found in the experimental designs of studies that evaluated how OS affected strength in upper body, we measured isokinetic peak torque (PT) in two different arm movements. The definition of movements and conditions analysed in this study was based on some of the findings of study 1. Electromyography (EMG) of upper body muscles was also evaluated in this study, to address how and if the use of OS affects neuromuscular activity of shoulder muscles responsible for these movements.

The following hypotheses were tested in this study:

a) The use of OS that repositions TMJ would affect arm strength;
b) The amplitude of EMG signals of main muscles involved in these movements increases using OS.

The **study 3** aimed to address the following objectives:

1) To determine if the use of a mandible controlled position mouthguard would affect acute measurements of strength and power in rugby trained athletes;
2) To ascertain and compare if OS is associated with positive changes when compared to other mouthpieces.

This third study was performed with rugby players as participants, since they are acquainted with strength and power training and also because they usually use mouthguards during training sessions and games. Therefore, they qualify as an ideal pool of subjects for testing the acute effects of OS on trained athletes. For this study, a dynamic and ballistic movement was chosen for assessing a range of variables. We also manufactured and evaluated a custom made mouthguard that promoted the similar changes in TMJ as the OS.

Two hypotheses were formulated for this study:

a) The use of OS would affect strength in a dynamic power movement;
b) The use of custom made mouthguards that promoted the same changes in TMJ as the OS has a positive effect on strength.

The **study 4** was directed to the following objective:

1) Determine the immediate effect of using OS on dynamic posture.

This fourth study examined how the use of OS could affect body dynamic posture during gait and running on a treadmill. With the aid of 3D kinematic analysis, body horizontal and vertical sway was determined and evaluated to see how it would variate with the use of OS. Therefore, we tested two hypotheses:

a) The use of OS would reduce body sway during gait;
b) The use of OS would reduce body sway during running.

Finally, **study 5** was performed in order to:

1) Establish if OS would affect static posture, upper limb activation and performance during pistol shooting in trained athletes.

Given that current literature shows that the use of OS affects static posture, this study intended to analyse if OS would affect posture and shooting performance. For this purpose, a group of national level pistol shooters was recruited for the study. The experimental protocol used in this study gaged kinetic variables, as well as EMG activity of the arm and shoulders muscles of the arm holding the pistol. Sports performance (target accuracy) was also recorded to compare between test conditions. Three hypotheses were formulated for this study, as follows:

a) The use of OS would create a positive effect on body sway, by reducing the dispersion area;
b) Muscle activity amplitude of arm and shoulder muscles would be affected when using OS;
c) Scoring accuracy would have an increment, with the use of OS

Structure of the thesis

This thesis follows a study compilation organization, and will be presented as follows:

- Chapter I – Includes an introduction where the problem of the research is identified, and sets the structure of the thesis, describing the sequence of studies, their objectives and related hypothesis.
- Chapter II – Displays a review of the literature, where the main concepts are defined and explained. The topics of occlusion, occlusal splints and support theories for the problem are explored and detailed.
- Chapter III – Presents the methodology used in experimental design studies in a general way.
- Chapter IV to VIII – Presents, in each chapter, the five studies previously mentioned. These chapters share a similar organization: Introduction, Methods, Results, Discussion, Conclusions and References.
- Chapter IX – The General Discussion of the results of different studies are included in this chapter. A summary of the main findings of the studies is presented, followed by a rationale of how these results can be useful for sports performance. The limitations of the thesis are also discussed in this chapter, as well as recommendations for future research.
- Chapter X – The general Conclusions of the thesis are presented here. A summary of the main findings of the studies is presented, as well as clues for future studies on this topic.

- Chapter XI – Presents the list of references used in chapters I, II, III and IX. This chapter does not include the references used in the studies, given that each one of them has its own reference list.

CHAPTER II – Review of the literature

1. Temporomandibular joint anatomy

The temporomandibular joint (TMJ) is one of the last joints to appear in the uterus, emerging only at the 8th week of gestation (Bag, Gaddikeri, Singhal, Hardin, Tran, Medina, Curé, 2014). It is considered underdeveloped at birth when compared to other body joints and continues its development in the early childhood years as the jaw is employed for sucking and chewing motions (Bag, Gaddikeri, Singhal, Hardin, Tran, Medina, Curé, 2014). When fully developed, the TMJ is one of the most complex joints in the human body. The joint provides hinging movements in one plane, (backward and forward) and consequently can be considered a ginglymoid joint. However, simultaneously provides gliding movements, which classifies it as an arthrodial joint. Thus, due to the combination of movements and classifications, it has been considered a ginglymoarthrodial joint (Alomar et al., 2007; Okeson, 2008).

The osseous portions of the joint are composed by the concavity of the temporal mandibular bone (mandibular fossa) where the mandibular condyle fits. This concavity is designated the glenoid fossa (Walker & MacLeod, 2017). Separating these two bones from direct contact is the articular disk, which as a round or oval shape and it is biconcave. This disk has a thick anterior and posterior areas, with the intermediate zone being considerable thinner (Nelson, 2013; Walker & MacLeod, 2017). Functionally, the disk separates the joint cavity in two compartments (superior and inferior) (Tanaka & Koolstra, 2008) and serves as a nonossified bone that permits the complex movements of the joint (Okeson, 2008). The joint movement provides largely passive movable articular surface accommodating the translational movement made by the condyle (Tanaka & Koolstra, 2008). Due to this function, the TMJ is considered a compound joint (Okeson, 2008).

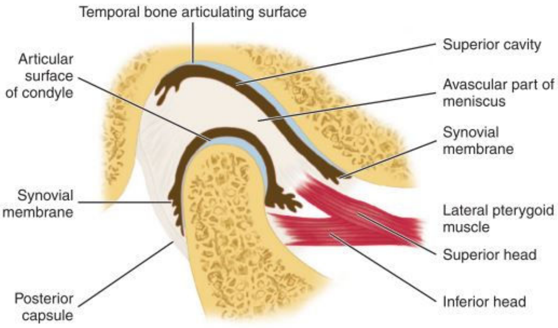

Figure 1. Schematic representation of the temporomandibular joint. Image retrieved from Nelson et al. (2012).

The capsule that encircles the TMJ contains a synovial membrane, responsible for the production of the synovial fluid that fills and nourishes the joint space. The joint has three functional types of ligaments: the collateral ligaments, the capsular ligaments and the temporomandibular ligament (Walker & MacLeod, 2017). The collateral ligaments spans from the mandible to the temporal bone and are responsible for allowing the disk to move passively with the condyle as it glides anteriorly and posteriorly. Thus, these ligaments are responsible for the hinging movement of the TMJ. The capsular ligaments are located inside the capsule and connect the disk to the poles of the condyle. These ligaments surround the TMJ and act to resist any lateral, medial or inferior forces that tend to separate or dislocate the articular surfaces. Additionally, these ligaments have a significant function of containing the synovial fluid, since they encompass the joint. Proprioceptive feedback regarding position and movement of the joint is also another function of these ligaments, since they are well innervated (Okeson, 2008). The temporomandibular ligament is composed of strong and tight fibers, overlaying the capsule, from the lateral aspect of the temporal bone to the neck of the condyle. This ligament is composed of two components: a horizontal component that resists to posterior displacement and an oblique component that limits rotational movement. This ligament is considered to play an important role in joint stabilization(Okeson, 2008; Walker & MacLeod, 2017). Additionally, two noncapsular accessory ligaments that have limited functional impact on the joint also exist: the sphenomandibular and the stylomandibular ligaments. The sphenomandibular ligament extends downward from the spine of the sphenoid bone to a small bony prominence on the medial surface of the mandible and it does not have any restrictive effects on the mandibular movement. The stylomandibular ligament arises in the styloid process and spreads downwards to the mandible. Its function is to limit excessive protrusive movements of the mandible (Okeson, 2008).

The TMJ exhibits several common features to other synovial joints, but most importantly, possesses exclusive characteristics that differentiates this joint, making it unique in several aspects. Both TMJ’s must function together, with a range of motion that has a fixed endpoint in the dentition. Contrasting to other synovial joints, that are covered by hyaline cartilage, the articular surfaces of the TMJ are covered by a layer of fibrous cartilage (Tanaka & Koolstra, 2008).

The muscular function of the TMJ is maintained by four pairs of muscles: the masseter, temporalis, medial and lateral pterygoid. All the four muscles are innervated by the anterior branch of the mandibular division of the trigeminal nerve (Walker & MacLeod, 2017).

The masseter originates in the zygomatic arch and has a downward profile to the lateral aspect of the lower border of the mandible, with a rectangular shape. When this muscle contracts, it elevates the mandible in such a way that teeth make contact, or in other words, its main function is the elevation of the mandible. When the mandible is protruded it can also assist in the stabilization of the condyle.

The temporalis is a muscle with a broad origin along the lateral temporal bone. It has a fan-shaped and extends downward forming a tendon between the zygomatic arch and the lateral surface of the skull that inserts on the coronoid process and anterior board of the ascending ramus. The temporalis can be divided into three different portions, according to fiber direction and function. The anterior portion is composed of fibers that are almost vertically in direction and when they contract, raises the mandible vertically. The middle portion contains fibers that are obliquely and has a function of elevation and retrusion of the mandible. The posterior portion has fibers that are aligned almost horizontally and when It contracts elevates and slightly retrudes the mandible. The temporalis is the principal positioner of the mandible during elevation, able of coordinating closing movements, due to the different angulation of its muscle fibers.

The medial pterygoid muscle originates in the pterygoid fossa and extends downward, backward and outward to insert along the medial surface of the mandibular angle. Along with the masseter, it forms a muscular sling that supports the mandible at the mandible angle. When active, this muscle elevates the mandible, but also helps in the protruding of the mandible. Unilateral contraction of this muscle will create a mediotrusive movement of the mandible.

The lateral pterygoid muscle is composed of two distinct portions. The superior portion originates from the base of the greater sphenoid wing and inserts into the articular disk. The inferior head originates from the lateral surface of the lateral pterygoid plate and inserts in the pterygoid fovea, on the front of the condylar neck. Their action together serves to pull the condyle and the disk simultaneously down the articular eminence, as well as helping in the protraction, depression and contralateral abduction. It also may be active during other movements for joint stabilization (Nelson, 2013; Okeson, 2008; Walker & MacLeod, 2017).

The TMJ is innervated by the same nerve that provides motor and sensory innervation to the muscles that control it. This sensory and motor innervation is provided by the trigeminal nerve, particularly by the mandibular division, which gives rises to four terminal branches (Walker & MacLeod, 2017). Most innervation is provided by the auriculotemporal nerve, which originates the mandibular nerve behind the joint and ascends laterally and superiorly to encompass the posterior region of the joint (Okeson, 2008). This nerve provides sensory innervation and proprioception from the TMJ.

Additional sensory innervation is also available anteriorly from the masseteric nerve and posteriorly form the posterior deep temporal nerve. Both nerves are branches of the anterior aspect of the mandibular division of the trigeminal nerve and provide sensory information to the TMJ, before innervating the muscles from which their names are derived (Walker & MacLeod, 2017).

2. Temporomandibular joint biomechanics

The fact that the two TMJs are connected to the same bone (mandible) makes this an extremely complex system. Each joint can concurrently act separately but is always dependent on the influence of the other. Adding to its intrinsic complexity, movement caused by the TMJ involves a high degree of interactions and coordination between bilateral condyles, disks, muscles and ligaments. Most frequently, an analogy is used to classify the movement of the mandible. The mandible is classified as a class III lever (Fig. 2), where the TMJ (via the condyle) acts as a fulcrum, the bite pressure as resistance and the musculature as applied forces, ultimately transmitting variable loads to the TMJ (Choi, Conway, Taraschi, & Ben-Nissan, 2015; Ellis & Throckmorton, 2005; Walker & MacLeod, 2017).

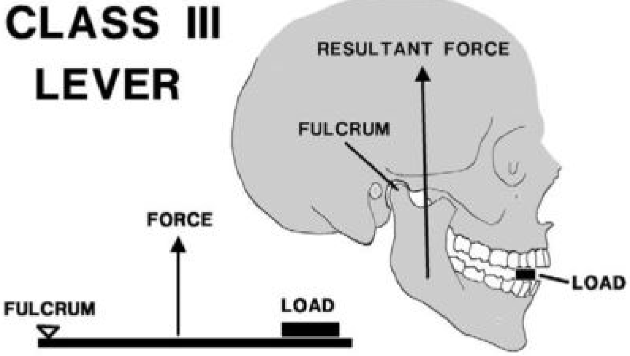

Figure 2. Illustration suggesting that the mandible functions as a class III lever. Image retrieved from Ellis et al. (2005)

In order to achieve mechanical equilibrium, the assumption behind the class III lever is that the bite force is less than the applied force, so that the entire system can achieve a mechanical advantage equal to less of one (Choi et al., 2015). This classification is not yet fully acknowledged and the interactions within the TMJ are to this day not fully understood (Bag et al., 2014). Some controversy still stands, since some authors argue that the condyle and articular fossa are not configured to withstand the large resultant forces required by the model. Also, according to the same authors, the model does not take in consideration the centre of mandibular rotation (Roberts & Tattersall, 1974).

Mathematical models of the forces acting on the TMJ have been made, but also with non-complying results, since a complete model of all the forces acting in the TMJ, with all vectors determined in a three dimension model is complex (Choi et al., 2015). For this model to be completed it is required to calculate the magnitude and direction of bite force, the magnitude and direction of each muscle force as well as the length of their moment arms.

The TMJ is a compound joint, and its structure and function can be divided into two distinct systems. The first system is composed by the tissues that surround the condyle and articular disk. Because this system is tightly bound by the lateral and medial discal ligaments, the only physiologic movement that can occur between these surfaces is the rotation of the disk on the articular surface of the condyle. Therefore, the condyle–disk complex is the joint system responsible for rotational movement in the TMJ (Choi et al., 2015; Okeson, 2008). The second system consists of the condyle-disk complex mentioned before functioning against the surfaces of the mandibular fossa. Since the disk is not tightly attached to the articular fossa, free sliding movement can happen between these surfaces in the superior cavity. This movement occurs when the mandible is positioned in a forward position, referred to as translation. Therefore, translation occurs in in the superior joint cavity between the superior surface of the articular disk and the mandibular fossa (Choi et al., 2015; Okeson, 2008). The articular disk plays a role in both joint systems, since it acts as a nonossified bone, and because of this function, it justifies the TMJ classification as a true compound joint (Okeson, 2008)

3. Occlusion and occlusal splints

The Glossary of Prosthodontic Terms defines dental occlusion as "*the static relationship between the incising or masticating surfaces of the maxillary or mandibular teeth or tooth analogues*" (Prosthodontics, 2005). This definition was the norm for many years and is in consonance with a view in which assessment and description of the occlusion is in static jaw positions, such as in intercuspal, lateral or protrusive jaw positions. But, more recently an evolution of this definition was conveyed, that assesses the teeth contacts from a more functional perspective. Therefore, a more fitting definition of dental occlusion is "*the dynamic biological relationship of the components of the masticatory system that determine tooth relationships*" (Klineberg & Jagger, 2004).

Occlusal splints (OS) are removable appliances that cover some or all of the occlusal surfaces of the teeth in either the maxillary or mandibular arches. The basic function of the OS is to prevent the existing occlusion from controlling the maxillo-mandibular relationship at maximum intercuspation (Yunus, 2009).

The use of OS may be defined as the process of establishing harmony in the neuromuscular system, when parafunctional forces are present. These parafunctional forces are harmful to the stomatognathic system and OS create a mechanical disadvantage for these forces, with removable appliances (Dylina, 2001), re-establishing a good relation of forces.

Most splints alter the vertical dimension of occlusion instantaneously. These changes can be summarized as (Boero, 1989):

a) Elevator muscles have greater length with an increase in vertical dimension of occlusion and can contract more efficiently;

b) The position of minimal muscle activity is obtained with a larger vertical dimension of occlusion;

c) An increase in the occlusal vertical dimension causes an immediate adaptation to a new freeway space;

d) The EMG activity of the postural muscles (anterior temporalis) is reduced with an increased vertical dimension of occlusion.

When a person uses an occlusal splint in his mouth, it causes an immediate and pronounced relaxation in the masticatory muscles, which will eventually result in the mandible repositioning and closing in a more retruded position without teeth interference. The OS also provides a platform for the teeth, which will allow for equal distribution of tooth contacts, immediate posterior tooth disclusion in all movements and reduced stress on the joint. An optimal function and comfort is achieved with this neuromuscular harmony, by the distribution of the force across the masticatory system (Yunus, 2009).

4. Stomatognathic system

The TMJ is part of a large system comprised of several structures. This system is designated by stomatognathic system (SS) and is a functional unit that embraces skeletal components (maxilla and mandible), dental arches, soft tissues (salivary glands, nervous and vascular supplies), and the temporomandibular joint and masticatory muscles (Cuccia & Caradonna, 2009) which are controlled by the central nervous system (Kandel, 2013). These structures act in harmony to perform different functional tasks: speech, open and closing , mastication, and deglutition as well as parafunctional actions (Prosthodontics, 2005).

4.1. Stomatognathic system and body posture

Posture refers to the position of the human body and its orientation in space. Posture involves muscle activation that, controlled by the central nervous system (CNS), leads to postural adjustments. These adjustments are the result of a complex system of mechanisms that are controlled by multisensory inputs (visual, vestibular, and somatosensory) integrated in the CNS. Through mechanisms of feed-back and feed-forward, postural adjustments play a critical role in orthostatic and dynamic postural control, influencing the ability to perform daily living activities. As with reflexes, postural adjustments improve through exercise and learning (Kandel, 2013).

The SS also plays an important role in postural control, as TMJ makes muscular and ligament connections to the cervical region, forming a functional complex called the "cranio-cervico-mandibular system" (Cuccia & Caradonna, 2009).

A study that measured the electromyography (EMG) activities of the jaw closing muscles and the sternocleidomastoid muscle showed a positive correlation between those two groups of muscles. Since the sternocleidomastoid muscle is related to head posture, the authors claimed that the act of teeth clenching affects the head posture (Kibana et al., 2002).

A functional coupling between trigeminal nerve and cervical systems was demonstrated in a study (Browne, Clark, Yang, Nakano, 1993) that inhibited the sternocleidomastoid muscle with a trigeminal stimulation. EMG was used to see if an electrical stimulation of the masseter muscles would have some influence on sternocleidomastoid muscle. The results showed that sternocleidomastoid could be triggered by activating masseter muscles, showing that a link exists between the two muscles.

The existence of connections between the SS and body posture was measured in different occlusal mandibular positions, using cotton rolls, of adults who underwent anterior cruciate ligament (ACL) surgery (Tecco et al., 2006). EMG measurements were made in the masseter, temporal, sternocleidomastoid and cervical muscles, to represent neck muscles and upper and lower trapezius as the trunk muscles with different occlusal mandibular positions using cotton rolls. The same measurements were made on a control group. Body sway was measured using a force platform and EMG measurements were recorded in different muscle groups: masseter, temporal, sternocleidomastoid, cervical muscles, neck muscles, upper and lower trapezius and trunk muscles. The results showed that, compared with the healthy subjects, ACL patients, the centre of pressure (COP) significantly moved into the right and forward directions in all tests situation, and EMG activity of the masseter, lower trapezius and sternocleidomastoid muscles increased significantly. According to the authors these results may reflect the extension of the muscular tensions, that is produced by the postural pathology of the knee, which appears to affect the muscle activity of neck and trunk muscles.

Subjects that had a TMJ disorder (TMD) were asked to fill a questionnaire on pain in the neck and jaw disability. This study was done to determine the relationship between pain and corresponding ineptitude for performing functional activities of daily living in patients with TMD. The results of this study demonstrated a strong correlation between jaw disability and neck disability (Olivo et al., 2010). This means that people who suffered from jaw pain, as a result, had a high level of jaw disability and also had a high disability in the neck region. A similar result was obtained when the prevalence of craniomandibular pain and cervical spinal pain was studied (Visscher, Lobbezoo, de Boer, van der Zaag, & Naeije, 2001). The authors concluded that chronic craniomandibular pain patients more often suffer from cervical spinal pain than person without craniomandibular pains.

An OS was used to access the changes in head position and postural alterations in subjects with TMD (Strini et al., 2009). The study evaluated the stomatognathic alterations before and after the installation of the occlusal splint. When analysing the results, after one week of continuous use, the patients tend to bring their head to an ideal position. After one month of use, significant differences were found in head position. Subjects also reported a major decrease in the level of pain. The authors concluded that results suggest an important interrelation between occlusion and head position, meaning that the postural position of the individual can suffer biomechanical alterations originated from stomatognathic modifications in dysfunctional individuals, causing clinically visible changes and affecting the performance of the involved structures.

The studies mentioned before appears to demonstrate that the muscular and ligament connections that exist between the TMJ and the cervical region may have an influence on head posture. Consequently, the change in head position may cause a variation in COP parameters for both static and dynamic balance. This topic will be discussed in the next point.

4.1.1. Occlusion and orthostatic position

Several studies have addressed the effect of occlusion on the body sway. Cotton rolls were used to change mandibular position and the COP was measured with a force platform with eyes opened and closed (Baldini, Nota, Tripodi, Longoni, & Cozza, 2013). The authors reported that the mandibular position had a significant influence in the sway area parameter, but did not influence sway velocity.

A force platform was also used to measure the effects of three different mandibular positions (centric occlusion, rest position and myocentric position) on postural stability (Bracco, Deregibus, & Piscetta, 2004b). The results support the observation that different jaws relations imply differences in body posture. In fact, the study showed a strong relationship between mandibular position and body posture: 95.8% of the subjects showed variations in load distribution when closing mouth either in centric occlusion or in myocentric position. Furthermore, 97.9% of the subjects showed changes also in the distance between theoretical and real barycenter on x axis, and all of them showed changes on y axis. The authors stated that a good balance of masticatory and head and neck muscles seems to be an important factor for postural stability.

With the use of EMG Hosoda and colleagues (Hosoda et al., 2007) were able to determine muscle activation on the masseter muscles during the maximum voluntary contractions (MVC). With this information, subjects were tested on a force platform while clenching (20% to 50% of MVC - occlusion) and without clenching (teeth not touching). To provoke body sway, an external disturbance was used. The results demonstrated only a little difference in latency with a small disturbance, between teeth clenching conditions. However, when greater disturbances were introduced, results grew apart. Latency became smaller in the presence of occlusion and greater with no occlusion. According to the authors, the time required for the beginning of the recovery in response to external disturbance in the standing position is shortened with jaw occlusion compared to without jaw occlusion, which suggests a possible role of occlusion in the improvement of balancing ability.

Other authors also scrutinized posture in the orthostatic position and its possible relation to the SS and found no differences in the results. A sample of women was divided into three sub-groups: healthy, malocclusion and TMD. Several occlusion positions were tested with the use of a force platform, in order to measure COP variability of each foot. When comparing the results of different sub-groups, there were no significant differences reported, despite a large intrasample variability. From a statistical point of view, the fact that sub-groups were small in numbers, combined with the variability of results, could have hidden between-group differences, according to the authors. They also state that it is possible that postural alterations can occur, via a complex neuromuscular mechanism, but maybe they are not detectable at the foot level (Virgilio F Ferrario, Chiarella, Taroni, & Schmitz, 1996).

Posturography was also used as a mean to access the influence of dental occlusion in COP movement, sway area, sway length and sway velocity in healthy subjects. Several occlusal conditions were tested, with eyes open and closed on a vertical force platform. A lack of significance on tests results revealed that posture was not affected by changes in dental occlusion in the age range of subjects included. According to the authors, the results of the study don´t necessarily deny the existence of an influence of dental occlusion in posture, but maybe support that such a connection is smaller in importance (Giuseppe Perinetti, 2006). In conclusion, the results on the effects of TMJ manipulation and its influence in orthostatic position are still debatable. Some studies point to a connection between them, while others dismiss that link, or state that it is small in significance. More studies are required, so that a consensus can be reached on this topic.

4.1.2. Occlusion and gait

Some evidences support that dental occlusion affects posture not only in the orthostatic condition, but also when the human body is in motion.

Six different mandibular positions were tested, with the use of occlusal splints, to investigate their effect on body equilibrium and gait stability (Fujimoto, Hayakawa, Hirano, & Watanabe, 2001). Subjects underwent tests in three different walking speeds and significant differences were reported at all gait speeds, for the coefficient of variation at fast speed and ordinary speed and for the gait velocity at fast speed. According to the authors, the results of this study suggested that a change in mandibular position conditioned gait stability.

The plantar surface is important for postural control since it has receptors that convey sensory information about the ground that a person is stepping. With this idea in mind, a study was conducted to compare subjects with and without TMD in three dental occlusion conditions, while walking in a force platform (Cuccia, 2011). When comparing both groups, the authors found differences between them in postural conditions and in the plantar arch. In an intra-group analysis, differences were also found when the subjects were clenching their teeth, which instigated a load reduction and an increase in surface contact on both feet. This study was pointed by the authors as a possible explanation for the interrelationship between stomatognathic inputs and locomotion.

An experimental induced imbalance of occlusion was created with the help of cotton rolls, to investigate possible correlations between postural loading on feet during walking (Simona Tecco, Polimeni, Saccucci, & Festa, 2010). The imbalance of dental occlusion was achieved with a cotton roll on one side of the dental arch. Three conditions were tested: with a cotton roll on each side of the dental arch and normal occlusion. The results demonstrated that when using a cotton roll on one side of the dental arch, the loading on the foot of the same side was significantly lower than in habitual occlusion or with cotton roll in the opposite side. These results suggest that in healthy adults, the loading on the foot may be changed with the manipulation of dental occlusion.

During gait, the mandible moves vertically relative to the maxilla during each step in all forms of locomotion in a manner that depends on the type and speed of gait. The movements occur within a small range and teeth normally don't make contact, possibly because there are passive elastic forces that limit these movements (Flavel, Nordstrom, & Miles, 2003). It is possible that, if the muscles involved in TMJ are active and contracting during gait, they could influence body stability. Despite several studies regarding TMJ manipulation and body posture (orthostatic position and gait), some controversy exists regarding the effects of dental occlusion on human body posture. Although most results point to some kind of relationship, the strength of that relationship is unclear, as well as how that relationship happens. There is still no agreement on the subject. Taking into account the conclusions of several studies reviewed so far, future experiments should have a strong factual base, with a solid statistical design.

5. Stomatognathic system and neuromuscular mechanisms

5.1. Feedback / feedforward theory

Previously it was demonstrated that a relationship appears to exist between the SS and posture, but the possible neuromuscular mechanisms that make that connection possible have not been addressed. EMG analysis of muscle activity has been helpful to determine onset and latency of neuromuscular activations and established a connection and explication for the relationship between TMJ muscles and muscles that control posture, as well as other muscles of the distal segments.

Yokoyama (Yokoyama, 1998) studied the EMG activity in different mandibular positions while performing exercise. The results showed that the onset of EMG activity on TMJ muscles was earlier than the agonist muscles, as well as EMG amplitude was lower when subjects had a voluntary mouth opening while performing the exercise. Also, numerous subjects presented involuntary teeth clenching during the exercise. These results suggested that SS and physical exercise had an interdepend relationship and that the involuntary teeth clenching can be explained by a feedforward mechanism.

TMJ muscles, as well as the sternocleidomastoid muscle, were analysed using EMG during a voluntary maximal clenching on an occlusal splint. The results demonstrated that the EMG onset of the sternocleidomastoid muscle started later, when compared to the jaw closing muscles. Since sternocleidomastoid muscle is responsible for head posture, it appears that the later activation of this muscle, in relation to the jaw clenching muscles is a response/adaptation to a change that occur, via a feedback mechanism (Kibana et al., 2002).

A connection between neuromuscular mechanisms and TMJ was also established in a study by Gangloff (Gangloff & Perrin, 2002). In this study, COP displacement was monitored with eyes opened and closed in two conditions: with and without unilateral truncular anaesthesia of the trigeminal nerve. Results showed that postural control is impaired when trigeminal proprioception inputs were blocked by anaesthesia, with the head posture being modified because of masseter and SCM muscle inhibition. It appears that a connection exists between trigeminal nerve, which innerves TMJ muscles and balance control.

Another study that used anaesthesia in the right feet plantar sole, measured EMG response of the soleus and tibialis anterior muscles during a balance perturbation. The results showed that proprioceptive inputs play a role in postural control and support the feedback and feedforward hypothesis (Thoumie & Do, 1996).

Previous studies suggest that there is a connection between the SS muscles, in particular TMJ muscles and muscle activities of other body regions, including those responsible for body posture, due to a reciprocal innervation between the trigeminal and the cervical systems that produces mutual inhibition and activation. So, it seems that there is a dynamic relationship among dental occlusion, 'space condition' and head posture (Daly, Preston, & Evans, 1982). It was hypothesized that changes in the peripheral proprioceptive input signals in the orofacial region are transmitted to the CNS via trigeminal nerve, and then the altered output signal is transferred via spinal and autonomic nerves to the whole body system (Milani et al., 2000).

It appears that a feedback / feedforward mechanism is a viable explication for the relationship between TMJ muscles and body muscles from distal segments. Several authors have found an EMG relationship between TMJ and lower limbs (Ishijima, Hirai, Koshino, Konishi, & Yokoyama, 1998), trunk muscles (Tecco, Caputi, & Festa, 2007), and upper limbs (Ferrario, Sforza, Serrao, Fragnito, & Grassi, 2001) that support this theory, but more research is required in order to create a consensus on the topic, as well as reliable evidence.

5.2. The anatomical hypothesis – fascial contraction

A more anatomical connection appears also to exist between TMJ muscles and muscles in other parts of the body. With the aid of ultrasound, it was possible to measure muscle thickness of arm flexors and leg extensors and relate them with masseter and temporal muscles thickness (Raadsheer, Van Eijden, Van Ginkel, & Prahl-Andersen, 2004). Results showed that the size of the jaw muscles was significantly related to the size of the limb muscles, suggesting that they were both influenced by the same metabolic and hormonal interactions as those reported for other skeletal muscles. In an effort to find an explanation for the effects of SS in the postural body, a review of studies was made (Cuccia & Caradonna, 2009), in order to find some common answers and also to promote an interdisciplinary approach. The authors of this review proposed the existence of muscular fascial chains as a base element of the correlation between SS and human body. Fascia is dense, fibrous connective tissue that interpenetrate and surround the human body to protect, nourish and hold organs in place (Schleip et al., 2005). The fascial system is important not only because it can passively distribute tension in the body muscles when mechanically stimulated, but also because it contains mechanoreceptors and possesses an autonomous contractile ability that influences the tension of the fasciae. According to the authors, the existence of these muscular-fascial chains could explain why TMD could influence distal musculature.

Myers (Myers, 2009) referred to fascia as myofascia and characterized them as structures that maintain their integrity due primarily to a balance of woven tensile forces continual through the structure as opposed to leaning on the continuous compressive force. According to the author, myofasciae provide a continuous network of restricting but adjustable tension around the individual bones and cartilage. This network, which the author called “tensegrity” (tension + integrity) is a structure that combines tension and compression members. Because the structure distributes strain along the lines of tension, the tensegrity structure may fail at one given point in the body, which leads to changes in other points of the body. In other words, the analysis of this model shows that an injury at any given part of the body affects other body parts, which apparently have no direct connection. This idea is identical to the one presented by another author (Cuccia & Caradonna, 2009) and can explain why an ACL injury affects EMG in cervical and trunk muscles (Tecco et al., 2006) or why EMG muscle amplitude is altered in upper and lower limbs with different jaw positions (Yokoyama, 1998).

A structural explication can be found in the fascia properties. Up until now, their role was seen as a passive contributor to biomechanical behaviour but the tensegrity model offers the possibility of active contractions by these structures, via the presence of a class of cells – fibroblasts – that can exert significant contractile force in a specific set of circumstances. Therefore, fascia may be able to adjust its degree of contraction spontaneously, in a time period that ranges from minutes to hours and therefore contribute to musculoskeletal dynamics (Schleip et al., 2005). A genetic study reinforces this supposition, since it revealed that fibroblasts, as well as chondroblasts and osteoblasts are connective tissue cells with muscle (Spector, 2001).. Adding to the concept, in broad fascial sheets, mechanoreceptors are found, that are equal to the ones contained in ligaments, which provide feedback for muscle coordination. Therefore it is reasonable to assume that they have a similar function in fascias (Yahia, Rhalmi, Newman, & Isler, 1992). This contractile behaviour of fascia was called Fascial Plasticity (Robert Schleip, 2003) as some study supports this hypothesis (Staubesand & Ly, 1996; Yahia, Pigeon, & DesRosiers, 1993)

With the aid of electron photomicroscopy, the fascia cruris in humans was analysed for several years. The authors (Staubesand & Ly, 1996) reported the discovery of smooth muscles cells in the collagen fibers. They concluded that these fascial muscle cells enable the autonomous nervous system to regulate a fascial pre-tension, independently of muscle tonus. They also add that this discovery of fascia as an organ with the capability of adaptation gives it a much higher functional importance.

A contractile behaviour was also described while studying human fascial sheets in in vitro conditions. This viscoelastic property, named by the authors as “ligament contraction” was an unexpected result of an isometric stretching of human lumbar fascia (Yahia, Pigeon, & DesRosiers, 1993). When stretched for a period of time and held at a constant length repeatedly, the tissues started to slowly increase their resistance, in other words, they were becoming stiffer. The most plausible explanation, according to the authors, was the presence of smooth muscles like cells in the fascia.

While alone, the results that were presented here don’t add a definite conclusion. However, when we add them together, we can carefully state that there are smooth muscle cells embedded in the fascias that are present in the human body, and that maybe they are involved in the regulation of a muscle-fascial chain or network of fascias. The capability of regulation by this fascias can have substantial biomechanical influences (Schleip et al., 2005) and perhaps can also play an important role in how TMJ can affect distal musculature in the human body. Even though these assumptions are factual based, they are not unanimous, since some studies did not find any evidence of connection supporting the fascial contraction theory (Ambrosina Michelotti et al., 2006).

CHAPTER III – Methodology

1. Testing conditions

Studies on this thesis have shared similar features in their methodology (Table 1). In order to compare the ergogenic effects of OS, analogous conditions were tested in the experimental designs (chapter V to VIII): a) occlusal splint; b) placebo splint and c) control condition (no splint). In the systematic review (chapter IV) the focus of the research strategy was also in studies that assessed similar OS used in the other studies. The only exception for those testing conditions happened in chapter VI, were the placebo splint was not tested. In his place, two different mouthguards were added, one of which served as a placebo.

2. Manufacturing of the oral appliances

For the manufacture of the oral appliances used in the experimental designs, full maxillar and mandibular arch impressions were taken using irreversible hydrocoloid (Zhermack OrthoPrint, Rovigo, Italy) and poured in Type III dental stone (Blue Stone,Proal, Toledo, Spain). Facebow records were obtained using an arbitrary facebow (Artex FaceBow, AmmanGirrbach, Koblach, Austria). Maxillo-mandibular relation (Centric relation -CR) was determined after subject patient deprogramming (cotton rolls interposed between teeth arches for 4 to 5 minutes) with a Leaf Gauge (Great Lakes Orthodontics, Tonawanda, USA). Then, subjects were asked to close and slide forward/backward two or three times and then holding the most posterior comfortable, non-restrained position, without operator guidance: Subjects were asked to open and close a few times within a 10 to 15mm opening limit . The records for CR were obtained with polyvynilsiloxane bite registration material (VPS- Hydro Bite, Henry Schein,Melville, USA). After material setting, leaf gauge was removed and confirmation of record position was obtained by repeated non- guided, non-restrained repeated closure. Maxillary stone casts were related to an Artex CP semi adjustable articulator (AmmanGirrbach, Koblach, Austria) with the use of a Artex Transfer Jig (AmmanGirrbach, Koblach, Austria) and secured in place with the use of mounting plaster (Quick Rock -Protechno, Vilamalla, Spain). Mandibular stones casts were related to the maxillary casts interposing the trimmed CR records, and secured in place with the use of mounting plaster (Quick Rock -Protechno, Vilamalla, Spain).

The OS were manufactured using a vacuum former machine (Easy Vac, Baekseokdong, South Korea). A 3-mm thermoforming foil (Erkodent, Pfalzgrafenweiler, Germany) was adapted over the maxillary casts, trimmed and adjusted in the articulator at the minimum vertical dimension of occlusion allowed by the thickness of the thermoformed foil, to the requisites of a stabilization splint in CR position. Afterwards, OS was tried in the subject´s mouth, checked for stability, retention and comfort and occlusal adjustments were performed until a mutually protected occlusion, coincident with TMJ centric relation was obtained.

Placebo devices were obtained using an identical three mm thermoforming foil (Erkodent, Pfalzgrafenweiler, Germany) adapted over maxillary casts and trimmed down on the occlusal surface to ensure that they would not interfere with the subjects normal maximum intercuspation. Placebos devices were tried in the subject’s mouth for comfort, stability and absence of conflict with subject’s normal dental occlusion.

In study 3, two over-the-counter mouthguards (Everlast Single Mouthguard, Moberly, USA) were tested additionally to OS. The mouthguards were prepared as per manufacturer instructions and fitted to each participant’s specific maxillary cast. The mouthguards were then adjusted into the subject’s mouth. For the mouthguards that had a controlled mandible position, intermaxillary stabilization was obtained using bilateral manipulation for positioning the mouthguard in the CR position. The mouthguards that had a non-controlled mandible position, who served as placebo in the study, were placed in the participants’ mouth and instructions were given to bite down and keep the position until cooling of the material occurred. All the mouthguards had the vertical dimension of occlusion (VDO) measured for comparison. This was done after the final fitting of the mouthpieces. Upon releasing of articulator centric latches, mounted stone casts where brought to maximum intercuspation and articulator incisal pin reading, used to establish reference baseline for test subjects VDO. Each of the test mouthpieces was subsequently placed on to the maxillary arch stone models and changes in VDO recorded at the incisal pin.

3. Evaluation methods

Regarding the methods used to evaluate the ergogenic effects of OS on the human body, they were assessed in two different manners. Two experimental studies examined the ergogenic effects on strength (chapters V and VI) and two focused on balance (chapters VII and VIII). For the design of the strength assessment studies, the recommendations and conclusions in chapter IV were substantial. Strength development and how it was affected by OS was analysed in two different procedures. In chapter V, strength was evaluated in an isokinetic manner, while the study of chapter VI focused on strength development in a power movement.

Body balance was the focus of the two other studies in this thesis. Both shared the same theoretical background, but focused on two different methods of balance evaluation. One study focused on dynamic balance (chapter VII) in gait and running, which are basic skills in any sports. Static balance was the focus of the final experimental study (chapter VIII), which is also a fundamental skill in specific sports.

Study	Participants	Objectives	Testing Conditions	Evaluation methods
2 (chapter V) Effects of occlusal splints on shoulder strength and activation	14 healthy untrained male participants. Age = 21.67 ± 0.86 yrs	1. Determine the acute effects of using OS on strength in upper limbs, using an isokinetic task; 2. Access how the use of OS affects EMG signals of the main muscles involved in the tasks;	1) Occlusal splint; 2) Placebo splint; 3) Control condition – Normal (no splint).	Isokinetic evaluation of shoulder abduction / adduction and shoulder external / internal rotation. Surface EMG of the three portions of the deltoid, lower trapezius, pectoralis major and infraspinatus
3 (chapter VI) The effect of a controlled mandible position mouthguard on strength and power in trained rugby athletes	22 male amateur rugby players. Age = 25 ± 3.84 yrs	1) To determine if the use of a mandible controlled position mouthguard would affect acute measurements of strength and power in trained athletes; 2) To ascertain and compare if OS are associated with positive changes when compared to other thicker mouthpieces.	1) Occlusal splint; 2) Mouthguard with a controlled mandible position; 3) Mouthguard with no controlled mandible position – Placebo; 4) Control condition - Normal (no splint or mouthguard).	A position transducer was used to assess different movement parameters during a ballistic bench throw.
4 (chapter VII) The effects of occlusal splints on gait and running patterns: A kinematic analysis	15 male healthy participants. Age: 21.13 ± 2.53 yrs	1. To determine the effect of using OS on dynamic posture;	1) Occlusal splint; 2) Placebo splint; 3) Control condition – Normal (no splint).	Three-dimensional kinematic analysis of body horizontal and vertical sway during gait and running.
5 (chapter VIII) Effects of dental occlusion on body sway, upper body muscle activity, and shooting performance in pistol shooters	13 pistol shooting athletes Age= 38.8 ± 10.9yrs	1) To establish if OS would affect static posture, upper limb activation and performance during pistol shooting in trained athletes		A force platform was used to evaluate centre of pressure oscillation. Surface EMG was recorded from medium deltoid, upper trapezius, biceps brachii, flexor digitorum superficialis, and extensor digitorum of the arm that holds the pistol. Performance evaluation was also done by recording shot performance.

Table 1. Main aspects of the methodology used for each experimental study.

4. Participants

Each of the studies in this thesis was designed to approach a specific topic and required, to some extent, participants that could fulfil the specific characteristics required. Therefore, no participants took part in more than one study. In total, 64 participants were tested in the different studies.

All of the participants in the different studies were male. The choice for including only male subjects in the studies was due to the fact that they have a lower incidence of TMJ disorders (Frederick & Steinkeler, 2013; Johansson et al., 2003; Manfredini et al., 2011; Pow et al., 2001), as well as a lower percentage of body fat (Blaak, 2001), which could have implications in the quality of the EMG signals.

In study 2, fourteen untrained male participants were recruited (age = 21.67 ± 0.86 yrs; height = 1.76 ± 0.61 m; weight = 76.33 ± 7 kg) to underwent isokinetic strength assessment.

For study number 3, that assessed a ballistic power movement of upper arms, twenty-two male amateur rugby players (age = 25 ± 3.84 yrs; height = 1.92 ± 0.07 m; weight = 93.91 ± 11.99 kg) volunteered for the study.

In study 4, fifteen healthy active participants participated (age: 21.13 ± 2.53 yrs; height: 1.80 ± 0.06 m; weight: 74.67 ± 7.04 kg) in a study that appraised how body oscillation in dynamic conditions was affected with OS.

Finally, study 5 evaluated body oscillation in static conditions, as well as performance in thirteen national level 10-meters pistol shooters (age= 38.8 ± 10.9yrs; kg; height= 1.75 ± 0.1m; weight= 79.7 ± 10.7).

In all the studies, testing procedures were explained to the participants, prior to executing them, as well as any questions were answered. Written consents were obtained from the participants. This research was approved by the ethics committee of the Faculdade de Motricidade Humana for use of human research (6/2016).

5. Testing procedures

5.1. Procedures for collection and processing of EMG signals

For studies 2 and 5, EMG signals were collected using detection surfaces (AMBU, Ballerup, Denmark) with a 10mm disk shape, attached to bipolar surface electrodes (Plux, Lisbon, Portugal). The EMG signals were amplified with a band pass filter (25-500Hz), common-mode rejection ratio (CMRR) of 110dB and a gain of 1000 (Pezarat-

Correia & Mil-Homens, 2004). All the EMG data was recorded at 1000hz, using a specific software (OpenSignals, Plux, Lisbon, Portugal). All the raw EMG signals were visually inspected before processing, to assure their quality. Afterwards, the signals were digitally filtered (20-500Hz), rectified, smoothed through low pass filter (12Hz, fourth-order Butterworth digital filter) and amplitude averaged for the specific time window. Processing and analysis of the signals were performed using a customized routine for each study, with Matlab software (version 2013a, Mathworks Inc., Natick Massachusetts, USA). Placement of the electrodes for both studies followed international guidelines (Criswell, 2011; Perotto, 2011).

5.2. Procedures for collection and processing isokinetic signals

Shoulder isokinetic evaluation was performed in study 2 using a Biodex Medical System Isokinetic dynamometer (Biodex System, Shirley, NY, USA). Participants were seated in the chair, in a comfortable position, with the axis of the dynamometer aligned with the axis of the movement. Straps were placed around chest, waist and wrist. The arm was statically weighted to provide gravity correction. For shoulder abduction and adduction movements, measurements were made with the elbow placed at a 45° flexion and a range of motion from 30° (start) abduction to 135° (end) abduction. When testing external and internal rotation, measurements were made with arm positioned at 45° abduction in the scapular plane, with elbow flexed to 90°. Range of motion was from 0° (start) to 90° (external rotation – end). For each movement, five maximal repetitions were performed at a velocity of 60°/sec with a rest period of three minutes between test conditions. Peak torque was determined in each repetition, for each movement.

5.3. Procedures for collection and processing power and strength during ballistic bench press throw exercise

For registering all the data in study 3, a two-session protocol was conducted, using a Smith machine. In the first session, the subjects were asked to perform a 1RM bench press. In the second session, the participants performed ballistic bench throws at 40% of the 1RM value determined previously. This load (40% of 1RM) was selected because it is within the range where rugby athletes can produce higher peak power outputs in the bench press throw (Baker et al., 2001; Bevan et al., 2010)

A linear position transducer (Chronojump, Barcelona, Spain) was attached to the bar of the smith machine and placed directly above the vertical axis of movement. The transducer was connected to a microcontroller (Chronopic) that recorded at 1000Hz and transmitted all the information in real time to a personal computed that was running a specific software (Chronojump 1.6.1) The variables assessed were: velocity; peak velocity; time to peak velocity; acceleration; peak acceleration; power; peak power; time to peak power; force, peak force and time to peak force.

5.4. Procedures for collecting and processing kinematic data

Three-dimensional kinematic analysis was used in study number 4. For that purpose, five high-speed cameras (Basler A602fc, Basler Vision Technologies, Ahrensburg, Germany) were used, operating at a sampling rate of 100 Hz. One camera was placed directly behind the treadmill used for testing and the other four cameras were placed at an oblique angle of 110 degrees, in anterior and posterior positions. Reflective markers were placed both acromion's, as well as on left and right anterior and posterior superior iliac spine. For body vertical sway, reflective markers were placed on C7 and L5. Recording and processing of marker trajectories were performed using a specialized software (SIMI motion system, Simi Reality Motion Systems GmbH, Unterschleissheim, Germany). A customized Matlab routine (Matlab software, VR2013a, The Mathworks Inc., Natick Massachusetts, USA) was used afterwards to detect gait cycles and calculate the oscillation angles.

5.5. Procedures for collecting and processing kinetic data

Center of pressure oscillation in static position was assessed in study 5. In order to evaluate center of pressure oscillation, a force platform was used (Plux, Lisbon, Portugal), with a dimension of 4500 x 4500 mm. The signal from the force platform was recorded at 1000Hz with the aid of a specific software (Opensignals, Plux, Lisbon). Subsequently, processing of the signal consisted of a downsample to 100hz, passed through a digital amplifier with a gain of 400, and processed with a low pass filter (12Hz, second-order Butterworth digital filter). All of the processing and analysis was performed with a Matlab routine (Matlab software, version 2013a, Mathworks Inc., Natick Massachusetts, USA).

5.6. Statistical analysis

Given that the independent variable in each of the studies will always be identical (occlusal splint, placebo splint and control condition), with the exception of study 3 (occlusal splint, controlled mouthguard, placebo mouthguard and control condition), there is a great similarity in the type of statistical treatment used in the different studies. A repeated measures ANOVA was used to verify the differences between the tested conditions. If the normality assumptions were not met, the non-parametric alternative, the Friedman test, was performed. When the sphericity does not occur, but the other assumptions are verified, a Greenhouse-Geisser correction was made. When differences were found between the tested conditions, the comparison between the possible pairs was analysed using multiple comparisons tests of Bonferroni or Dunn. Additionally, Cohen’s d was calculated to estimate effect sizes between the paired conditions that presented differences.

CHAPTER IV - A systematic review on the effects of occlusal splint therapy on muscle strength

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Status: Submitted; under review

ABSTRACT

The aim of this study was to conduct a systematic review on the effectiveness of occlusal splints for improving muscle strength. Occlusal splints are oral appliances that cause joint stabilization, by changing the relationship between mandible and maxillae. They serve to reduce imbalances within the temporomandibular joint. A mix of medical and sports science terms was used to perform the search on several databases (Web of Science, Science Direct, SPORT Discus, PubMed and Springer). Nine studies met the inclusion criteria. Our analysis indicates that there is a trend pointing towards an interaction between the use of occlusal splints and improved muscle strength (increased isometric strength in some upper limb muscle groups). However, the extent of its impact on muscle strength is presently unknown. As importantly, it is unknown whether using occlusal splints may improve performance within the context of select sports modalities (e.g. football, volleyball and basketball). For all these reasons, at this stage, there is no general agreement as to whether occlusal splints can be used as ergogenic aids. The number of studies on this specific topic and their different experimental designs precludes drawing more definite conclusions. Further research is warranted to elucidate possible changes in neuromuscular activation patterns (e.g. by means of electromyography) resulting from occlusal splint therapy during exercise.

Keywords: Review; performance; ergogenic effects; temporomandibular joint; occlusal splints

INTRODUCTION

The use of oral appliances in sports is widespread and several studies have focused on their impact in motor performance. There is conflicting data on whether these devices are effective for improving muscle strength and performance. Nevertheless, if proven effective, their use might be valuable for ergogenic purposes in athletes of several sport modalities.

There are various types of oral appliances and they all affect the temporomandibular joint (TMJ) differently (Okeson, 2008). For this reason, it is difficult to draw definite conclusions on their effects on performance in the field of sports and exercise. Occlusion consists in the static and dynamic relationship between the incising or masticating surfaces of the maxillary or mandibular teeth or tooth analogues (Prosthodontics, 1999). The term occlusal splint (OS) refers to any removable and/or artificial occlusal adjustment made by an appliance, that affects the relationship of the mandible to the maxillae (Prosthodontics, 1999). The purpose of OS is not teeth protection, like regular mouthpieces, but joint stabilization. All OS alter the vertical dimension (VD) of occlusion and there is some evidence that this might enhance muscular strength as well as athletic performance by means of jaw repositioning (Gelb et al., 1996; Park, J., 1994). Past studies have shown that OS therapy increase upper and lower body muscles activity during exercise and that this is associated with changes in the position of the TMJ (Yokoyama, 1998). From a mechanistic perspective, this might be secondary to changes in peripheral proprioceptive input signals originating from the orofacial region. These signals, which are transmitted to the central nervous system (CNS) via the trigeminal nerve, likely alter the output signal that is transferred to the rest of the body via spinal and autonomic nerves (feedback/feedforward mechanism) (Milani et al., 2000). However, it is important to note that the significance of such relationship, as well as the physiological basis of an eventual interaction, remains largely unknown. (Ferrario et al., 2001; Tecco et al., Yokoyama, 1998).

For all these reasons, we aimed at providing an overview on the interaction between TMJ repositioning (by means of OS) and improved muscle strength in humans. We also outlined the major strengths/weaknesses of using OS with respect to sports performance.

METHODS

Search strategy

A systematic search of the literature was conducted using the following dental medical terms “occlusal splint”, “bite plane”, “occlusal device”, “overlay splint”, “bite splint”, “repositioning appliance” and “relaxation splint” combined with the sports science related terms “EMG”, “sports”, “neuromuscular”, “force”, “strength” and “isokinetic”. The terms were combined using the Boolean term “AND” (e.g. occlusal splint AND strength). This search was performed on the electronic databases Web of Science, Science Direct, SPORT Discus, PubMed and Springer. No protocol exists for this systematic review.

Inclusion criteria for review

The inclusion criteria were as follows: (1) articles referring or specifying the intermaxillary therapeutic test position in a tridimensional frame promoted by the oral appliance, (2) articles mentioning the nature of change in the relation/dimension or position between the maxillary and mandibular masticating surfaces achieved by the oral appliance, (3) articles examining the acute effects of OS on muscle strength, (4) articles written in English, French or Portuguese languages, and (5) articles published from 1970 to 2016. We excluded all the articles involving: (1) patients with any form of TMJ disorder, (2) languages other than those used in the inclusion criteria, and (3) the effects of oral appliances on the head and facial muscles.

Quality analysis of the results

The PEDro scale for randomized controlled trials was used to ascertain the methodological quality of the studies included (Table 2). This scale uses 11 items to search for external and internal validity, as well as sufficient statistical information to interpret the results. A cut-off value of 6 on PEDro scale was used to determine the inclusion in this review because it was considered sufficient to distinguish between high and low-quality studies (Maher, 2003). Two independent investigators that were part of the research team completed these analyses. The results were compared and differences were discussed to reach a consensus.

Table 2. PEDro scale results of the included studies

Author / Year	ITEM 1	ITEM 2	ITEM 3	ITEM 4	ITEM 5	ITEM 6	ITEM 7	ITEM 8	ITEM 9	ITEM 10	Results
Alexander (1999)	Y	N	Y	Y	Y	Y	N	Y	Y	N	7
Chakfa et al. (2002)	N	N	Y	Y	N	Y	N	Y	Y	Y	6
Greenberg et al (1981)	N	N	Y	Y	Y	Y	Y	Y	Y	Y	8
Golem (2012)	Y	Y	Y	N	N	N	Y	Y	Y	Y	7
Jung et al. (2013)	N	N	Y	Y	N	N	Y	Y	Y	Y	6
Lee et al. (2013)	Y	N	Y	N	N	N	Y	Y	Y	Y	6
Lee et al. (2014)	Y	N	Y	N	N	N	Y	Y	Y	Y	6
Schubert et al (1984)	Y	N	Y	Y	N	N	Y	Y	Y	Y	7
Yates et al. (1984)	N	N	Y	Y	N	N	Y	Y	Y	Y	6

RESULTS

Literature search results

The electronic database search retrieved 12066 results that matched the terms used in the research. All duplicates were excluded using a reference manager software (Endnote X7.0.2, Thompson Reuters, USA), which left 4250 results. A manual screening of these articles was then made by reading the article title or abstract. An additional 4152 articles were excluded because, while some included patients with known TMJ disorders, others did not explore the effects of OS on muscle strength nor mentioned the nature of change in the relation/dimension between the masticating surfaces of the maxillary or mandibular teeth. After this first screening, the 98 remaining articles were subjected to a more profound analysis that involved reading each article carefully and performing a methodological quality assessment. From those, only 9 articles fulfilled the inclusion criteria (Fig.3).

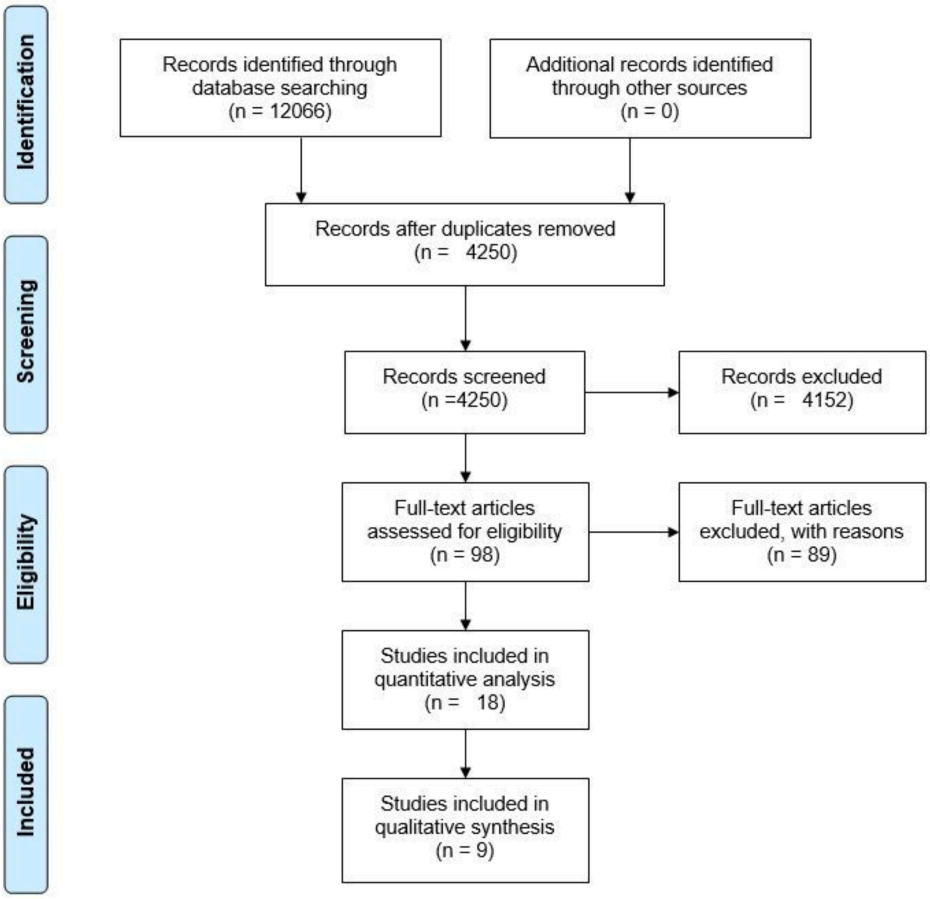

Figure 3. Flow chart of the methodology for the search results

Isometric muscle strength

Most published studies that explored the effects of OS on upper limb muscle strength used isometric tests (Alexander, 1999; Chakfa et al., 2002; Lee et al., 2013; Lee et al., 2014; Yates, 1984) (Table 3). Of these studies, two (Lee et al., 2013; Lee et al., 2014) measured electromyographic muscle activity (EMG), while the other three focused exclusively on muscle endurance and strength (Alexander, 1999; Chakfa et al., 2002; Yates, 1984).

Lee et al.(Lee et al., 2013) measured EMG activity on the muscles of the upper limb and trunk during maximal isometric contractions, using the manual muscle test position. Their results revealed that OS induces a significantly higher level of muscle activation. In another study, a group of twenty women was tested to determine the effects of different VD on isometric strength levels during arm abduction (Chakfa et al., 2002). The authors found that increased VD of occlusion improved isometric muscle strength during arm abduction. As importantly, they also demonstrated that the VD of occlusion resulting in enhanced isometric muscle strength is unique to each participant and should be, therefore, determined on an individual basis.

Two studies complying with the inclusion criteria investigated the effects of OS on grip strength. Both these studies used hand-held dynamometers, but only one (Lee et al., 2014) used EMG to measure muscle activation. One of these studies (Alexander, 1999) included a large number of participants of both sexes (n = 123) that were previously informed that OS might increase their muscle strength and endurance. This study used a placebo device that did not alter the jaw position of the participants. They were all tested with either OS or the placebo device and both were compared to a non-device condition. The results demonstrated that 74% of the participants increased their average grip strength with OS when compared to that seen in the non-device condition. Also, 53% of the tested participants showed a significant increase in grip strength when using the placebo device vs. non-device. The authors concluded that occlusion therapy improves grip strength in both men and women. They also stated that a placebo effect is indeed observable, especially in men. The other study that approached the effects of OS on grip strength used an experimental procedure where participants performed three 5-s trials for each condition. The average value of each variable was then calculated. EMG measurements were taken on the forearm muscles, as well as masseters. Analysis of the results demonstrated a significant increase in EMG muscle activation with OS for all tested muscles. Grip strength was also significantly improved with OS.

In a different experimental design, a small number of athletes (American football players) were tested to determine if OS affected muscle strength in response to two different paradigms of isometric exercise: isometric two-arm pull and isometric dead-lift (Yates, 1984). Each athlete performed two trials per condition. The conditions were control, placebo and OS. No significant differences were obtained between conditions for peak or integrated force. The authors concluded that OS does not enhance isometric muscle strength in well-conditioned adults without TMJ disorders.

Isokinetic muscle strength

The interaction between isokinetic upper limb muscle strength and VD of occlusion or jaw position was tested in three different studies (Greenberg, 1981; Schubert, 1984; Yates, 1984). Two of these experimental designs used shoulder abduction movements, both bilateral (Schubert, 1984) and unilaterally (Greenberg, 1981). For both the shoulder abduction studies, no differences were found between conditions (OS vs. no-device). In a study including American football athletes, the authors used an alternative isokinetic task for the upper limb (upright rowing movement) (Yates, 1984). Three conditions were tested (control vs. placebo vs. OS) in a randomized order. The results also revealed no differences in isokinetic muscle strength between conditions and no placebo effect.

The lower leg muscles were evaluated with isokinetic tests in two studies focused on bilateral leg testing (Jung et al., 2013; Schubert, 1984). Several occlusion positions were tested using isokinetic knee extension and flexion at different angular velocities (Jung et al., 2013). There were no placebo splints, but each participant was blinded on detailed information concerning each type of occlusion devices. Data analysis showed no changes between conditions for any of the tested variables. In their study, Schubert et al. (Schubert, 1984) compared the effect of OS with a placebo device in athletes performing bilateral knee flexion and extension. Again, no statistical differences were observed between conditions.

Muscle Power

Data on the impact of OS on muscle power are very scarce. A counter-movement jump was used in healthy collegiate students with the purpose of assessing lower body muscle power (Golem, 2012). In this study, several OS were tested (custom-fitted, self-adapted, placebo). Each athlete performed 3 trials per OS condition as well as without OS (control). Statistical comparisons revealed non-significant differences between testing conditions for vertical jump height and power output.

Table 3. Summary of the reviewed studies

Author / Year	*n*	Body segment	Type of test	Dependent variables	Jaw position with occlusal splint	Placebo	Statistical method	Findings
Alexander (1999)	123	Upper limbs	Isometric grip strength	Average peak strength	Condyle moved forwardly and downwardly away from the glenoid fossa	Yes	Wilcoxon signed-rank test; Paired 2-tail T-test	Statistical significance for grip strength when comparing oral appliance with no appliance; placebo effect was present for male subjects
Chakfa et al. (2002)	20	Upper limbs	Isometric test during arm abduction	Maximal strength	Vertical dimension increased in 2, 4, 6 and 12 mm	No	Two-way ANOVA	Increasing vertical dimension lead to an increase in strength; increase of the vertical dimension beyond the height associated with maximum strength results in a decrease of isometric deltoid.
Greenberg et al (1981)	14	Upper limbs	Isokinetic shoulder abduction and adduction of dominant arm	Peak torque	Covering the occlusal surfaces of the posterior teeth, with increase in vertical dimension	Yes	Two-way ANOVA	No statistical differences were found for both movements.
Golem (2012)	22	Lower limbs	Counter-movement jump	Vertical jump height	Vertical dimension increased in 2 to 3 mm for both splints: custom-fitted and self-adapted	Yes	Repeated measures multivariate ANOVA	Vertical height and power output had no differences between conditions
Jung et al. (2013)	20	Lower limbs	Isokinetic knee extension and flexion of both legs	Peak torque	Vertical dimension increased in 2 mm for both splints: full coverage and half coverage	No	One-way ANOVA with repeated measures	Full coverage splint did no increased muscle endurance or power; flexor muscles of both knees increased muscular power under half coverage occlusal support.
Lee, Hong, Park, & Choi (2013)	20	Upper limbs; Trunk	Maximal isometric contractions in the manual muscle testing	EMG of upper trapezius, biceps and triceps brachii, lumbar erector spinae, rectus abdominis, internal abdominal obliques, external abdominal obliques	Vertical dimension increase in 3 mm at the centric relation	No	Independent T-tests	Occlusal splint increased muscles EMG activity with statistical relevance for all muscles analysed when in isometric maximum contraction.
Lee et al. (2014)	28	Upper limbs	Isometric grip strength	Peak grip strength / EMG of forearm extensor bundle, forearm flexor bundle and masseters	Vertical dimension increased in 3mm at the centric relation	No	Paired t-test	Occlusal splint significantly increased grip strength and muscle EMG activity.
Schubert et al (1984)	20	Upper and lower limbs	Isokinetic shoulder abduction and adduction of both arms; Knee flexion and extension of both legs	Peak torque	In centric relation	Yes	T-tests; Two-by-two contingency test (Fisher's exact test)	No statistical significances were found for both tests
Yates et al. (1984)	14	Upper Limbs Trunk	Isokinetic upright rowing movement/ Isometric two-arm pull and dead lift	Peak torque / Peak strength	Vertical dimension increased in 2 to 3mm	Yes	Repeated measures ANOVA	No statistical differences were found for any of the conditions and no placebo effect was visible.

DISCUSSION

The main purpose of this systematic review was to determine whether the use of OS improves human muscle strength and performance. We focused our analysis specifically on OS designed to increase TMJ stabilization. These oral appliances promote the stable seating of the TMJ condyles in a congruent skeletal relation to the articular fossae, commonly known as centric relation (Okeson, 2008). After applying the above-mentioned search criteria, nine articles were included in the present review. The available data indicate a positive relationship between OS and enhanced isometric muscle strength in upper body exercise. Conversely, for isokinetic muscle contractions, as well as for tasks involving muscle power, the existent research has several methodological inconsistencies (Hanke et al., 2007; Perinetti & Contardo, 2009). Most of the articles included in this analysis used different methods, testing protocols and focused on several body movements/parameters. As importantly, few studies were double-blinded; thus, predisposing to experimental bias. These methodological differences between studies, as well as the reduced number of participants, or even the use of different testing protocols for similar body movements/exercises preclude direct comparisons. Additionally, the methods of OS construction were not similar between reports.

Given the inexistence of guidelines for standardizing the construction of OS, the options for OS development (including VD) should be properly described in future research. This aspect is of utmost importance for enabling comparisons in the future. Finally, it is also important to note that some designs accounted for the placebo effect (Alexander, 1999; Golem, 2012; Greenberg, 1981; Schubert, 1984; Yates, 1984) and others did not (Chakfa et al., 2002; Gabaree, 1981; Jung et al., 2013; Lee et al., 2013; Lee et al., 2014). In two of these, where this effect was controlled for, only half of the participants were tested for a placebo effect. The other half used a regular protective mouthpiece. Different types of OS were also tested in other investigations (Jung et al., 2013).

Interestingly, there are two common features within the few studies that reported a positive impact of OS in muscle strength (Alexander, 1999; Chakfa et al., 2002; Lee et al., 2013; Lee et al., 2014). First, they all included healthy untrained participants. Second, assessments of upper body strength (specifically shoulder and arm strength) were made in all of them using isometric muscle contractions. Therefore, these data strongly indicate that, in healthy untrained participants, OS enhances upper body isometric muscle strength. Conversely, there is no available research on the effects of OS in lower body muscle strength and this represents a serious gap in the existent literature.

Most studies that reported no changes in strength with OS used isokinetic upper (Greenberg, 1981; Schubert, 1984; Yates, 1984) and lower body (Jung et al., 2013; Schubert, 1984) muscle contractions. Despite using different methods, all these designs determined OS-related changes in peak torque. Their findings indicate that OS is not ergogenic. Despite this, it is important to highlight that participants included in these studies were healthy trained athletes. In our review, we found no prior research on the association between OS and isokinetic strength in untrained healthy adults. Future research should explore this issue to allow a better insight into the role of fitness in the interaction between OS and muscle strength.

We only found one study that assessed the effects of OS on muscle power (Golem, 2012). In this experimental design, a counter-movement jump was used to assess power output and vertical jump height. It was shown that OS does not affect muscle power under these conditions. However, as with isokinetic muscle contractions, this study only included healthy trained athletes.

There are two important aspects that underlie all the existent studies on OS and muscle performance. (1) Training status. While the studies showing a positive effect of OS on muscle strength only tested untrained adults, the exact opposite occurred in those reporting no benefits of OS on strength. This suggests that training is an important factor in the relationship between OS and muscle strength. Accordingly, OS is likely to be more effective for improving exercise performance in untrained than trained people. (2) Type of muscle contraction. Positive effects of OS were only obtained with isometric muscle contractions. In contrast, OS was shown to be ineffective for improving muscle performance during isokinetic muscle contractions. For this reason, we believe that the benefits of OS may also vary with the type of muscle contraction involved in a given motor task. Finally, in conventional resistance training, the load remains constant throughout the exercise. Despite its relevance for motor and sports performance, the effect of OS on improving muscle strength and performance with this type of training (i.e. free weights) has not yet been explored (Anderson et al., 2008).

Upper limb muscle performance

Three studies included in this review analysed muscle strength during arm abduction (Chakfa et al., 2002; Greenberg, 1981; Schubert, 1984). Despite the methodological differences in strength assessment between them, one observed improvements in motor performance in response to an isometric arm abduction task supplemented with OS (Chakfa et al., 2002). Theoretically, this relationship can be explained by two different arguments. The first argument is related to functional anatomy. There is a close relationship between the cervical spine, cranium and mandible, and the scapula and clavicle. This is due to the existence of muscles and ligaments that, while attaching to some of these bones, may effectively act on others. More specifically, variations in VD of occlusion might influence several cervical muscles such as the sternocleidomastoid and upper trapezius (Ferrario et al., 2003; Miralles & Dodds, 2002). These muscles play an important role in fixating the scapula and the clavicle. Moreover, their stabilizing role is necessary to potentiate the activation of the deltoid muscle. The trapezius and the sternocleidomastoid originate from the occipital and temporal bones and insert at the level of the scapula and the clavicle. The origin of the deltoid muscle (the prime abductor of the arm) is aligned with the insertion of the trapezius (lateral third of the clavicle, acromion process and spine of the scapula). The second argument is grounded on neurophysiological mechanisms. It is well known that afferent fibers originating from the masticatory system (conducting afferent information from masticatory muscles and TMJ) project to the accessory nerve nucleus which controls the sternocleidomastoid and trapezius muscles (Gangloff et al, 2000). For this reason, changes in proprioceptive feedback, secondary to occlusion (arising from the TMJ), likely influence scapular muscles such as the trapezius and sternocleidomastoid; both of which are important to stabilize the bones serving as the origin for the deltoid muscle. This concept is further corroborated by the findings of Wang et al. (Wang, 1996). These authors found that OS increases both muscle strength and EMG activation of the trapezius and deltoid muscles during isometric muscle contractions. As previously shown, this can be caused by involuntary clenching that accompanies isometric muscle contractions (Yokoyama, 1998). However, the same concept does not apply to isokinetic upper arm movements because muscle strength was virtually unchanged under these conditions (Greenberg, 1981; Schubert, 1984). Finally, data on muscle strength obtained during arm adduction movements (isokinetic testing) revealed that OS does not interact with dynamic motor performance. Contrary to that seen in muscles responsible for arm abduction, the origin of the main arm adduction agonists (i.e. pectoralis major and the latissimus dorsii) is not located at the level of the scapula or the clavicle (Perotto, 2011) Thus, the action of these muscles may not benefit from an improved stabilization of the trapezius muscle.

Forearm isometric muscle strength was tested in two previous reports using a hand-held dynamometer (Alexander, 1999; Lee et al., 2014). Each study used different contraction times and positions for testing. Regardless of those differences, these studies concluded that OS increases handgrip muscle strength. In addition, Lee et al. found enhanced muscle activation in the OS condition. (Lee et al., 2014). Nevertheless, one of these investigations described a positive placebo effect in men, but not in women (Alexander, 1999). These results provide preliminary evidence of sexual dimorphism on the effectiveness of oral appliances in improving handgrip isometric muscle strength. In the other study that showed an improvement in grip strength, a placebo device was not used and the design was limited to comparisons between OS and non-OS conditions (Lee et al., 2014). As importantly, the authors did not randomize the order of testing and this represents an additional limitation. The degree of improvement in upper limb muscle strength was not reported in either study that found a positive impact of OS in performance (Alexander, 1999; Chakfa et al., 2002; Lee et al., 2013; Lee et al., 2014). Even though all these investigations relied on different designs, we calculated Cohen's D based on their findings to gain further insight into the magnitude of OS effects. According to our computations, effect size varied from moderate (> 0.6) to large (> 0.8) and this corroborates the notion that OS is effective for increasing isometric strength in the upper limb muscles.

Lower limb muscle performance

There are also some reports exploring the influence of OS at the level of lower limb muscle strength (Jung et al., 2013; Schubert, 1984). Several research groups investigated the effects of OS on isokinetic of knee extension and flexion and demonstrated that OS has no impact on muscle strength under these conditions. Regardless of their methodological dissimilarities, there is a trend toward the lack of OS influence in motor performance during isokinetic knee extension and flexion. The effects of OS on leg muscle power were analysed by means of a counter-movement jump (Golem, 2012). The VD used for the participants included in this study was similar to that of other studies (Chakfa et al., 2002; Jung et al., 2013; Lee et al., 2013; Lee et al., 2014; Yates, 1984). There were no differences between conditions and no placebo effect was evident. The OS used in this investigation were not constructed with the aid of an expert dentist and this may have influenced the results.

Muscular activation

Theoretically, with OS, the participants clench their teeth involuntary and on a constant basis. This ensures a steady contraction of the TMJ muscles which might then translated into improved muscle strength in different body regions (Ebben, 2006; Ebben & Jensen, 2008). Yokoyama determined EMG activity in different mandibular positions during exercise (Yokoyama, 1998). This study showed that the onset of EMG activity on TMJ muscles precedes that of agonist muscles recruited during the exercise. Their findings also indicate that EMG amplitude of agonist's muscles was lower when the participants kept their mouth open during exercise. Furthermore, most participants performed involuntary teeth clenching during exercise. All these findings suggest that the stomatognathic system (where the TMJ is included) and physical exercise exhibit an interdependent relationship and that involuntary teeth clenching may well be explained by a feedforward mechanism. This is similar to that seen in other studies exploring relationships between OS and EMG in muscles from the TMJ, upper limbs (Lee et al., 2013; Lee et al., 2014) and trunk (Lee et al., 2013). Irrespectively of this, the overall effects of OS on muscle strength remain largely unknown.

EMG activity was measured only in two past studies that investigated effects of OS on upper body muscle strength (Lee et al., 2013; Lee et al., 2014). These studies analysed the changes in muscle activation during isometric contractions. Occlusal therapy enhanced EMG amplitude in both experimental designs. Similarly, to that done for muscle strength, we also calculated the effect size for the interaction between OS and EMG. While one study (Lee et al., 2014) demonstrated a moderate effect size (> 0.6), the other (Lee et al., 2013) achieved a large effect size (> 0.8) This suggests that OS is effective for improving EMG activation in upper body muscles. Surface EMG is a low cost, non-invasive and painless method (Basmajian, 1985) that can be used to gain a better understanding of the communication between the CNS and the effector's muscles. Thus, EMG may be helpful for extracting important information on the neuromuscular effects of occlusion. It might prove useful for characterizing neuromuscular coordination patterns (e.g. EMG onset) and to establish a cause-effect relationship between the activation of TMJ muscles and that of more distal muscles. This concept is supported by previous research showing that EMG amplitude is affected by different mandibular positions during exercise (Yokoyama, 1998). Surface EMG, by means of spectral decomposition, might also provide further insight into neuromuscular fatigue with and without OS. Taken together, we believe EMG could be a valuable tool for determining whether muscle patterns change with OS.

Recommendations for future research

Future research on the interaction between OS and muscle strength should focus on comparing different conditions (OS vs. placebo vs. control) in a large sample of participants (to ensure high statistical power). Isometric assessments of lower body muscle strength should also be performed. It is important to explore whether, as reported for upper body isometric muscle contractions, OS is effective for improving lower body muscle strength. In addition, we believe that these analyses should not be limited to isometric and/or isokinetic muscle contractions. The effects of OS on other dynamic muscle actions should also be examined because this might translate into gains in functional tasks and motor performance in sports. The role of physical fitness on the interaction between OS and muscle strength clearly needs to be further explored. Additionally, sexual dimorphism in muscle strength should be taken into consideration. This is particularly important for upper body muscle strength in which, sex likely displays a more relevant influence (Miller, 1993). The inclusion of both sexes leads to variance inflation due to sample heterogeneity; thus, affecting statistical analyses and inherent outcomes. Thus, future research might benefit from analysing data obtained from both sexes separately. Finally, further research on this topic should also consider the following aspects: (1) precise description of OS construction material, (2) detailed quantification of VD and mandibular position (3) aid from an expert dentist for OS manufacturing and (4) standardization of muscle strength testing protocols.

CONCLUSIONS

After conducting a rigorous analysis of the existing literature on the interaction between OS therapy and motor performance, we selected nine research articles matching our search criteria. These reports focused on the effectiveness of OS in improving muscle strength. We conclude that most research on this specific topic provides very preliminary data. Nevertheless, based on the results of these studies, it is possible to conclude that OS increases muscle strength in upper body isometric exercises, with a moderate to large effect size. These findings are not extensive to isokinetic muscle contractions because, under these conditions, OS did not improve neither upper nor lower body strength. Thus, taken together, these data strongly suggest that OS may be particularly relevant for improving motor performance in tasks involving isometric upper body muscle contractions (e.g. pistol and rifle shooting).

Acknowledgments

The authors would like to acknowledge the Universidade de Lisboa for the free access to the databases used in this review.

REFERENCES

Alexander, C. (1999). *A Study on the Effectiveness of a Self-Fit Mandibular Repositioning Appliance on Increasing Human Strength and Endurance Capabilities.* (Master of Science Master thesis), University of Tennessee, Knoxville.

Anderson. CE; Sforzo, G. (2008). The effects of combining elastic and free weight resistance on strength and power in athletes. *Journal of Strength and Conditioning research, 22*(2), 567-574.

Basmajian, J. (1985). *Muscles alive. Theirs functions revealed by electromyography* (5th ed.): Baltimore: William & Wilkins.

Chakfa, A., Mehta, N., Forgione, A., Al-Badawi, E., Lobo, S.., & Zawawi, K. (2002). The effect of stepwise increases in vertical dimension of occlusion on isometric strength of cervical flexors and deltoid muscles in nonsymptomatic females. *Cranio : the journal of craniomandibular practice, 20*, 264-273.

Ebben, W. (2006). A brief review of concurrent activation potentiation: Theoretical and pratical constructs. *Journal of Strength and Conditioning research, 20*(4), 985-991.

Ebben, W., Jensen, R. (2008). Jaw clenching results in concurrent activation potentiation during the countermovement jump. *Journal of Strength and Conditioning research, 22*(6), 1850- 1854.

Ferrario, V., Sforza, C., Serrao, G., Fragnito, N., & Grassi, G. (2001). The influence of different jaw positions on the endurance and electromyographic pattern of the biceps brachii muscle in young adults with different occlusal characteristics. *Journal of oral rehabilitation, 28*, 732-739.

Ferrario, V., Dellavia, C., Tartaglia, G. (2003). Evidence of an influence of asymmetrical occlusal interferences on the activity of the sternocleidomastoid muscle. *Journal of Oral Reabilitation, 30*(1), 34-40.

Gabaree, W. (1981). The mandibular repositioning appliance, temporomandibular muscular balance and athletic performance. *Journal of the Connecticut State Dental Association, 55*, 6-8.

Gangloff, P., Louis, J., & Perrin, P. (2000). Dental occlusion modifies gaze and posture stabilization in human subjects. *Neuroscience letters, 293*, 203-206.

Gelb, H., Mehta, N., & Forgione, A. (1996). The relationship between jaw posture and muscular strength in sports dentistry: a reappraisal. *Cranio : the journal of craniomandibular practice, 14*, 320-325.

Golem, D. (2012). *Improving Physical Performance: The Role of Jaw-Repositioning.* (Doctor of Philosophy Ph.D Thesis), State University of New Jersey.

Greenberg, M., Springer, P., Kotwick, J., Vegso, J. (1981). Mandibular position and upper body strength: a controlled clinical trial. *The Journal of the American Dental Association, 103*, 576-579.

Hanke, B. A., Motschall, E., & Türp, J. C. (2007). Association between orthopedic and dental findings: what level of evidence is available? *Journal of orofacial orthopedics, 68*, 91-107. doi:10.1007/s00056-007-0634-0

Jung, J., Chae, W., & Lee, K. (2013). Analysis of the characteristics of mouthguards that affect isokinetic muscular ability and anaerobic power. *The journal of advanced prosthodontics, 5*, 388-395. doi:10.4047/jap.2013.5.4.388

Lee, S., Hong, M., Park, M., & Choi, S. (2013). Effect of the Mandibular Orthopedic Repositioning Appliance on Trunk and Upper Limb Muscle Activation during Maximum Isometric Contraction. *Journal of physical therapy science, 25*, 1387-1389. doi:10.1589/jpts.25.1387

Lee, S., Park, Y., Park, H., Bae, H., Yu, M., Choi, H., & Hwang, N. (2014). Effect of the Mandibular Orthopedic Repositioning Appliance (MORA) on Forearm Muscle Activation and Grasping Power during Pinch and Hook Grip. *Journal of physical therapy science, 26*, 195-197. doi:10.1589/jpts.26.195

Maher, C., Herbert, R., Moseley, A., Elkins, M. (2003). Reliability of the PEDro Scale for Rating Quality of Randomized Controlled Trials. *Physical Therapy, 83*(7), 713-721.

Milani, R., De Perière, D., Lapeyre, L., & Pourreyron, L. (2000). Relationship between dental occlusion and posture. *Cranio : the journal of craniomandibular practice, 18*, 127-134.

Miller, A., Tarnopolsky, M., Sale, G. (1993). Gender differences in strength and muscle fiber characteristics. *European Journal of Apllied Physiology, 66*, 254-262.

Miralles R., Dodds, C., Palazzi, C. Jaramillo, C., Quezada, V., Cavada, G. (2002). Vertical dimension. Part 2: the changes in electrical activity of the cervical muscles upon varying the vertical dimension. *Cranio, 20*(1), 39-47.

Okeson, J. (2008). *Management of Temporomandibular Disorders and Occlusion* (J. Dolan Ed. 6th ed.): Elsevier.

Park J.,, Overton, B., Donly, K. (1994). Improving mouth guards. *The Journal of Prosthetic Dentistry, 72*(4), 373-380.

Perinetti, G., & Contardo, L. (2009). Posturography as a diagnostic aid in dentistry: a systematic review. *Journal of oral rehabilitation, 36*, 922-936. doi:10.1111/j.1365-2842.2009.02019.x

Perotto, A. (2011). *Anatomical guide for the electromyographer : the limbs and trunk* (5th ed.): Charles C Thomas.

Prosthodontics (1999). The Glossary od Prosthodontic Terms. *The Journal of Prosthetic Dentistry, 94*(1), 10-92.

Schubert, M., Guttu, R., Hunter, L., Hall, R., Thomas, R. (1984). Changes in shoulder and leg strength in athletes wearing mandibular orthopedic repositioning appliances. *The Journal of the American Dental Association, 108*, 334-337.

Tecco, S., Caputi, S., & Festa, F. (2007). Electromyographic activity of masticatory, neck and trunk muscles of subjects with different skeletal facial morphology--a cross-sectional evaluation. *Journal of oral rehabilitation, 34*, 478-486. doi:10.1111/j.1365-2842.2007.01724.x

Wang, K., Taniguchi, H., Ohyama, T. (1996). Influence on isometric muscle contraction during shoulder abduction by changing occlusal situation. *Bulletin of Tokyo Medical Dentist University, 43*, 1-12.

Yates, J., Semenick, D., & Kuftinec, M.. (1984). Effect of a mandibular orthopedic repositioning appliance on muscular strength. *The Journal of the American Dental Association, 108*, 331-333.

Yokoyama, Y. (1998). Involuntary Teeth Clenching during Physical Exercise. *Journal of the Japan Prosthodontic Society, 42*, 90-101

CHAPTER V - Effects of occlusal splints on shoulder strength and activation

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Status: Submitted; under review

ABSTRACT

The use of oral appliances to enhance sports performance has been advocated by some authors, however, studies addressing the effectiveness of these strategies are inconclusive. Here we investigate the effects of dental occlusions on shoulder strength. Fourteen healthy male subjects (age = 21.67 ± 0.86 yrs) without temporomandibular joint (TMJ) disorder participated in this study. Isokinetic strength was evaluated in shoulder abduction/adduction and arm external/internal rotation tests. Three randomized conditions were assessed: (1) occlusal splint (OS), which repositioned the TMJ in centric relation; (2) placebo splint (PS); and (3) no-splint (N). The strength tests were performed at a speed of 60°/sec in concentric mode. Muscle activity was measured by surface electromyography (EMG) in the main muscles engaged in the movements. Results showed significant differences in peak torque between the OS condition and the other conditions. Moreover, there was significantly higher muscular EMG activation in the OS condition when compared to the other conditions. These data suggest that splints have a positive ergogenic effect on shoulder muscular strength in healthy male subjects. Thus, OS may provide an advantage for healthy subjects engaged in sports whereby shoulder and arm strength are important for performance.

Key Words: Occlusal splint, isokinetic, strength, performance, ergogenic effect, EMG

INTRODUCTION

Muscular performance and motor skills in sports are determined by a wide array of factors (Clarys and Cabri, 1993). An extensive number of studies in sports performance research has focused on motor performance enhancement (Clarys and Cabri, 1993; Rehn et al., 2006; Shrier, 2004; Zech et al., 2010). Sports dentistry is an emerging field with strong potential for preventing sports injury and enhancing performance (Ramagoni et al., 2014). As up to 18% of sports-related injuries occur in the maxillofacial area (Sane, 1988), dental medicine is essential for the athletes' well-being and health, and it has been suggested that sports teams should have a dentist in their staff (Winters, 1996).

Occlusal splints (OS) are removable appliances for treating temporomandibular joint (TMJ) disorders that partially or totally cover the occlusal surfaces of the teeth (Yunus, 2009). In recent years, OS have also been used to enhance sports performance (Arent et al., 2010; Lee et al., 2014, 2013) based on research suggesting that dental occlusion (i.e. dynamic relationship between the maxillary and mandibular teeth when they approach each other) may affect muscle strength elsewhere in the body (Klineberg and Jagger, 2004; Verban et al., 1984; Williams et al., 1983). For instance, changes in vertical dimension of occlusion (VDO) caused by OS influence the upper limb muscles (e.g. trapezius muscle), which play an important role in fixating the scapula and clavicle (Ferrario et al., 2003; Miralles et al., 2002). Moreover, the proprioceptive feedback from the TMJ also seems to be affected by the VDO (Gangloff et al., 2000). Importantly, these proprioceptive changes are projected via afferent fibers to the accessory nerve nucleus that controls the sternocleidomastoid and trapezius muscles (Gangloff et al., 2000). This modification in afferent information is also likely to influence scapular muscles, which stabilize bones supporting upper limb muscles, including the deltoid, pectoralis major, and rotator cuff muscles (Wang et al., 1996).

Over the past decades, numerous studies have examined the potential of using occlusal appliances for improving muscular strength in athletes (Greenberg et al., 1981; Williams et al.,1983; Yates et al., 1984), Arent et al., 2010; Grosdent et al., 2014; Jung et al., 2013; Lee et al., 2014). Studies addressing the effects of OS on lower body muscle strength through isokinetic evaluation of knee extension and flexion were unanimous in reporting that OS has no impact on lower limb strength (Grosdent et al., 2014; Jung et al., 2013; Schubert et al., 1984; Williams et al., 1983). In contrast, research assessing isometric strength in the upper limbs revealed that OS increased peak strength in a significant manner (Alexander, 1999; Chakfa et al., 2002; Forgione et al., 1992; Lee et al., 2014). A similar study measuring electromyography (EMG) activity showed an increase in upper body muscle activity in athletes using OS (Lee et al., 2013). However, others have found opposite results.

Greenberg et al. (1981) showed that an OS that increased VOD produced no effects on the peak torque (PT) of shoulder abduction/adduction movements, and these findings were corroborated independently by others (Schubert et al., 1984; Williams et al., 1983). Finally, results from an alternative upper limb isokinetic task (upright rowing movement) on American football athletes further confirmed that OS increasing VOD caused no effects on PT (Yates et al., 1984).

Although some studies suggest a physiological connection between OS and muscle strength, the literature remains controversial and unambiguous evidence supporting this hypothesis is currently lacking. Here, we investigate the effects of OS on shoulder strength in healthy male subjects.

METHODS

Subjects

Fourteen male subjects were recruited (age = 21.67 ± 0.86 yrs; body mass = 76.33 ± 7 kg; height = 1.76 ± 0.61 m) for this experiment. A dental examination conducted according to the clinical guidelines published by the American Academy of Orofacial Pain (De Leeuw & Klasser, 2013) confirmed that none of the participants had any type of temporomandibular joint (TMJ) disorders . An occlusal splint (OS) that repositioned the TMJ in centric relation (CR) was fabricated for each of the subjects. The CR is considered the most stable position for the mandible, and it is achieved when the TMJ condyles are in their most anterior superior position in the articular fossae. This position encourages the condyles to seat stably in a congruent skeletal arrangement (Okeson, 2008). A placebo splint was also fabricated for each subject. This research was approved by the ethics committee of the Faculdade de Motricidade Humana for use of human research (6/2016) and all subjects signed an informed consent

Experimental protocol

All measurements were performed on a Biodex Medical System Isokinetic dynamometer (Biodex System, Shirley, NY, USA). The dominant arm was defined as that used for writing. The subjects started with a warm-up of approximately five minutes of specific light exercises. Subsequently, two tests were conducted: shoulder abduction/adduction, and external/internal rotation of the arm. These tests were applied in two different days separated by 72 hours, to avoid fatigue. Each subject performed the tests in a randomized order and was unaware of the differences between the occlusal or placebo splints. Test conditions were: occlusal splint (OS), placebo splint (PS) and normal condition (N, no splint or and no contact between teeth) (Fig. 4).

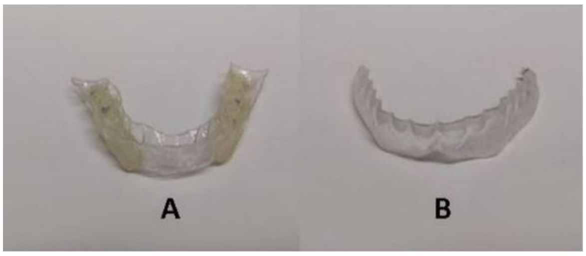

Figure 4. Oral devices tested. A - Occlusal splint; B - Placebo splint

EMG signals were collected using bipolar surface electrodes (Plux, Lisbon, Portugal) and the skin preparation and placement of the electrodes followed guidelines previously described (Criswell, 2011; Perotto, 2011). Amplification of the EMG signal was done with a bandpass filter (25-500Hz), common-mode rejection ratio (CMRR) of 110dB and a gain of 1000. The signals were sampled at 1000Hz. The position of the subjects was identical in all tests: seated in a chair in a comfortable position, with the seatback at an angle of 70º relative to the seat. The axis of the dynamometer was aligned with the axis of the movement. Straps were placed around chest, waist and wrist. The arm was statically weighted to provide gravity correction. Five maximal repetitions were performed at a velocity of 60°/sec (Adsuar, Olivares, Parraca, Hernández-Mocholí, & Gusi, 2013; Ruivo, Pezarat-Correia, & Carita, 2012) with a rest period of three minutes between test conditions.

For shoulder / abduction and adduction movements, measurements were made in the scapular plane (angle of the scapula in its resting position, normally 30° to 45° forward from the frontal plane toward the sagittal plane) with the elbow placed at a 45° flexion and a range of motion from 30° (start) abduction to 135° (end) abduction. EMG measurements were done on anterior and middle portions of the deltoid, lower trapezius, and pectoralis major muscles. When testing external and internal rotation of the arm, measurements were made with the arm positioned at 45° abduction in the scapular plane, and elbow flexed to 90°. The range of motion was from 0° (start) to 90° (external rotation – end). EMG measurements were collected from the deltoid (anterior and posterior portions) and infraspinatus muscles. Peak EMG and PT were assessed for both isokinetic tests.

Signal processing and analysis

EMG and PT signals were collected for all tests and conditions. To ensure the EMG signals were of good quality, experienced researchers visually examined the EMG patterns before processing. EMG signals were digitally filtered (25-500Hz), rectified, smoothed through a low-pass filter (12Hz, fourth-order Butterworth digital filter) and the amplitude was normalized using a 100ms window on peak EMG in the normal condition. In both tests, the peak EMG was selected and measured during the part of the movement when the muscles act as agonists. The peak EMG was determined for every muscle, repetition, and condition by using the average EMG of a 200ms window on the normalized EMG peak. The mean value of each repetition was retrieved and transformed to percentage for better comparison. The EMG data were processed with Matlab software VR2013a (The Mathworks Inc., Natick Massachusetts, USA).

Statistical analysis

Statistical analysis was performed with IBM SPSS Statistics 22.0 (IBM Corporation, New York, USA). The data were tested for normality by using the Shapiro-Wilk test. For testing differences between conditions (OS, PS, N), a repeated measures ANOVA test was used. Mauchly's test was used for sphericity. When the assumption of normality was not supported, the Friedman's test was applied instead. For the variables that demonstrated significant results, a multiple comparison test with Bonferroni adjustment was applied. For estimation of effect size, Cohen's D for matched pairs was calculated in GPower 3.1.9.2. (Universitat Dusseldorf, Germany). The magnitudes of the effects were interpreted using thresholds of 0.2, 0.6 and 1 for small, moderate, and large, respectively. An effect size lower than 0.2 was considered trivial (Hopkins, Marshall, Batterham, & Hanin, 2009). The significance level was set at 5%.

RESULTS

The results of the shoulder abduction/adduction test are shown in Table 4. The PT for abduction and adduction movements was significantly increased ($p<0.05$) in the OS condition when compared to N condition. The effect size for abduction was 0.72 and for adduction was 1.50. However, no significant differences in mean PT values were found between the OS and PS conditions. Muscular EMG activity was significantly higher in the OS condition when compared to the N and PS conditions in the anterior deltoid ($p<0.01$) and pectoralis major ($p<0.01$), but no changes in muscle activity were detected in the middle deltoid in any condition. The OS condition also had a significant increase in peak EMG when compared to the N condition in the lower trapezius ($p<0.05$), but no differences in EMG activity were found between the OS and PS conditions in this muscle. No significant changes in muscle activity were detected between the N and PS conditions in the abduction/adduction tests.

The results of the arm external/internal rotation tests (Table 5) revealed that the PT was increased in the OS condition when compared with the N ($p<0.05$) and PS ($p<0.05$) conditions, with large effect sizes (>1). Muscle peak EMG was increased in every muscle in the OS condition when compared to the N condition ($p<0.01$), with effect sizes ranging from 1.5 to 2.9. However, no differences in EMG activity were detected between the OS and the PS conditions in any muscle. Consistent with the results of the abduction/adduction tests, no significant changes in muscle activity were detected between the N and PS conditions in the external/internal rotation tests.

DISCUSSION

The purpose of this study was to determine whether OS improve upper body strength in healthy male subjects by measuring surface EMG, a non-invasive method to assess neuromuscular patterns of activation. Previous research addressing the effects of OS on strength using isokinetic methods focused exclusively on output performance (peak torque or peak strength). To date, only one report addressing isometric strength has used EMG to measure how shoulder muscle activity is affected by OS (Wang et al., 1996). Thus, to our knowledge, our study is the first to use EMG activity measurements to determine the influence of OS on muscular activation during isokinetic movements. In contrast to previous studies (Greenberg et al., 1981; Schubert et al., 1984; Yates et al., 1984), our results suggest that OS have an ergogenic effect (i.e. enhancing physical performance) and promote the ability of the shoulder to produce movements with higher PT. This hypothesis is supported by the following findings: 1) when compared with both the N and PS conditions, the OS condition had significantly higher PT values in the external/rotation test, and significantly increased peak EMG in the anterior deltoid and pectoralis major in the abduction/adduction test; 2) the OS condition showed consistently significantly higher PT and peak EMG in every muscle and movement when compared to the N condition, except for the middle deltoid muscle; 3) even when no significant changes in PT and EMG activity were detected between the OS and PS conditions, we found a trend for higher values in the OS condition; 4) there was no placebo effect in these experiments, since no significant changes in muscle EMG activity were detected between the PS and N conditions in any of the movements tested.

Table 4. Results of the shoulder abduction / adduction tests

		Conditions			*p value*	Multiple comparison post-hoc tests	Effect size (dz)
		N	OS	PS			
Peak Torque (N/m)	*Abduction*	52.76 ± 9.88	57.72 ± 2.70	53.75 ± 1.78	0.040	0.044a	0.72
	Adduction	61.3 ± 2.47	68.53 ± 1.47	61.98 ± 2.20	0.040	0.021a	1.50
Peak EMG (%)	*Anterior deltoid*	75.613 ± 1.86	83.644 ± 2.59	70.325 ± 4.13	0.001	0.01a	2.89
						0.004b	2.74
	Medium deltoid	78.564 ± 1.45	79.314 ± 2.38	74.811 ± 3.09	0.270		
	Lower trapezius	69.421 ± 2.31	82.893 ± 4.81	72.123 ± 4.58	0.038	0.04a	2.56
	Pectoralis major	64.432 ± 2.81	78.134 ± 5.07	58.546 ± 3.99	0.001	0.03a	2.36
						0.007b	3.05

a – Differences between Normal and Occlusal splints conditions;
b – Differences between Occlusal splint and Placebo splint conditions

Table 5. Results of the shoulder external / internal rotation tests

		Conditions			*p value*	Multiple comparison post-hoc tests	Effect size (dz)
		N	OS	PS			
Peak Torque (N/m)	*External Rotation*	32.15 ± 0.95	36.99 ± 1.92	31.93 ± 1.08	0.012	0.04a	2.29
						0.031b	2.32
	Internal Rotation	33.72 ± 1.79	40.93 ± 2.72	33.64 ± 1.67	0.001	0.026a	2.24
						0.021b	2.31
Peak EMG (%)	*Posterior deltoid*	69.493 ± 2.79	88.051 ± 5.69	77.725 ± 4.03	0.002	0.01a	2.94
	Infraspinatus	74.141 ± 2.34	86.285 ± 4.68	84.126 ± 4.56	0.022	0.04a	2.36
	Anterior deltoid	65.819 ± 2.84	73.077 ± 4.03	68.312 ± 3.77	0.002	0.038a	1.50

a – Differences between Normal and Occlusal splints conditions;
b – Differences between Occlusal splint and Placebo splint

Our results showing that participants using OS had significantly increased EMG activity in the main muscles involved in shoulder movements (except for the middle deltoid) when compared to the control condition (not wearing OS) strongly suggest that OS have an ergogenic effect. Notably, significant increased EMG activation was also observed in the anterior deltoid (during abduction) and pectoralis major (during adduction) when the OS condition was compared with the PS condition. Together these results demonstrate that OS promote robust muscle activation in the anterior deltoid and pectoralis major during abduction/adduction movements, and suggest that splints may also facilitate the activation of other muscles involved in these movements, except for the middle deltoid. This difference in muscle activation in the middle deltoid could be explained by the arm position and range of motion of the abduction/adduction movements. In this study, the participants conducted the abduction/adduction test with the arm in the scapular plane, which may have affected the relative contribution of the different parts of the deltoid muscle (Politti, Felice, & Valentinuzzi, 2003). Moreover, a high abduction angle (135º) probably increased the engagement of other muscles (i.e. rotator cuff) in the movement (Michiels & Bodem, 1992). The ergogenic effect induced by the OS is likely caused by a combination of several factors. The OS manufactured in this study reposition the TMJ in a CR position, which increases the occlusal stability of the jaw through bilateral simultaneous and symmetrical contacts of the teeth in both TMJs. This increased stability leads to an upsurge in EMG activity in the masseter muscles during strength tests, due to an involuntary contraction of the mandible (Yokoyama, 1998). Moreover, changes in proprioceptive feedback may occur, which project information via afferent fibers from the masticatory system to the accessory nerve nucleus that controls the sternocleidomastoid and trapezius muscles (Gangloff, Louis, & Perrin, 2000). It was previously shown by measuring H-reflex amplitude that higher EMG activities are associated with increments in spinal excitability (Miyahara et al., 1996). In addition, some authors have suggested that stimuli increasing acute H-reflex activity (e.g. clenching) may potentially increase chronic H-reflex activity and ultimately improve strength in other parts of the body (Buscà et al., 2016; Ebben, 2006; Miyahara et al., 1996). Thus, it is possible that the OS produced an effect in untrained subjects but not in athletes (Greenberg et al, 1981; Schubert et al., 1984; Yates et al., 1984) because the latter have larger H-reflex amplitudes (Aagaard et al., 2002; Nielsen et al., 1993), and therefore have less scope for enhancements in excitability and motor activity than untrained subjects. Finally, the cervical spine, cranium, scapula, and clavicle are thought to interact via muscles and ligaments, and variations in VDO may influence several cervical muscles, such as the sternocleidomastoid and trapezius (V F Ferrario, Sforza, Dellavia, & Tartaglia, 2003; Miralles et al., 2002). These muscles play an important role in fixating the scapula and the clavicle, which in turn support the muscles analysed in this study (deltoid, pectoralis major, and infraspinatus muscles).

Since the stabilizing role of the bones is necessary to potentiate the activation of the muscles attached to them, it is reasonable to assume that OS promote an increase in EMG activation in the muscles attached to the scapula and clavicle, such as the lower trapezius, anterior deltoid, pectoralis major, and infraspinatus muscles, as observed in our study.

Some of our results contradict previous reports, however, this is likely due to differences in methodological approaches. For instance, Greenberg (Greenberg et al., 1981) and Yates (Yates et al., 1984) used OS that increased VDO without repositioning the TMJ. In addition, in our study we screened for and excluded subjects with TMJ disorders, whereas some studies tested subjects with a TMJ disorder or malocclusion (Schubert et al., 1984; Williams et al., 1983). Finally, studies reporting that OS has no ergogenic effects were conducted on athletes (Greenberg et al., 1981; Schubert et al., 1984; Yates et al., 1984), whereas in our study and in a previous report showing that OS increase PT, the subjects were not athletes (Verban et al., 1984).

Recently, it was shown that clenching produces a positive effect on strength (Buscà et al., 2016; Garceau et al., 2012). In our study, the subjects were not asked to clench during the strength tests, however, it has been previously established that clenching is a natural reaction that occurs involuntarily during strength performance (Dunn-Lewis et al., 2012; Yokoyama, 1998). More importantly, clenching seems to increase EMG activity of masseters muscles in healthy subjects using equilibrated splints such as those used in our study (Manns et al., 1988; Wood & Tobias, 1984). Correspondingly, in subjects using an unbalanced splint, clenching caused a decrease in EMG activity of masseters muscles (Wood & Tobias, 1984). Thus, we cannot rule out that clenching may have influenced our results, and this is an important limitation of this study. Future research is needed to address this issue. For instance, it will be necessary to measure EMG activity in the masseters and quantify bite force/clenching during the strength exercises. Moreover, future studies should also investigate how the H-reflex is affected by OS, particularly in athletic or sports environments (e.g.: Golf, Tennis, Handball), to assess whether splints have an impact on arm and shoulder movements required for optimal performance.

CONCLUSIONS

Our results from isokinetic strength and EMG activation assays suggest that OS have a positive ergogenic effect on shoulder and arm strength in healthy subjects, when compared to a no-splint condition. Thus, this study may have important implications for healthy subjects engaged in sports or other physical activities where upper body strength is relevant for performance.

REFERENCES

Aagaard, P., Simonsen, E. B., Andersen, J. L., Magnusson, P., & Dyhre-Poulsen, P. (2002). Neural adaptation to resistance training: changes in evoked V-wave and H-reflex responses. *Journal of Applied Physiology*, *92*(6), 2309–2318. http://doi.org/10.1152/japplphysiol.01185.2001

Adsuar, J. C., Olivares, P. R., Parraca, J. a, Hernández-Mocholí, M. a, & Gusi, N. (2013). Applicability and test-retest reliability of isokinetic shoulder abduction and adduction in women fibromyalgia patients. *Archives of Physical Medicine and Rehabilitation*, *94*(3), 444–50. http://doi.org/10.1016/j.apmr.2012.08.198

Alexander, C. F. (1999). *A Study on the Effectiveness of a Self-Fit Mandibular Repositioning Appliance on Increasing Human Strength and Endurance Capabilities*. University of Tennessee.

Allen, C.; Dabbs, N.; Zachary, C.; Garner, J. (2014). The acute effect of a commercial bite-aligning mouthpiece on strength and power in recreationally trained men. *Journal of Strength and Conditioning Research*, *28*(2), 499–503.

Alomar, X., Medrano, J., Cabratosa, J., Clavero, J. A., Lorente, M., Serra, I., … Salvador, A. (2007). Anatomy of the Temporomandibular Joint. *Seminars in Ultrasound, CT and MRI*, *28*(3), 170–183. http://doi.org/10.1053/j.sult.2007.02.002

Arent, S. M., McKenna, J., & Golem, D. L. (2010). Effects of a neuromuscular dentistry-designed mouthguard on muscular endurance and anaerobic power. *Comparative Exercise Physiology*, *7*(2), 73–79. http://doi.org/10.1017/S1755254010000231

Ariji, Y., Koyama, S., Sakuma, S., Nakayama, M., & Ariji, E. (2015). Regional brain activity during jaw clenching with natural teeth and with occlusal splints: a preliminary functional MRI study. *CRANIO®*, 1–7. http://doi.org/10.1080/08869634.2015.1097320

Baechle, T.; Earle, R. (2008). *Essentials of Strength Training and Conditioning*. *Journal of athletic training* (3rd ed., Vol. 31). Human Kinetics. http://doi.org/10.1016/S0031-9406(05)66120-2

Bag, A.; Gaddikeri, S.; Singhal, A.; Hardin, S.; Tran, B.; Medina, J.; Curé, J. (2014). Imaging of the temporomandibular joint: An update. *World Journal of Radiology*, *6*(8), 567. http://doi.org/10.4329/wjr.v6.i8.567

Baker, D.; Nance, S.; Moore, M. (2001). The Load That Maximizes the Average Mechanical Power Output During Jump Squats in Power-Trained Athletes. *The Journal of Strength and Conditioning Research*, *15*(1), 92. http://doi.org/10.1519/1533-4287(2001)015<0092:TLTMTA>2.0.CO;2

Baldini, A., Nota, A., Tripodi, D., Longoni, S., & Cozza, P. (2013). Evaluation of the correlation between dental occlusion and posture using a force platform. *Clinics*, *68*(1), 45–49. http://doi.org/10.6061/clinics/2013(01)OA07

Bevan, H.; Bunce, P.; Owen, N.; Bennett, M.; Cook, C.; Cunningham, D.; Newton, R.; Kilduff, L. (2010). Optimal loading for the development of peak power output in professional rugby players. *Journal of Strength and Conditioning Research*, *24*(1), 43–47.

Bevan, H. R., Bunce, P. J., Owen, N. J., Bennett, M. A., Cook, C. J., Cunningham, D. J., … Kilduff, L. P. (2010). Optimal loading for the development of peak power output in professional rugby players. *Journal of Strength and Conditioning Research*, *24*(1), 43–7. http://doi.org/10.1519/JSC.0b013e3181c63c64

Blaak, E. (2001). Gender differences in fat metabolism. *Current Opinion in Clinical Nutrition and Metabolic Care*, *4*(6), 499–502. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/11706283

Boero, R. (1989). The physiology of splint therapy_a literature review.pdf. *Angle Orthodontist*, *59*(3), 165–180.

Bracco, P., Deregibus, A., & Piscetta, R. (2004a). Effects of different jaw relations on postural stability in human subjects. *Neuroscience Letters*, *356*(3), 228–30. http://doi.org/10.1016/j.neulet.2003.11.055

Bracco, P., Deregibus, A., & Piscetta, R. (2004b). Effects of different jaw relations on postural stability in human subjects. *Neuroscience Letters*, *356*, 228–230. http://doi.org/10.1016/j.neulet.2003.11.055

Bravi, A., Longtin, A., & Seely, A. J. E. (2011). Review and classification of variability analysis techniques with clinical applications. *Biomedical Engineering Online*, *10*, 90. http://doi.org/10.1186/1475-925X-10-90

Browne, PA; Clark, GT; Yang, Q; Nakano, M. (1993). Sternocleidomastoid muscle inhibiton induced by trigeminal stimulation. *Journal of Dental Research*, *72*(11), 1503–1508.

Buscà, B., Morales, J., Solana-Tramunt, M., Miró, A., & García, M. (2016). Effects of Jaw Clenching While Wearing a Customized Bite-Aligning Mouthpiece on Strength in Healthy Young Men. *Journal of Strength and Conditioning Research*, *30*(4), 1102–10. http://doi.org/10.1519/JSC.0000000000001192

Chakfa, A. M., Mehta, N. R., Forgione, A. G., Al-Badawi, E. a, Lobo, S. L., & Zawawi, K. H. (2002). The effect of stepwise increases in vertical dimension of occlusion on isometric strength of cervical flexors and deltoid muscles in nonsymptomatic females. *Cranio : The Journal of Craniomandibular Practice*, *20*(4), 264–73. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/12403184

Choi, A. H., Conway, R. C., Taraschi, V., & Ben-Nissan, B. (2015). Biomechanics and functional distortion of the human mandible. *Journal of Investigative and Clinical Dentistry*, *6*(4), 241–251. http://doi.org/10.1111/jicd.12112

Criswell, E. (2011). *Cram's introduction to surface electromyography*. (E. Criswell, Ed.) (2nd ed.). Jones and Bartlett.

Cuccia, A., & Caradonna, C. (2009). The relationship between the stomatognathic system and body posture. *Clinics*, *64*(1), 61–66. http://doi.org/10.1590/S1807-59322009000100011

Cuccia, A. M. (2011). Interrelationships between dental occlusion and plantar arch. *Journal of Bodywork and Movement Therapies*, *15*(2), 242–50. http://doi.org/10.1016/j.jbmt.2010.10.007

Dadswell, C. E., Payton, C., Holmes, P., & Burden, A. (2013). Biomechanical analysis of the change in pistol shooting format in modern pentathlon. *Journal of Sports Sciences*, *3112*(March), 1294–1301. http://doi.org/10.1080/02640414.2013.777762

Daly, P., Preston, C. B., & Evans, W. G. (1982). Postural response of the head to bite opening in adult males. *American Journal of Orthodontics*, *82*(2), 157–60. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/6961786

De Leeuw, L, & Klasser, G. (2013). Orofacial Pain. Guidelines for Assessment, Diagnosis, and Management. 5h edition, Chicago, IL: Quintessence Publishing Co, Inc.

Devoize, L., Doméjean, S., Melin, C., Raboisson, P., Artola, A., & Dallel, R. (2010). Organization of projections from the spinal trigeminal subnucleus oralis to the spinal cord in the rat: A neuroanatomical substrate for reciprocal orofacial–cervical interactions. *Brain Research*, *1343*, 75–82. http://doi.org/10.1016/j.brainres.2010.04.076

Dunn-Lewis, C., Hydren, J. R., Kraemer, W. J., Denegar, C. R., Watts, A. M., Comstock, B. A., … Volek, J. S. (2012). The Effects of a Customized Over-the-Counter Mouth Guard on Neuromuscular Force and Power Production in Trained Men and Women. *Journal of Strength and Conditioning Research*, *26*(September 2015), 1085–1093. http://doi.org/10.1519/JSC.0b013e31824b4d5b

Dylina, T. J. (2001). Dylina - A common-sense approach to splint therapy.pdf. *The Journal of Prosthetic Dentitry*, *86*(5), 539–545.

Ebben, W. P. (2006a). A brief review of concurrent activation potentiation: theoretical and practical constructs. *Journal of Strength and Conditioning Research / National Strength & Conditioning Association*, *20*(4), 985–91. http://doi.org/10.1519/R-19375.1

Ebben, W. P. (2006b). A brief review of concurrent activation potentiation: theoretical and practical constructs. *Journal of Strength and Conditioning Research / National Strength & Conditioning Association*, *20*(4), 985–91. http://doi.org/10.1519/R-19375.1

Ellis, E., & Throckmorton, G. S. (2005). Treatment of mandibular condylar process fractures: Biological considerations. *Journal of Oral and Maxillofacial Surgery*, *63*(1), 115–134. http://doi.org/10.1016/j.joms.2004.02.019

Ferrario, V. F., Chiarella, B., Taroni, A., & Schmitz, H. (1996). Occlusion and center of foot pressure variation: Is there a relationship ? *The Journal of Prosthetic Dentitry*, *76*(3), 302–308.

Ferrario, V. F., Sforza, C., Dellavia, C., & Tartaglia, G. M. (2003). Evidence of an influence of asymmetrical occlusal interferences on the activity of the sternocleidomastoid muscle. *Journal of Oral Rehabilitation*, *30*(1), 34–40. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/12485381

Ferrario, V., Sforza, C., Serrao, G., Fragnito, N., & Grassi, G. (2001). The influence of different jaw positions on the endurance and electromyographic pattern of the biceps brachii muscle in young adults with different occlusal characteristics. *Journal of Oral Rehabilitation*, *28*(8), 732–9. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/11556954

Flavel, S. C., Nordstrom, M. a., & Miles, T. S. (2003). Postural stability of the human mandible during locomotion. *Journal of Biomechanics*, *36*(6), 759–764. http://doi.org/10.1016/S0021-9290(03)00009-5

Forgione, A.; Mehta, N.; McQquade, C.; Westcott, W. (1992). Strength and bite, Part 2: Testing isometric strength using a MORA set to a functional criterion. *Cranio*, *10*(1), 13–20.

Forgione, A. G. (1991). Strength and bite Part I.pdf. *The Journal of Craniomandibular Practice*, *9*(4), 305–315.

Frederick, L. ., & Steinkeler, A. (2013). Epidemiology, Diagnosis, and Treatment of Temporomandibular Disorders. *Dental Clinics of North America*, *57*(3), 465–479. http://doi.org/10.1016/j.cden.2013.04.006

Fujimoto, M., Hayakawa, I., Hirano, S., & Watanabe, I. (2001). Changes in gait stability induced by alteration of mandibular position. *Journal of Medicine and Dental Sciences*, *48*, 131–136.

Gangloff, P., Louis, J., & Perrin, P. P. (2000). Dental occlusion modifies gaze and posture stabilization in human subjects. *Neuroscience Letters*, *293*, 203–206.

Gangloff, P., & Perrin, P. P. (2002). Unilateral trigeminal anaesthesia modifies postural control in human subjects. *Neuroscience Letters*, *330*(2), 179–82. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/12231441

Garceau, L.: Petushek, E.; McKenzie, F.; Ebben, W. (2012). Effect of Remote Voluntary Contractions on Isometric Prime Mover Torque and Electromyography. *Journal of Exercise Physiology*, *15*(4), 40–46. http://doi.org/10.1519/JSC.0b013e3181874564

Golem, D. (2012). *Improving Physical Performance: The Role of Jaw-Repositioning*. Graduate School - New Brunswick.

González-Hernádez, J., García-Ramos, A., Capelo-Ramírez, F., Castaño-Zambudio, A., Marquez, G., Boullosa, D., & Jiménez-Reyes, P. (2017). Mechanical, metabolic, and perceptual acute responses to different set configurations in full squat. *Journal of Strength and Conditioning Research*. http://doi.org/10.1519/JSC.0000000000002117

Greenberg, M.; Cohen, S.; Springer, P.; Kotwick, J.; Vegso, J. (1981). Mandibular position and upper body strength: a controlled clinical trial. *The Journal of the American Dental Association*, *103*, 576–579.

Hanke, B. A., Motschall, E., & Türp, J. C. (2007). Association between orthopedic and dental findings: what level of evidence is available? *Journal of Orofacial Orthopedics*, *68*(2), 91–107.

http://doi.org/10.1007/s00056-007-0634-0

Hernández Davó, J. L., Solana, R. S., Sarabia Marín, J. M., Fernández Fernández, J., & Moya Ramón, M. (2016). Rest Interval Required for Power Training With Power Load in the Bench Press Throw Exercise. *Journal of Strength and Conditioning Research*, *30*(5), 1265–74. http://doi.org/10.1519/JSC.0000000000001214

Hoffman, J. (2014). *Physiological aspects of sport training and performance* (2nd ed.). Human Kinetics.

Hopkins, W. G., Marshall, S. W., Batterham, A. M., & Hanin, J. (2009). Progressive statistics for studies in sports medicine and exercise science. *Medicine and Science in Sports and Exercise*, *41*(1), 3–12. http://doi.org/10.1249/MSS.0b013e31818cb278

Hosoda, M., Masuda, T., Isozaki, K., Takayanagi, K., Sakata, K., Takakuda, K., … Morita, S. (2007). Effect of occlusion status on the time required for initiation of recovery in response to external disturbances in the standing position. *Clinical Biomechanics (Bristol, Avon)*, *22*(3), 369–73. http://doi.org/10.1016/j.clinbiomech.2006.11.001

Ishijima, T., Hirai, T., Koshino, H., Konishi, Y., & Yokoyama, Y. (1998). The relationship between occlusal support and physical exercise ability. *Journal of Oral Rehabilitation*, *25*(6), 468–71. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/9687121

Johansson, A.; Unell, L.; Carlsson, G., Söderfeldt, B.; Halling, A. (2003). Gender difference in symptoms related to temporomandibular disorders in a population of 50-year-old subjects. *Journal of Orofacial Pain*, *17*, 29–35.

Julià-Sánchez, S., Álvarez-Herms, J., Gatterer, H., Burtscher, M., Pagès, T., & Viscor, G. (2015). Dental Occlusion Influences the Standing Balance on an Unstable Platform. *Motor Control*, *19*(4), 341–354. http://doi.org/10.1123/mc.2014-0018

Jung, J.-K., Chae, W.-S., & Lee, K.-B. (2013). Analysis of the characteristics of mouthguards that affect isokinetic muscular ability and anaerobic power. *The Journal of Advanced Prosthodontics*, *5*(4), 388–95. http://doi.org/10.4047/jap.2013.5.4.388

Kandel, E. (2013). *Principles of Neural Science*. (A. Kandel, Eric; Schwartz, James; Jessell, Thomas; Sielgelbaum, Steven; Hudspeth, Ed.) (5th ed.). McGraw-Hill.

Kibana, Y., Ishijima, T., & Hirai, T. (2002). Occlusal support and head posture. *Journal of Oral Rehabilitation*, *29*, 58–63.

Klineberg, I., & Jagger, R. G. (2004). *Occlusion and clinical practice : an evidence-based approach*. Wright.

Lee, S.-Y., Park, Y.-J., Park, H.-M., Bae, H.-J., Yu, M.-J., Choi, H.-W., & Hwang, N.-Y. (2014). Effect of the Mandibular Orthopedic Repositioning Appliance (MORA) on Forearm Muscle Activation and Grasping Power during Pinch and Hook Grip. *Journal of Physical Therapy Science*, *26*(2), 195–7. http://doi.org/10.1589/jpts.26.195

Manfredini, D., Guarda-Nardini, L., Winocur, E., Piccotti, F., Ahlberg, J., & Lobbezoo, F. (2011). Research diagnostic criteria for temporomandibular disorders: a systematic review of axis I epidemiologic findings. *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontology*, *112*(4), 453–462. http://doi.org/10.1016/j.tripleo.2011.04.021

Manns, A., Miralles, R., & Pena, M. C. (1988). The Effect of Different Occlusal Splints on The Electromyographic Activity of Elevator Muscles : A comparative Study. *The Journal of Gnathology*, *7*(1), 61–73.

Michelotti, A., Buonocore, G., Farella, M., Pellegrino, G., Piergentili, C., Altobelli, S., & Martina, R. (2006). Postural stability and unilateral posterior crossbite: is there a relationship? *Neuroscience Letters*, *392*(1–2), 140–4. http://doi.org/10.1016/j.neulet.2005.09.008

Michelotti, A., Buonocore, G., Manzo, P., Pellegrino, G., & Farella, M. (2011). Dental occlusion and posture: An overview. *Progress in Orthodontics*, *12*(1), 53–58. http://doi.org/10.1016/j.pio.2010.09.010

Michiels, I., & Bodem, F. (1992). The deltoid muscle: an electromyographical analysis of its activity in arm abduction in various body postures. *International Orthopaedics*, *16*(3), 268–271. http://doi.org/10.1007/BF00182709

Milani, R. S., De Perière, D. D., Lapeyre, L., & Pourreyron, L. (2000). Relationship between dental occlusion and posture. *Cranio : The Journal of Craniomandibular Practice*, *18*(2), 127–34. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/11202823

Miralles, R., Dodds, C., Manns, A., Palazzi, C., Jaramillo, C., Quezada, V., & Cavada, G. (2002). Vertical dimension. Part 2: the changes in electrical activity of the cervical muscles upon varying the vertical dimension. *Cranio : The Journal of Craniomandibular Practice*, *20*(1), 39–47. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/11831343

Miyahara, T., Hagiya, N., Ohyama, T., & Nakamura, Y. (1996). Modulation of human soleus H reflex in association with voluntary clenching of the teeth. *Journal of Neurophysiology*, *76*(3), 2033–41. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/8890312

Myers, T. W. (2009). *Anatomy Trains: Myofascial Meridians for Manual and Movement Therapists*. (C. Livingstone, Ed.) (2nd ed.). Elsevier.

Nelson, S. (2013). *Wheeler's dental anatomy, physiology and Occlusion*. (Elsevier, Ed.)*Journal of Chemical Information and Modeling* (10th ed., Vol. 53). http://doi.org/10.1017/CBO9781107415324.004

Nielsen, J., Crone, C., & Hultborn, H. (1993). H-reflexes are smaller in dancers from The Royal Danish Ballet than in well-trained athletes. *European Journal of Applied Physiology and Occupational Physiology*, *66*(2), 116–121. http://doi.org/10.1007/BF01427051

Okeson, J. (2008). *Management of Temporomandibular Disorders and Occlusion*. (J. Dojan, Ed.) (Sixth). Elsevier.

Olivo, S. A., Fuentes, J., Major, P. W., Warren, S., Thie, N. M. R., & Magee, D. J. (2010). The association between neck disability and jaw disability. *Journal of Oral Rehabilitation*, *37*(9), 670–9. http://doi.org/10.1111/j.1365-2842.2010.02098.x

Perinetti, G. (2006). Dental occlusion and body posture: no detectable correlation. *Gait & Posture*, *24*(2), 165–8. http://doi.org/10.1016/j.gaitpost.2005.07.012

Perinetti, G., & Contardo, L. (2009). Posturography as a diagnostic aid in dentistry: a systematic review. *Journal of Oral Rehabilitation*, *36*(12), 922–36. http://doi.org/10.1111/j.1365-2842.2009.02019.x

Perotto, A. (2011). *Anatomical Guide for the Electromyographer - The limbs and trund*. *Journal of anatomy* (Fifth, Vol. 186). Springfield, Illinois, USA: Charles C. Thomas. http://doi.org/10.1097/00002060-199505000-00020

Politti, J. C., Felice, C. J., & Valentinuzzi, M. E. (2003). Arm EMG during abduction and adduction: Hysteresis cycle. *Medical Engineering and Physics*, *25*(4), 317–320. http://doi.org/10.1016/S1350-4533(02)00218-7

Pow, E.; Leung, K.; McMillan, A. (2001). Prevalence of symptoms associated with temporomandibular disorders in Hong Kong Chinese. *Journal of Orofacial Pain*, *15*(3), 228–34.

Prosthodontics, T. A. of. (2005). THE GLOSSARY OF PROSTHODONTIC TERMS. *THE JOURNAL OF PROSTHETIC DENTISTRY*, *94*(1), 10–92.

Raadsheer, M. C., Van Eijden, T. M. G. J., Van Ginkel, F. C., & Prahl-Andersen, B. (2004). Human jaw muscle strength and size in relation to limb muscle strength and size. *European Journal of Oral Sciences*, *112*(5), 398–405. http://doi.org/10.1111/j.1600-0722.2004.00154.x

Roberts, D. C., & Tattersall, I. (1974). Skull form and the mechanics of mandibular elevation in mammals. American Museum novitates ; no. 2536. *American Museum Novitates*, (2536), 1–9. Retrieved from http://digitallibrary.amnh.org/handle/2246/2739

Ruivo, R., Pezarat-Correia, P., & Carita, a. I. (2012). Elbow and shoulder muscles strength profile in judo athletes. *Isokinetics and Exercise Science*, *20*(1), 41–45. http://doi.org/10.3233/IES-2012-

0439

Schleip, R. (2003). Fascial plasticity – a new neurobiological explanation: Part 1. *Journal of Bodywork and Movement Therapies*, *7*(1), 11–19. http://doi.org/10.1016/S1360-8592(02)00067-0

Schleip, R., Klingler, W., & Lehmann-Horn, F. (2005). Active fascial contractility: Fascia may be able to contract in a smooth muscle-like manner and thereby influence musculoskeletal dynamics. *Medical Hypotheses*, *65*(2), 273–7. http://doi.org/10.1016/j.mehy.2005.03.005

Schubert, Mark; Guttu, Ronald; Hunter, Letha; Hall, Richard; Thomas, R. (1984). Changes in shoulder and leg strength in athletes wearing mandibular orthopedic repositioning appliances. *The Journal of the American Dental Association*, *108*, 334–337.

Spector, M. (2001). Perspective article Musculoskeletal connective tissue cells with muscle : Expression of muscle actin in and contraction of fibroblasts , chondrocytes , and osteoblasts. *WOUND REPAIR AND REGENERATION*, *9*(1), 11–18.

Staubesand, J.; Ly, Y. (1996). Zum Feinbau der Fascia cruris mit besonderer Berucksichtigung epi- und intrafaszialer Nerven. *Manuelle Medizin*, *34*, 196–200.

Strini, P. J. S. A., Machado, N. A. D. G., Gorreri, M. C., Ferreira, A. D. F., Sousa, G. D. C., & Fernandes Neto, A. J. (2009). Postural evaluation of patients with temporomandibular disorders under use of occlusal splints. *Journal of Applied Oral Science : Revista FOB*, *17*(5), 539–43. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/19936539

Tanaka, E., & Koolstra, J. H. (2008). Biomechanics of the Temporomandibular Joint. *Journal of Dental Research*, *87*(11), 989–991. http://doi.org/10.1177/154405910808701101

Tecco, S., Caputi, S., & Festa, F. (2007). Electromyographic activity of masticatory, neck and trunk muscles of subjects with different skeletal facial morphology--a cross-sectional evaluation. *Journal of Oral Rehabilitation*, *34*(7), 478–86. http://doi.org/10.1111/j.1365-2842.2007.01724.x

Tecco, S., Polimeni, A., Saccucci, M., & Festa, F. (2010). Postural loads during walking after an imbalance of occlusion created with unilateral cotton rolls. *BMC Research Notes*, *3*, 141. http://doi.org/10.1186/1756-0500-3-141

Tecco, S., Salini, V., Calvisi, V., Colucci, C., Orso, C. a, Festa, F., & D'Attilio, M. (2006). Effects of anterior cruciate ligament (ACL) injury on postural control and muscle activity of head, neck and trunk muscles. *Journal of Oral Rehabilitation*, *33*(8), 576–87. http://doi.org/10.1111/j.1365-2842.2005.01592.x

Thoumie, P., & Do, M. C. (1996). Changes in motor activity and biomechanics during balance recovery following cutaneous and muscular deafferentation. *Experimental Brain Research*, *110*(2), 289–97. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/8836692

Valentino, B.; Melito, F.; Aldi, B.; Valentino, T. (2002). Correlation between interdental occlusal plane and plantar arches. An EMG study. *Bulletin Du Groupement International Pour La Recherche Scientifique En Stomatologie et Odontologie*, *44*(1), 10–13.

Verban, E.; Groppel, J.; Pfautsch, E.; Ramseyer, G. (1984). The Effects of a Mandibular Orthopedic Repositioning Applianceon Shoulder Strength. *The Journal of Craniomandibular Practice*, *2*(3), 232–237.

Visscher, C. M., Lobbezoo, F., de Boer, W., van der Zaag, J., & Naeije, M. (2001). Prevalence of cervical spinal pain in craniomandibular pain patients. *European Journal of Oral Sciences*, *109*(2), 76–80. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/11347659

Walker, C. J., & MacLeod, S. P. R. (2017). Anatomy and Biomechanics of Condylar Fractures. *Atlas of the Oral and Maxillofacial Surgery Clinics*, *25*(1), 11–16. http://doi.org/10.1016/j.cxom.2016.10.002

Wang, K.; Ueno, T.; Taniguchi, H.; Ohyama, T. (1996). Influence on isometric muscle contraction during shoulder abduction by changing occlusal situation. *Bulletin of Tokyo Medical Dentist University*, *43*, 1–12.

Williams;M.; Chaconas, S..; Bader, P. (1983). The effect of mandibular position position on appendage muscle strength. *The Journal of Prosthetic Dentistry*, *49*(4), 560–567.

Wood, W. W., & Tobias, D. L. (1984). EMG response to alteration of tooth contacts on occlusal splints during maximal clenching. *The Journal of Prosthetic Dentistry*, *51*(3), 394–396.

Yahia, L. H., Pigeon, P., & DesRosiers, E. a. (1993). Viscoelastic properties of the human lumbodorsal fascia. *Journal of Biomedical Engineering*, *15*(5), 425–9. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/8231161

Yahia, L., Rhalmi, S., Newman, N., & Isler, M. (1992). Sensory innervation of human thoracolumbar fascia. An immunohistochemical study. *Acta Orthopaedica Scandinavica*, *63*(2), 195–7. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/1590057

Yates, J; Koen, Tom; Semenick, Doug; Kuftinec, M. (1984). Effect of a mandibular orthopedic repositioning appliance on muscular strength. *The Journal of the American Dental Association*, *108*, 331–333.

Yokoyama, Y. (1998). Involuntary Teeth Clenching during Physical Exercise. *Journal of the Japan Prosthodontic Society*, *42*, 90–101.

Yunus, N. (2009). Occulusal Splints Therapy : A Review. *Indian Journal of Dental Education*, *2*(1), 33–37.

CHAPTER VI - The effects of a controlled mandible position mouthguard on strength and power in trained athletes

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Status: Submitted; under review

ABSTRACT

Background: It is widely accepted that mouthguards are effective for injury protection in sports. However, findings on the effects of mouthguards in strength and power production remains controversial. Therefore, the aim of this study was to determine whether controlled-mandible position mouthguards influence strength and power production in well trained athletes. **Methods:** Twenty-two male amateur rugby players (25 ± 3.84 yrs; 1.92 ± 0.07 m; 93.91 ± 11.99 kg) volunteered for this study. Every participant performed a 1RM bench press test (113.20 ± 16.83 kg) to determine his maximal strength. In a randomized order, a ballistic bench press using 40% of the obtained 1RM (44.93 ± 6.76 Kg) was performed in a guided bar attached to a linear position transducer (LPT) for the following conditions: a) no mouthguard (CON); b) controlled mouthguard (MCM - jaw in centric relation); c) non-controlled mouthguard (NCM) and d) occlusal splint (OS). **Results:** Athletes using a controlled mouthguard demonstrate a significant ($p < 0.05$) higher peak acceleration and peak force than those using no mouthguard. **Conclusion:** Controlled mouthguards enhance peak force and peak acceleration in the ballistic bench press exercise without negatively affecting any other measure. We speculate that this is possibly due to an increased stability of the temporomandibular joint.

Key Words: Ergogenic effects; mouthpieces; ballistic bench throw; rugby

INTRODUCTION

The use of mouthguards is optionally used by athletes in certain sports (e.g., soccer, basketball), being mandatory in sports where athletes are exposed to contact (e.g., rugby, boxing or American football) to prevent oral and facial injuries (Knapik et al., 2007). The mouthguards can be divided into three main types: a) Standard, which is ready to use and thus no fitting is required; this type of mouthguard is widely used due to their low cost; b) Self-adapted, also known as 'boil and byte', which are made of a material that when heated moulds to the teeth during the fitting process; c) Customized, which are manufactured based on the dental impression of the athlete and thus provide a perfect fit (Buscà, Morales, Solana-Tramunt, Miró, & García, 2016). The use of a mouthguard creates a vertical increase in dental occlusion (VDO) that may affect muscle activity and force production in upper body (Miralles et al., 2002). This variation in force capabilities may result from alterations in the strength of important stabilizers of the cervical spine such as the sternocleidomastoid and the upper trapezius (Ferrario, Sforza, Dellavia, & Tartaglia, 2003; Miralles et al., 2002). These muscles are necessary to potentiate the activation of the deltoid muscles, as they play an important role fixating the clavicle and scapula. However, there seems to be an optimal distance created by the VDO, as a reduction in force production has been previously observed when the VDO increases above an optimal distance (Chakfa et al., 2002).

Jaw clenching has also been demonstrating to affect performance (Buscà et al., 2016; Ebben, Leigh, & Geiser, 2008; Ebben, Petushek, Fauth, & Garceau, 2010; Garceau, Petushek, McKenzie, & Ebben, 2012). Recent studies have shown evidence of increments in dynamic strength and power (Buscà et al., 2016; Ebben, Flanagan, & Jensen, 2008; Ebben, Kaufmann, Fauth, & Petushek, 2010), isometric and isokinetic force (Buscà et al., 2016; Ebben, Leigh, et al., 2008; Ebben, Petushek, et al., 2010) and cardiopulmonary parameters (Morales, Buscà, Solana-Tramunt, & Mirò, 2015) when subjects used a mouthguard. These studies were based on the premise that when one part of the motor cortex is active, connections to other areas of the motor cortex are affected (Ebben, 2006a), a phenomenon called concurrent activation potentiation (CAP). This type of potentiation phenomenon is proposed to increase prime mover activation via simultaneous contractions remote from the prime mover. Such muscles contractions have been referred to as remote voluntary contractions (RVC). Research using electromyography to evaluate the effect of RVC demonstrated that both prime movers and remote muscles (i.e. jaw clenching muscles) are more active during an isokinetic movement of knee flexion/extension (Ebben, Petushek, et al., 2010). Changes in dental occlusion can have a major repercussion on human body mechanics (Hosoda et al., 2007), for instance, mechanical changes in the temporomandibular joint (TMJ) may affect muscles located in other parts of the body (Hosoda et al., 2007). Moreover, Raadsheer et al. (Raadsheer, Van Eijden, Van Ginkel, & Prahl-Andersen, 2004) found a significant relationship between the muscle thickness of arm flexors and leg extensors and the muscle thickness of masseter and temporal muscles, suggesting that these muscles are influenced by the same interactions, and/or could play an important role in the same muscles contractions patterns.

While mouthguards are widely used within the athletic population, the findings from previous research investigating the effects of mouthguards in performance remains controversial (Forgione et al., 1992; Francis & Ma, 1991). Several methodological issues have been pointed to previous research, reinforcing the need for well design experimental studies (Gelb, Mehta, & Forgione, 1996). A recent literature review has stated that enhancement of performance by using a mouthguard is not yet proven, but recent studies tend to validate the assumption of positive effects (Gunepin et al., 2017). Some of these studies demonstrated that mouthguards are associated with improved performance in sports (Alexander, 1999; Arent, McKenna, & Golem, 2010; Dunn-Lewis et al., 2012; Lee, Hong, Park, & Choi, 2013).

For instance, two studies reported that individuals using a customized mouthpiece had a greater isometric grip strength when compared to individuals using a placebo (Alexander, 1999; Lee et al., 2013). Lee et al. (Lee et al., 2013) used a mouthpiece that repositioned the temporomandibular joint (TMJ) and tested muscle activity in an upper arm maximal voluntary contraction. Results revealed an increased level of muscle activity for the analysed muscles when using the mouthguard.

Dunn-Lewis et al. (Dunn-Lewis et al., 2012) compared the effects of using customized and self-adapted mouthguards in upper body strength and power. The authors of this study found that individuals using customized mouthguards showed significantly higher power and strength during a bench press throw than those using self-adapted or no mouthguards. Moreover, when Arent et al. (Arent et al., 2010) compared the effect of using different types of mouthguard in the vertical jump, they observed that athletes using dentist-based customized mouthguards had a greater performance in counter-movement jump (CMJ) height and mean power output in comparison to standard self-custom mouthguards.

The type of mouthguard used in these studies may explain the outcomes. All of the studies presented an increase in VDO as well as a repositioning of the TMJ, which may explain the results, since changes in TMJ position could have an impact on human body and affect distal areas (Hosoda et al., 2007). However, some studies have presented opposite results (Duarte-Pereira et al., 2008; Golem, 2012; Jung, Chae, & Lee, 2013), and did not detect acute changes in force related parameters, while using customized mouthguards. For instance, Jung et al. (Jung et al., 2013) measured isokinetic peak force of the lower limbs in individuals using customized mouthguards and found no differences in isokinetic muscular strength or power when compared to individuals without mouthguard. Moreover, Duarte-Pereira et al. (Duarte-Pereira et al., 2008) could not detect any differences in athletes during the CMJ in three different conditions (using self-adapted, customized and no mouthguard).

The lack of positive effects in these studies, could be related to the fact that the mouthguards used did not repositioned TMJ, and as such did not cause any mechanical changes, that could affect the rest of the body (Hosoda et al., 2007)

There is currently no standard protocol to manufacture mouthguards, and different types of mouthguards induce different changes on the TMJ (Okeson, 2008). Moreover, the position of the mandible was not controlled in the majority of the studies examining the effects of mouthguards on sports performance. Thus, it is difficult to draw conclusions on the ergogenic effects of mouthguards on sports performance. Therefore, there is a need to clarify these issues with unambiguous evidence (Perinetti & Contardo, 2009) and to uncover the mechanisms underlying the possible ergogenic effect of using mouthguards (Allen, Dabbs, Zachary, & Garner, 2014). The purpose of this study is to examine the effects of using a mouthguard that places the mandible in a known and controlled position on physical performance, particularly on acute measures of power and maximal strength in well-trained athletes.

METHODS

Study Design

The aim of this study was to investigate if using a controlled mandible position mouthguard provides ergogenic aid to athletes during a ballistic bench press throw exercise. For this purpose, a within-subjects design with randomized trials was used. Each athlete underwent a clinical evaluation conducted according to the clinical guidelines published by the American Academy of Orofacial Pain (De Leeuw & Klasser, 2013) in a specialized dental clinic for making the casts used in the mouthpieces. A medical assessment for TMJ disorders was performed by a dentist to exclude any disorder/syndrome. A two-session protocol was conducted. In the first session, the subjects were asked to perform a 1RM bench press. In the second session, the participants performed ballistic bench throws (BBT) at 40% of the 1RM value determined previously. This load (40% of 1RM) was selected because it is within the range where rugby athletes can produce higher peak power outputs in the bench press throw (Baker, Nance, & Moore, 2001; Bevan et al., 2010).

All the participants were familiarized with mouthguards and had previously used them. The participants were asked to refrain from any type of vigorous physical activity before and in between the protocol sessions. Four different conditions were tested: a) no mouthguard (CON); b) over the counter mandible controlled mouthguard (MCM); c) non-controlled over the counter mouthguard (NCM) and d) occlusal splint (OS)

Subjects

Twenty-two male athletes (25 ± 3.84 yrs; 1.92 ± 0.07 m; 93.91 ± 11.99 kg) participated in this study. All the participants were rugby athletes who played at national and international level and had several years of experience in resistance training (bench press 1RM = 113.20 ± 16,83 kg). The experimental risks and benefits of the study were explained to the participants before they signed the informed consent forms. This research was approved by the ethics committee of the Faculdade de Motricidade Humana for use of human research.

Procedures

To avoid diurnal variations, the protocol was conducted at the same time of day for every participant and the two sessions were separated by 48h. At the beginning of both sessions, the participants performed a general warm-up of five minutes that consisted of dynamic mobilization of the trunk and arms, followed by a specific warm-up for each session (Hoffman, 2014). In the first session, the 1RM was determined, with the used protocol been previously described (Baechle & Earle, 2008). For the second session, athletes underwent the BBT testing. Athletes were experienced in this exercise as it was part of their training routines. After a general warm-up, the participants did a specific warm-up consisting of three BBT with no weight. Testing was done at 40% of 1RM, with the data collection protocol based on the work of Bevan et al. (Bevan et al., 2010). For every condition, three BBT were completed with a two-second interval between them. Between each condition, a four-minute period of rest was allowed, which is adequate to avoid a decrease in power output (Hernández et al., 2016). All the conditions were randomized between participants and participants were blinded to the mouthguards used.

Instrumentation and variables assessed

All the BBT were recorded using a linear position transducer (Chronojump, Barcelona, Spain) placed directly above the vertical axis of the bar. The transducer was connected to a microcontroller (Chronopic) that recorded at 1000Hz. The microcontroller was also connected to a personal computer (PC) that was running Chronojump 1.6.1 software for data evaluation. The validity and reliability of this setup has been previously established for measuring movement velocity and for estimating several variables in conditioning training exercises (González-Hernádez et al., 2017). The variables assessed were: Velocity, peak velocity, time to peak velocity, acceleration, peak acceleration, power, peak power, time to peak power, force, peak force and time to peak force.

Mouthguards and occlusal splint fitting

The construction of the mouthguards and occlusal splints (OS) was done by an expert dentist (Fig. 5). The purpose of including OS in this study was to test whether they are associated with positive changes in the subjects when compared to the other thicker mouthguards. Two over-the-counter mouthguards (Everlast Single Mouthguard, Moberly, USA) were used. The MCM mouthguard as well as OS were prepared by the dentist and positioned the jaw in a centric relation (CR) position. The NCM mouthguard did not have any dentist intervention. All the different mouthpieces had the VDO measured for comparison.

The choice for using the CR position as a reference for the jaw position, for both OS and MCM mouthguards, was due to two reasons: 1) it is labelled as the most orthopaedic musculoskeletal stable position for the mandible and 2) it is reproducible. This specific position is achieved when the condyles are in their most anterior-superior position in the articular fossae, promoting the stable seating of the TMJ condyles in a congruent skeletal position (Okeson, 2008). The CR position is considered an optimal arrangement of joint, disk and muscle (Dylina, 2001).

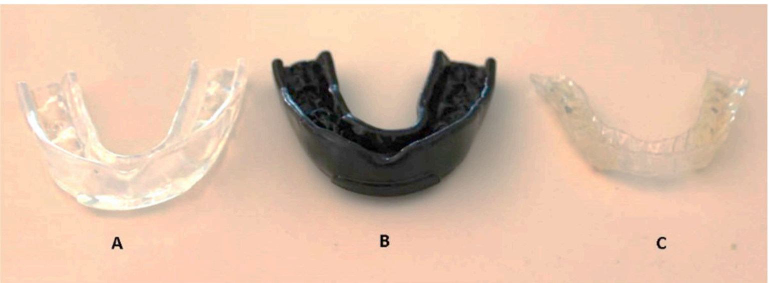

Figure 5. The occlusal devices used. A – Mandible controlled mouthguard; B – Non-controlled Mouthguard; C - Occlusal splint

Statistical analyses

All data are presented as mean ± SD and was examined for normal distribution using the Shapiro-Wilk test and for homogeneity of variance the Levene's test. When this assumption was met, repeated ANOVA measures were used to calculate significance among the mouthguard conditions for each of the variables previously mentioned. Sphericity was assessed using the Mauchly's test, and when this assumption was not admitted, the Greenhouse-Geisser correction was performed. When the data presented a non-normal distribution, the Friedman's test was applied. For the variables that demonstrated significant results, a multiple comparison test with Bonferroni adjustment was used. The changes in mean for the experimental variables (CR, NCM, MCM), compared to the normal condition (CON) of those same variables, was determined and expressed as effect sizes (Cohen's d). Magnitudes of the effects were interpreted using thresholds of 0.2, 0.6 and 1 for small, moderate and large respectively. An effect size lower than 0.2 was considered trivial (Hopkins, Marshall, Batterham, & Hanin, 2009). Where the 90% confidence limits overlapped small positive and negative values, the effect was deemed unclear.

Statistical analyses were performed using SPSS (version 22.0 for Windows, IBM-SPSS Inc., Chicago, IL, USA) with a significance set at $p < 0.05$.

RESULTS

The measurements of the different BBT variables and the statistical results are presented in Table 6. Peak force and peak acceleration were the only variables with a significant increase in mean results (p < 0.01). As shown in Table 7, post hoc tests revealed that the BBT mean results under the MCM condition were significantly higher when compared with the CON condition, for the two variables analysed. For peak force, tests results were (F (3.168) =4.296, $p < 0.05$) and for peak acceleration (F (3.168) =4.031, $p < 0.05$). No significant differences were obtained between the other conditions. Regarding effect size, Cohen's D was small for peak strength ($d = 0.21$) and peak acceleration ($d = 0.32$).

The MCM condition showed the highest mean values for VDO (Fig. 6). Statistical analyses revealed that these values were statistically relevant when compared with the OS and NCM conditions.

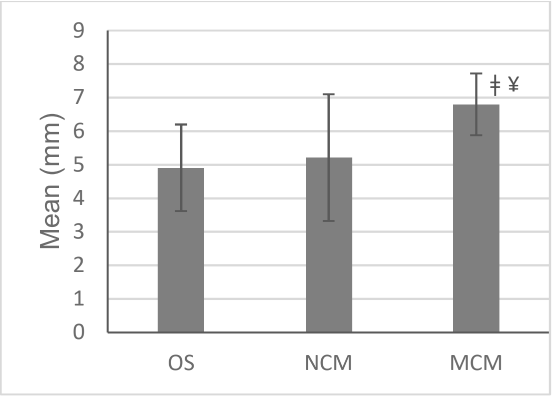

Figure 6. VDO results. Significant at p ≤ 0.05: ¥ higher than OS; ǂ higher than NCM

DISCUSSION

The aim of this study was to determine the effect of using MCM in comparison to NCM, OS and CON conditions on upper body acute power and strength in a group of well-trained amateur athletes. The MCM used in this study was designed to place the jaw in the CR position because it provides good control of the jaws' position and displacement, but also because CR is a stable and reproducible position. Our results show that athletes using a commercial mouthguard with a mandible-controlled position demonstrate higher mean values for peak acceleration and peak force when compared to a control condition, In the other analysed parameters, no changes in mean results were detected. For OS and NCM conditions, no changes were noticeable when comparing to CON or between them.

While some studies have demonstrated an improvement in upper body isometric and isokinetic strength when subjects were using mouthpieces (Alexander, 1999; Chakfa et al., 2002; Lee et al., 2014), others have demonstrated no changes in comparison to not using any mouthpieces (Allen et al., 2014; Golem, 2012). Such discrepancies in the results may have resulted from the different methods of evaluation used (Forgione, 1991). In one of the studies (Allen et al., 2014) no information was given on how subjects were acquainted with the use of mouthguards. Moreover, the authors did not describe how the mouthguard aligned the participants' jaw. In the other study (Golem, 2012), the mouthguards were developed without the aid of a dentist, which may have influenced the results.

To our knowledge, only one study investigated if using customized mouthguards changes performance in BBT training (Dunn-Lewis et al., 2012). Notably, these results showed that athletes using a customized mouthguard had significantly higher power and strength when performing BBT than athletes without a mouthguard (control), or those using an over-the-counter mouthguard. These results are in agreement with our findings showing that athletes using an MCM had higher peak force during BBT than those without a mouthguard.

Table 6. Values of ballistic bench throws variables in the four conditions: No mouthguard (CON), Non-controlled Mouthguard (NCM); Mandible controlled mouthguard (MCM) and Occlusal splints (OS)

Variables	CON	NCM	MCM	OS	*p value*
Velocity (m/s)	1.181 ± 0.11	1.201 ± 0.15	1.191 ± 0.19	1.199 ± 0.14	0.135
Peak velocity (m/s)	1.772 ± 0.13	1.755 ± 0.24	1.774 ± 0.15	1.783 ± 0.13	0.529
Time to peak velocity (s)	0.341 ± 0.40	0.332 ±0.05	0.337 ± 0.03	0.344 ± 0.03	0.233
Acceleration (m/s^2)	5.670 ± 0.63	5.695 ± 0.59	5.816 ± 0.56	5.578 ±0.81	0.115
Peak acceleration (m/s^2)	10.317 ± 2.45	11.025 ± 3.12	11.294 ± 3.56	10.956 ± 3.03	0.008*
Power (W)	575. 621 ± 135. 45	582. 932 ± 139. 92	566. 608 ± 148. 01	586. 25 ± 137. 63	0.366
Peak Power (W)	987.661 ± 171.19	996. 14 ± 179.40	985. 07 ± 180.64	1003. 90 ± 159. 43	0.793
Time to peak power (s)	0.303 ± 0.07	0.290 ± 0.43	0.290 ±+0.03	0.295 ± 0.05	0.115
Force (N)	520.727 ±99.47	530.09 ± 99.06	527.09 ± 101.59	527.79 ± 103.69	0.415
Peak force (N)	883.25 ± 187.81	917.64 ± 237.23	929.18 ± 243.89	933.27 ± 211.57	0.006*
Time to peak Force (s)	0.038 ± 0.44	0.037 ±0.05	0.039 ± 0,05	0.057 ± 0,11	0.332

∗ $p<0.05$

Table 7. Multiple comparisons between conditions: No mouthguard (CON), Non-controlled Mouthguard (NCM), Mandible controlled mouthguard (MCM) and Occlusal splint (OS).

			95% CI	
Comparisons	Mean Difference	Std Error	Lower Bound	Upper Bound
Peak Strength (N)				
CON vs OS	-37.946	14.460	-77.498	1.607
CON vs NCM	-37.181	15.193	-78.739	4.376
CON vs MCM	-46.943 *	15.932	-90.521	-3.365
OS vs NCM	0.765	11.579	-30.905	32.435
OS vs MCM	-8.997	14.240	-47.947	29.953
NCM vs MCM	9.762	13.434	-26.985	46.508
Peak Acceleration (m/s^2)				
CON vs OS	-0.690	0.318	-1.561	0.181
CON vs NCM	-0.777	0.314	-1,636	0,082
CON vs MCM	-0.984 *	0.324	-1.870	-0.99
OS vs NCM	-0.087	0.269	-0.822	0.648
OS vs MCM	-0.294	0.300	-1.114	0,526
NCM vs MCM	0.207	0.275	-0.544	0.958

∗ $p<0.05$

However, in their study, Dunn-Lewis et al (Dunn-Lewis et al., 2012) also reported differences in strength between athletes using customized and over-the-counter mouthguards, which did not occur in our study. This may have been related to the fact that VDO was not controlled in this study.

The differences between MCM and CON conditions may be partially explained by the changes in VDO, as we found significant differences in VDO between the MCM and the other testing conditions (Figure 1). It has been suggested that changes in VDO may influence the modulation of motoneuron pools, depending on the magnitude of those changes (Miralles et al., 2002). The MCM used in our study created an increased VDO when compared to the OS and NCM. This increased VDO may induce optimal spacing between the teeth, which combined with the CR position could have contributed to the results of this study. The lack of results on the other analysed parameters could be explained by the body's need for an adaptation period to the new TMJ position.

Other researchers investigated if clenching (on a mouthguard) renders a physical advantage in strength exercises by measuring neuromuscular performance in different types of jump movements (Buscà et al., 2016; Ebben, Flanagan, et al., 2008; Ebben, Kaufmann, et al., 2010). Notably, these studies demonstrated a positive effect of clenching on sports performance in mouthguard users. Moreover, clenching also appears to occur in an involuntary manner during resistance training exercises (Ebben, 2006b), as it was shown by electromyography (Yokoyama, 1998). In our study, the participants did not receive any instructions on how they should clench their jaw during the exercise, and hence we cannot exclude the possibility that clenching occurred, in particular during the concentric explosive push of the bar, which required maximal muscular effort. It might be speculated that involuntary teeth clenching in MCM, combined with the increase in VDO and positioning of the jaw in CR position potentiated strength and speed during BBT. As biting force data was not collected, this constitutes an open question in our study, and to some extent also a limitation. We suggest that the ergogenic effect of using customized mouthguards results from a combination of factors including CR position, VDO and involuntary clenching. Specifically, mouthguards that position the mandible in CR and increase VDO may provide better mandible stability and optimal height between teeth for improving strength-based skills at the neuromuscular level. This idea is supported by Milani et al. (Milani, De Perière, Lapeyre, & Pourreyron, 2000), who proposed that, through a CAP, the activation of facial muscles (when clenching) enhances the activation and response of limb muscles in sport-related tasks. This mechanism may be the underlining reason for the ergogenic effects, assisted by the change in TMJ position and increase in VDO.

While there is extensive research on the effects of using mouthguards on upper body strength, to our knowledge this is the first study investigating how mouthguards placing the mandible in CR may affect strength and power in trained athletes. Moreover, in contrast to previous research (Allen et al., 2014; Dunn-Lewis et al., 2012; Rexhepi & Brestovci, 2013), in the present study, the position of the mandibles was clinically controlled and changes in VDO were quantified.

Addressing the effects of using a mouthguard that anatomically sets the position of the mandible in a reproducible manner provides a novel approach to the existing literature. Since there are no standard guidelines for the construction of mouthguards, this study can be considered as the first attempt in that direction. As the MCM mouthguard places the mandible in a reproducible position, the results in this study can be directly compared with future studies using this type of mouthpiece in various sports settings. Future research should focus on controlling and quantifying jaw clenching and the position of the mandible in athletes using mouthguards comparing them to those without mouthguards, in an effort to determine the usefulness of mouthguards as performance enhancers.

CONCLUSIONS

Our results support the hypothesis that using customized mouthguards improves some physical performance parameters to a small extent. Additionally, we have demonstrated that they do not induce negative performance effects. The outcomes of this study suggest that these mouthguards, besides protecting the teeth and preventing facial injury, have some positive ergogenic effect as demonstrated by the increases in peak strength and peak acceleration. Therefore, these results encourage athletes to use mandible controlled position mouthguards, since upper body ballistic movements are involved in a variety of sports skills and tasks.

Acknowledgments

The research team wishes to extend their gratitude to the athletes for their contributions and participation in this study. The authors declare that there is no conflict of interests between the researchers of this study and the participants, the companies providing the materials and equipment used, or any other procedures undertaken during the experiments.

REFERENCES

Alexander, C. (1999). *A Study on the Effectiveness of a Self-Fit Mandibular Repositioning Appliance on Increasing Human Strength and Endurance Capabilities*. University of Tennessee.

Allen, C., Dabbs, N., Zachary, C., & Garner, J. (2014). The acute effect of a commercial bite-aligning mouthpiece on strength and power in recreationally trained men. *Journal of Strength and Conditioning Research*, *28*(2), 499–503.

Arent, S., McKenna, J., & Golem, D. (2010). Effects of a neuromuscular dentistry-designed mouthguard on muscular endurance and anaerobic power. *Comparative Exercise Physiology*, *7*(2), 73–79. http://doi.org/10.1017/S1755254010000231

Baechle, T. & Earle, R. (2008). *Essentials of Strength Training and Conditioning*. *Journal of athletic training* (3rd ed., Vol. 31). Human Kinetics. http://doi.org/10.1016/S0031-9406(05)66120-2

Baker, D., Nance, S., & Moore, M. (2001). The Load That Maximizes the Average Mechanical Power Output During Jump Squats in Power-Trained Athletes. *The Journal of Strength and Conditioning Research*, *15*(1), 92. http://doi.org/10.1519/1533-4287(2001)015<0092:TLTMTA>2.0.CO;2

Bevan, H., Bunce, P., Owen, N., Bennett, M., Cook, C., Cunningham, D., Newton, R., & Kilduff, L.. (2010). Optimal loading for the development of peak power output in professional rugby players. *Journal of Strength and Conditioning Research*, *24*(1), 43–47.

Bevan, H., Bunce, P., Owen, N., Bennett, M., Cook, C., Cunningham, D., & Kilduff, L.. (2010). Optimal loading for the development of peak power output in professional rugby players. *Journal of Strength and Conditioning Research*, *24*(1), 43–7. http://doi.org/10.1519/JSC.0b013e3181c63c64

Buscà, B., Morales, J., Solana-Tramunt, M., Miró, A., & García, M. (2016). Effects of Jaw Clenching While Wearing a Customized Bite-Aligning Mouthpiece on Strength in Healthy Young Men. *Journal of Strength and Conditioning Research*, *30*(4), 1102–10. http://doi.org/10.1519/JSC.0000000000001192

Chakfa, A., Mehta, N., Forgione, A., Al-Badawi, E., Lobo, S., & Zawawi, K. (2002). The effect of stepwise increases in vertical dimension of occlusion on isometric strength of cervical flexors and deltoid muscles in nonsymptomatic females. *Cranio : The Journal of Craniomandibular Practice*, *20*(4), 264–73. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/12403184

Duarte-Pereira, D., Rey-Santamaria, M., Javierre-Garcés, C., Barbany-Cairó, J., Paredes-Garcia, J., Valmaseda-Castellón, E., & Gay-Escoda, C. (2008). Wearability and physiological effects of custom-fitted vs self-adapted mouthguards. *Dental Traumatology : Official Publication of International Association for Dental Traumatology*, *24*(4), 439–42. http://doi.org/10.1111/j.1600-9657.2008.00595.x

Dunn-Lewis, C., Hydren, J., Kraemer, W., Denegar, C., Watts, A., Comstock, B., & Volek, J. (2012). The Effects of a Customized Over-the-Counter Mouth Guard on Neuromuscular Force and Power Production in Trained Men and Women. *Journal of Strength and Conditioning Research*, *26*(September 2015), 1085–1093. http://doi.org/10.1519/JSC.0b013e31824b4d5b

Dylina, T. (2001). A common-sense approach to splint therapy. *The Journal of Prosthetic Dentitry*, *86*(5), 539–545.

De Leeuw, L, & Klasser, G. (2013). Orofacial Pain. Guidelines for Assessment, Diagnosis, and Management. 5h edition, Chicago, IL: Quintessence Publishing Co, Inc.

Ebben, W. (2006a). A brief review of concurrent activation potentiation: theoretical and practical constructs. *Journal of Strength and Conditioning Research / National Strength & Conditioning Association*, *20*(4), 985–91. http://doi.org/10.1519/R-19375.1

Ebben, W. (2006b). A brief review of concurrent activation potentiation: theoretical and practical constructs. *Journal of Strength and Conditioning Research / National Strength & Conditioning Association*, *20*(4), 985–91. http://doi.org/10.1519/R-19375.1

Ebben, W., Flanagan, E., & Jensen, R. (2008). Jaw clenching results in concurrent activation potentiation during the countermovement jump. *Journal of Strength and Conditioning Research / National Strength & Conditioning Association*, *22*(6), 1850–4. http://doi.org/10.1519/JSC.0b013e3181875117

Ebben, W., Kaufmann, C., Fauth, M., & Petushek, E. (2010). Kinetic analysis of concurrent activation potentiation during back squats and jump squats. *Journal of Strength and Conditioning Research / National Strength & Conditioning Association*, *24*(6), 1515–9. http://doi.org/10.1519/JSC.0b013e3181dc4761

Ebben, W., Leigh, D., & Geiser, C. (2008). The effect of remote voluntary contractions on knee extensor torque. *Medicine and Science in Sports and Exercise*, *40*(10), 1805–1809. http://doi.org/10.1249/MSS.0b013e31817dc4ad

Ebben, W., Petushek, E., Fauth, M., & Garceau, L. (2010). EMG analysis of concurrent activation potentiation. *Medicine and Science in Sports and Exercise*, *42*(3), 556–562. http://doi.org/10.1249/MSS.0b013e3181b66499

Ferrario, V., Sforza, C., Dellavia, C., & Tartaglia, G. (2003). Evidence of an influence of asymmetrical occlusal interferences on the activity of the sternocleidomastoid muscle. *Journal of Oral Rehabilitation*, *30*(1), 34–40. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/12485381

Forgione, A., Mehta, N., McQquade, C., & Westcott, W. (1992). Strength and bite, Part 2: Testing isometric strength using a MORA set to a functional criterion. *Cranio*, *10*(1), 13–20.

Forgione, A. (1991). Strength and bite Part I.pdf. *The Journal of Craniomandibular Practice*, *9*(4), 305–315.

Francis, K., & Ma, J. (1991). Physiological effects of wearing mouthguards. *British Journal of Sports Medicine*, *25*(4), 227–232.

Garceau, L., Petushek, E., McKenzie, F., & Ebben, W. (2012). Effect of Remote Voluntary Contractions on Isometric Prime Mover Torque and Electromyography. *Journal of Exercise Physiology*, *15*(4), 40–46. http://doi.org/10.1519/JSC.0b013e3181874564

Gelb, H., Mehta, N. R., & Forgione, A. (1996). The relationship between jaw posture and muscular strength in sports dentistry: a reappraisal. *Cranio : The Journal of Craniomandibular Practice*, *14*(4), 320–5. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/9110627

Golem, D. (2012). *Improving Physical Performance: The Role of Jaw-Repositioning*. Graduate School - New Brunswick.

González-Hernádez, J., García-Ramos, A., Capelo-Ramírez, F., Castaño-Zambudio, A., Marquez, G., Boullosa, D., & Jiménez-Reyes, P. (2017). Mechanical, metabolic, and perceptual acute responses to different set configurations in full squat. *Journal of Strength and Conditioning Research*. http://doi.org/10.1519/JSC.0000000000002117

Gunepin, M., Derache, F., Blatteau, J.-É., Trousselard, M., Castagna, O., & Risso, J. (2017). Potential of mouthguards for enhancing sport and physical performances: A review of 50 years of medical research. *Médecine Buccale Chirurgie Buccale*, *23*(1), 21–31. http://doi.org/10.1051/mbcb/2016025

Hernández, J., Solana, R., Marín, J., Fernández, J., & Moya, M. (2016). Rest Interval Required for Power Training With Power Load in the Bench Press Throw Exercise. *Journal of Strength and Conditioning Research*, *30*(5), 1265–74. http://doi.org/10.1519/JSC.0000000000001214

Hoffman, J. (2014). *Physiological aspects of sport training and performance* (2nd ed.). Human Kinetics.

Hopkins, W., Marshall, S., Batterham, A., & Hanin, J. (2009). Progressive statistics for studies in sports medicine and exercise science. *Medicine and Science in Sports and Exercise*, *41*(1), 3–12. http://doi.org/10.1249/MSS.0b013e31818cb278

Hosoda, M., Masuda, T., Isozaki, K., Takayanagi, K., Sakata, K., Takakuda, K., & Morita, S. (2007). Effect of occlusion status on the time required for initiation of recovery in response to external disturbances in the standing position. *Clinical Biomechanics (Bristol, Avon)*, *22*(3), 369–73. http://doi.org/10.1016/j.clinbiomech.2006.11.001

Jung, J., Chae, W., & Lee, K. (2013). Analysis of the characteristics of mouthguards that affect isokinetic muscular ability and anaerobic power. *The Journal of Advanced Prosthodontics*, *5*(4), 388–95. http://doi.org/10.4047/jap.2013.5.4.388

Knapik, J., Marshall, S., Lee, R., Darakjy, S., Jones, S., Mitchener, T., & Jones, B. (2007). Mouthguards in sport: Activities history, physical properties and injury prevention effectiveness. *Sports Medicine*, *37*(2), 117–144. http://doi.org/10.2165/00007256-200737020-00003

Lee, S., Hong, M., Park, M., & Choi, S. (2013). Effect of the Mandibular Orthopedic Repositioning Appliance on Trunk and Upper Limb Muscle Activation during Maximum Isometric Contraction. *Journal of Physical Therapy Science*, *25*(11), 1387–9. http://doi.org/10.1589/jpts.25.1387

Lee, S., Park, Y., Park, H., Bae, H., Yu, M., Choi, H., & Hwang, N. (2014). Effect of the Mandibular Orthopedic Repositioning Appliance (MORA) on Forearm Muscle Activation and Grasping Power during Pinch and Hook Grip. *Journal of Physical Therapy Science*, *26*(2), 195–7. http://doi.org/10.1589/jpts.26.195

Milani, R., De Perière, D., Lapeyre, L., & Pourreyron, L. (2000). Relationship between dental occlusion and posture. *Cranio : The Journal of Craniomandibular Practice*, *18*(2), 127–34. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/11202823

Miralles, R., Dodds, C., Manns, A., Palazzi, C., Jaramillo, C., Quezada, V., & Cavada, G. (2002).

Vertical dimension. Part 2: the changes in electrical activity of the cervical muscles upon varying the vertical dimension. *Cranio : The Journal of Craniomandibular Practice*, *20*(1), 39–47. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/11831343

Morales, J., Buscà, B., Solana-Tramunt, M., & Mirò, A. (2015). Acute effects of jaw clenching using a customized mouthguard on anaerobic ability and ventilatory flows. *Human Movement Science*, *44*, 270–276. http://doi.org/10.1016/j.humov.2015.09.008

Okeson, J. (2008). *Management of Temporomandibular Disorders and Occlusion*. (J. Dojan, Ed.) (Sixth). Elsevier.

Perinetti, G., & Contardo, L. (2009). Posturography as a diagnostic aid in dentistry: a systematic review. *Journal of Oral Rehabilitation*, *36*(12), 922–36. http://doi.org/10.1111/j.1365-2842.2009.02019.x

Raadsheer, M., Van Eijden, T., Van Ginkel, F., & Prahl-Andersen, B. (2004). Human jaw muscle strength and size in relation to limb muscle strength and size. *European Journal of Oral Sciences*, *112*(5), 398–405. http://doi.org/10.1111/j.1600-0722.2004.00154.x

Rexhepi, A., & Brestovci, B. (2013). The functional efficiency of mouthguards in martial sports. *Human Movement*, *14*(4), 353–359. http://doi.org/10.2478/humo-2013-0043

Yokoyama, Y. (1998). Involuntary Teeth Clenching during Physical Exercise. *Journal of the Japan Prosthodontic Society*, *42*, 90–101.

CHAPTER VII - The effects of occlusal splints on gait and running patterns. A kinematic analysis

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Status: Submitted; under review

ABSTRACT

Background / Aim: The relationship between dental occlusion and static body posture has been well researched and debated in several publications. Far less attention has been spent on studying the same relationship, but with regards to human locomotion, with only a scarce number of studies addressing the matter. Therefore, the aim of this study was to determine if changes in dental occlusion are correlated to body posture while walking and running.

Methods: This study enrolled fifteen healthy subjects (age: 21.13 ± 2.53 yrs), assessed by an expert dentist and deemed asymptomatic for temporomandibular disorders. Gait and running analysis was randomly performed on a treadmill in three different conditions: a) Occlusal splint; b) Placebo splint and C) No splint (control). The occlusal splint used in this study positioned the temporomandibular joint in a centric relation position. Kinematic data were collected using a 3D motion capture, consisting five high speed cameras system, for body horizontal sway (shoulders, anterior and posterior superior iliac spine) and vertical sway (spine).

Results: The use of occlusal splints did not influence the body sway during gait and running since no differences were found in the mean values for both horizontal and vertical body sway, for all the test conditions.

Conclusions: The use of occlusal splints that changes the temporomandibular joint into centric relation position appears to have no effect on body horizontal and vertical sway, for gait and running in healthy male subjects. High inter-subject variability in the kinematic parameters was found, mainly during gait. Due to this, intra-subject variability should be considered in future studies in order to understand the occlusal splints influence among subjects.

Keywords: Dynamic balance; gait; running; occlusal splints; kinematic

INTRODUCTION

Posture is used to describe the position of the human body or the arrangements of body parts relative to one another and its orientation in space (Kandel, 2013). The central nervous system (CNS) controls the muscles activation involved in postural adjustments These postural adjustments perform a critical part in the orthostatic and dynamic posture control and are the result of a complex system of mechanisms that benefit from several inputs (visual, vestibular and somatosensory), which are all integrated by the CNS. These mechanisms provide feedback and feedforward stream of information, necessary for our daily activities (Kandel, 2013).

In recent years, studies have speculated about a functional connection between body posture and the stomatognathic system (SS), particularly the temporomandibular joint (TMJ) (Baldini, Nota, Tripodi, Longoni, & Cozza, 2013; Michelotti, Buonocore, Manzo, Pellegrino, & Farella, 2011). These interactions remain controversial, since some authors did not found any relationship between TMJ and posture (Ferrario, Chiarella, Taroni, & Schmitz, 1996; Perinetti, 2006), while others have reported a significant relation (Bracco, Deregibus, & Piscetta, 2004; A. M. Cuccia, 2011)

The current body of knowledge tells us that TMJ and the neuromuscular system of the whole body are connected via the CNS (Ohlendorf, Seebach, Hoerzer, Nigg, & Kopp, 2014). Research has shown that when a change in mandible position occurs, it triggers a dependent reflex response that affects posture (Flavel, Nordstrom, & Miles, 2003). So, it appears that the SS, where TMJ is a central part, may influence muscle function on other parts of the body (Ishijima, Hirai, Koshino, Konishi, & Yokoyama, 1998). This may be explained by deviations of afferent information in TMJ, that causes changes in the activity of stabilizing muscles of the upper body, by efferent adaptation or compensation patterns (Ohlendorf et al., 2014). This information appears to be mediated by the trigeminal nerve (Julià-Sánchez et al., 2015), which has a neuronal connection to the vestibular nuclei, responsible for the equilibrium control (Devoize et al., 2010). Thus, any changes in the trigeminal nerve caused by changes in the TMJ may also affect the vestibular nuclei. This connection strengthens the argument for a relationship between TMJ and balance control. Studies that used surface electromyography (EMG) have reported changes in muscle activity of distal body segments when TMJ position is changed with an occlusal splint (Lee et al., 2014; Wang, K.; Ueno, T.; Taniguchi, H.; Ohyama, 1996). However, a recent review of studies reported a low degree of correlation in this changes, mainly due to the low number of studies on the topic (Perinetti, Türp, Primožič, Di Lenarda, & Contardo, 2011).

Some studies have explored how the mandible responds to gait and running, accessing how mandible posture was maintained (Flavel et al., 2003; Miles, Flavel, & Nordstrom, 2004). They reported that while walking, the small amplitude oscillations induced in the mandible were minimized by passive visco-elastic mechanisms. However, in running, with the impact of the feet landing, larger forces are transmitted to the skull and mandible and this causes the mandible to move more quickly in a downward motion. This movement triggers a clear reflex response in the mandible-closing muscles, that causes an upward movement of the mandible (Miles et al., 2004), thus affecting TMJ position. It seems that when walking the impact on the mandible is below the threshold level and no reflex response is generated, but when running, it elicits a monosynaptic pathway response in the masseter muscles (Miles et al., 2004). It can be hypothesized that this reflex response in the masseter muscles may affect the afferent information conveyed by the mandibular branch of the trigeminal nerve. This nerve conducts the information to the trigeminal mesencephalic nucleus, which subsequently projects to the vestibular nuclei. Here, this information is subsequently integrated with other signals involved in balance control (Yin, Lee, & Lee, 2007), and subsequently generates changes in body posture.

The effects of shifting TMJ position and how it correlates to body motion have been studied and established, but focusing on global gait parameters, like gait cycle and gait velocity (Fujimoto, Hayakawa, Hirano, & Watanabe, 2001), as well as kinetic variables, such as foot plantar pressure distribution (Cuccia, 2011; Simona, Polimeni, Saccucci, & Festa, 2010). Despite these data, the question remains on how the manipulation of the mandible position can affect human body posture in healthy subjects. Several studies have addressed this matter on static conditions (Baldini et al., 2013; Bracco et al., 2004; Ferrario et al., 1996; Julià-Sánchez et al., 2015), with contradicting results, but few studies have analysed the effects on dynamic conditions, i.e. locomotion. Two recent studies assessed how changes in occlusion could affect body posture in healthy subjects during locomotion. One study focused on gait (Ohlendorf et al., 2014) and the other one investigated running condition (Maurer et al., 2015). Both studies revealed an association between occlusion changes and symmetrical motion pattern.

The main aim of this study was to provide additional knowledge on the effects caused by changing TMJ position on body oscillation in dynamic conditions, assessed through horizontal and vertical sway. For this purpose, an occlusal splint that altered TMJ position was used, as well as a placebo splint. These conditions were compared to a normal condition (no splints) for both gait and running conditions. To assess body oscillation, a 3D motion capture system was used.

METHODS

Subjects

Fifteen healthy male subjects participated in this study (age: 21.13 ± 2.53 yrs; height: 1.80 ± 0.06 m; body mass: 74.67 ± 7.04 kg). Subjects underwent dental examination conducted according to the clinical guidelines published by the American Academy of Orofacial Pain (De Leeuw & Klasser, 2013) with an expert dentist and were excluded if a TMJ disorder was diagnosed. For each subject, a complete maxillary and mandibular arch impression were casted and an occlusal splint and a placebo splint was fabricated (Fig.7). This research was approved by the ethics committee of the Faculdade de Motricidade Humana for use of human research (6/2016).

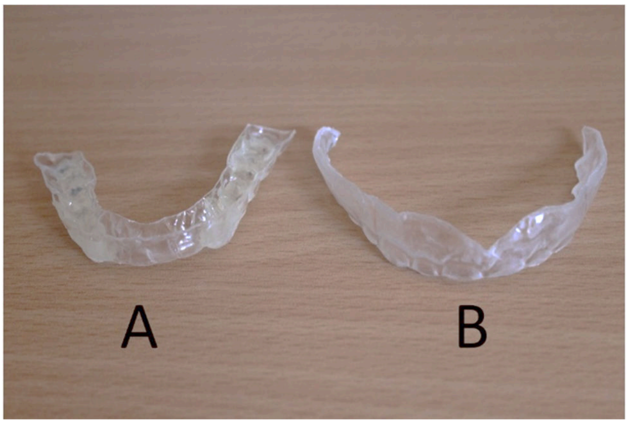

Figure 7. Oral devices tested. A - Occlusal splint; B - Placebo splint

Experimental protocol

Three conditions were tested for gait and running: Occlusal splint (OS), placebo splint (PS) and no splint (control – CON). The test order was randomized and subjects were unaware of the usage of a placebo splint. Subjects were asked to refrain from any high intensity physical activity, 48h prior to the tests. Before the tests, subjects performed a 5-min warm up on the treadmill. For each of the three conditions tested, subjects performed a 1-min test at speeds of 1.4 m s^{-1} and 2.8 m s^{-1} (5 km/h and 10 km/h respectively). These speeds were identical to the ones used in other studies (Flavel et al., 2003; Miles et al., 2004). The last thirty gait cycles of each test were recorded for kinematic analysis. Between each test, subjects had a 3-min rest period.

The occlusal splint used in this study was designed to place the TMJ in the centric relation (CR) position. The choice for using this position for the occlusal splint was because it is considered the most orthopaedic musculoskeletal stable position for the mandible, and because it is reproducible (Okeson, 2008). The CR position is achieved when the condyles are in their most anterior superior position in the articular fossae, promoting the stable seating of the TMJ condyles in a congruent skeletal position (Okeson, 2008). It is considered an optimal arrangement of joint, disk and muscle (Dylina, 2001).

For kinematic analysis five high-speed cameras (Basler A602fc, Basler Vision Technologies, Ahrensburg, Germany) were used, operating at a sampling rate of 100 Hz. One camera was placed directly behind the subject (perpendicularly to the subject’s frontal plane) and the other cameras were placed at an oblique angle of 110 degrees, in anterior and posterior positions. For the gait and running tests, a “Laufergotest” treadmill was used (E. Jaegar, Wuerzburg, Germany). In order to analyse body horizontal sway, reflective markers were placed on left and right acromion, as well as on left and right anterior and posterior superior iliac spine. For body vertical sway, reflective markers were placed on C7 and L5. All markers were placed according to SENIAM guidelines (Hermens, Freriks, Disselhorst-Klug, & Rau, 2000).

Data was processed with the use of specialized 3D software (Simi Reality Motion Systems GmbH, Unterschleissheim, Germany) for marker trajectories. Afterwards, data was examined using a routine by Matlab software VR2013a (The Mathworks Inc., Natick Massachusetts, USA). This routine detected the gait cycles and calculated mean oscillation angles in the frontal plane in each gait cycle (horizontal and vertical components). For comparison of the horizontal sway, the lines between left and right acromion, anterior superior iliac spine and posterior superior iliac spine were used. The line between C7 and L5 was used to compare the vertical sway.

Statistical analysis

All the data are presented in degrees and as *mean ± sd.* Data were examined for normal distribution using Shapiro-Wilk test and for homogeneity of variance with the Levene’s test. When this assumption was met, repeated ANOVA measures were used to calculate significance among the different conditions tested in both gait and running. Sphericity was assessed using the Mauchly’s test, and when this assumption was not admitted, the Greenhouse-Geisser correction was performed. When the data presented a non-normal distribution, the Friedman’s test was applied. For all tests, a significance level of 0.05 was used.

Table 8. Results of the three experimented conditions in gait and running. OS - Occlusal splint; PS - placebo splint; CON - no splint: control condition

	Gait				Running			
	OS	PL	CON	*p value*	OS	PL	CON	*p value*
Shoulders	14.55 ± 26.26°	15.83 ± 21.82 °	10.93 ± 31.28 °	0.395	20.48 ±5.60 °	19.62 ±5.36°	20.97 ±4.56 °	0.752
Anterior superior iliac spine	21.75 ±8.12 °	21.91 ±7.22 °	19.06 ± 17.21 °	0.741	20.41 ±4.70 °	20.86 ±4.71 °	21.83 ±3.07 °	0.479
Posterior superior iliac spine	21.66 ±8.40 °	21.90 ±7.43 °	19.32 ±17.21 °	0.301	20.31 ±4.70 °	20.54 ±4.92 °	21.66 ±3.26 °	0.492
Spine	9.28 ±29.46°	11.99 ± 22.53 °	1.64 ± 34.86 °	0.495	20.43 ±5.59 °	19.89 ±5.32 °	20.94 ±4.40 °	0.746

RESULTS

The changes in TMJ position caused by the occlusal splints showed no statistically significant differences for both gait and running tests (Table 8). The mean values for all the conditions were very similar for the gait tests, except in the vertical sway, measured by spine sway, were control condition had lower mean values that the other conditions, but with no statistical significance. In the running tests, for all the experimental conditions, mean values were identical, with small variations in the results. The standard deviation results for the gait tests were very high.

DISCUSSION

The main purpose of this study was to understand if and how OS affects human body locomotion, in both gait and running. The OS used in this study was designed to position the mandible in the CR position because it provides good control of the mandible position and displacement, but also because CR is a stable and reproducible position. Modifications of TMJ position appear to influence body equilibrium function in the static condition (Cuccia & Caradonna, 2009; Gangloff, Louis, & Perrin, 2000; Julià-Sánchez et al., 2015, 2016; Tardieu et al., 2009), but little is known under dynamic conditions. For this study, gait was selected as an experimental condition because it is a basic, natural and spontaneous movement of the human body, while running was chosen since it's a fundamental motor skill, required for most sports.

In this study, the mean values of body horizontal and vertical sway were not altered when a variation in TMJ position was introduced using an OS. When looking at the standard deviation values during gait tests we can see that they were high in all experimental conditions. This may imply very different movement patterns for the pool of subjects. Running tests revealed similar mean values between conditions, as well as smaller standard deviations. The similar values in the running tests appear to suggest that the human body neutralizes the changes in movement pattern and creates a more even pattern for all subjects.

Studies on the effects of a manipulated dental occlusion and how it can affect human body in dynamic conditions have been done focusing on kinetic parameters in gait tests (Cuccia, 2011; Tecco, D'Attilio, & Festa, 2008; Tecco et al., 2010). Tecco et al (S Tecco et al., 2008) used a force platform to record the loading pressure during gait. For this study, subjects with and without TMJ disorders were recruited. Subjects were asked to walk on the force platform in two conditions: normal occlusion and altered occlusion conditions – using cotton rolls between the teeth. The results revealed that the loading surface and foot pressure were affected when using cotton rolls, but only for the TMJ disorders subjects. The control subjects did not have any changes in the same variables. A similar study was performed by Cuccia (Cuccia, 2011), which used a similar method, but added another condition, voluntary tooth clenching. Subjects without TMJ disorders also did not revealed differences in the results while using cotton rolls, but the opposite occur in the clenching condition. In this condition, for both subjects with and without TMJ disorders, voluntary tooth clenching determined a reduction in foot load pressure and an increase in surface contact for both feet. One other study (Tecco et al., 2010) explored the effects of changing occlusion (with cotton rolls) and how it affected foot load pressure and load surface on healthy subjects during locomotion. The authors reported that when using cotton rolls in both dental arches no changes were detected, which corroborates the studies mentioned before. However, when an imbalance of occlusion was created by using cotton rolls on just one dental arch, the percentage of loading and loading surface on the corresponding foot was reduced significantly. These studies support the association between SS and locomotion, as it showed measurable relationships between changes in occlusion and gait.

To the best of our knowledge, few studies have explored how manipulated dental occlusion affects human body posture in locomotion (Maurer et al., 2015; Ohlendorf et al., 2014). Nevertheless, only one tested OS (Maurer et al., 2015). This study analysed running through kinematic parameters using machine learning for movement pattern identification. They found differences in split running conditions when comparing with the neutral one. However, these differences occur only within subjects, not across them. The reason behind of using machine learning was because they considered the changes in running kinematics too small and hard to detect. Another difference should be noted, these authors look at running cycle in the sagittal plane, when the present study analysed the frontal one. Our results presented a high standard deviation for the conditions analysed, which implies an increased level of variability between subjects, and consequently great differences between subject's motion patterns. This supports the need for individual analysis of each subject. In our study, we did not have sufficient data due to the short duration of each test, to perform a complete and proper analysis and comparison of each subject and this is a limitation of this study.

The other study focused on spine position while walking (Ohlendorf et al., 2014). For this study, ultrasonic equipment was used for measuring changes in the different spine regions and silicon panels were applied between the teeth in several positions. These silicon panels were intended to mimic OS and they increased vertical dimension of occlusion. Results revealed that, independently of the placement of the silicon panels, there were significant changes in spine position for frontal and sagittal planes. This study demonstrated that there may be a connection between manipulated dental occlusion and changes in spine position while walking for healthy subjects.

Other possible reason for the different results in our study compared with previous studies (Maurer et al., 2015; Ohlendorf et al., 2014) may be related to clenching and to the displacement of the mandible. Maurer et al. (Maurer et al., 2015) ask the subjects to byte with moderate force while running, as did Cuccia (Cuccia, 2011) in his study of plantar arch changes during gait. Ohlendorf et al. (Ohlendorf et al., 2014) did not ask the subjects to byte but placed silicon panels between the subjects' teeth and it is reasonable to assume that they had to byte, to keep them in place. When clenching, there is a contraction of the masseter muscles, which have been reported to have an association with posture (Hosoda et al., 2007), through a functional coupling with the trigeminal nerve (Browne, Clark, Yang, & Nakano, 1993). This connections produces mutual inhibition and activation appearing to be a dynamic relationship (Daly, Preston, & Evans, 1982). Clenching causes an increase in masseter muscle activity that may affect input signals to the central nervous system transmitted by the trigeminal nerve, which in turn transfers the altered output signal via spinal nerves and autonomic nerves to the whole body (Milani, De Perière, Lapeyre, & Pourreyron, 2000). This could be the reason why the studies previously mentioned reported changes in motion patterns and we failed to do so, since we did not asked subjects to clench while performing the tests.

This study only investigated the acute effects caused by the OS. Future studies should focus on a longitudinal design, to further examine how the kinematic pattern could change over several days. Also, studies should focus on individual kinematics analysis for comparison, instead of comparing mean values in a pool of subjects.

CONCLUSIONS

This study did not find, for healthy male subjects, a detectable relationship between TMJ changes to a CR position and body oscillation during gait and running. The high inter-subject variability found in this study, especially for gait, advises caution while interpreting the results. Considering that the effects of occlusal splints could differ from subject to subject, in the future it would be important to evaluate the influence of occlusal splints with an individual analysis of each subject. This study has provided with further understandings of how the stomatognathic system could affect locomotion.

Acknowledgments

The authors wish to extend their gratitude to the athletes for their contributions and participation in this study. The authors declare that there is no conflict of interests between the researchers of this study and the participants, the companies providing the materials and equipment used, or any other procedures undertaken during the experiments.

REFERENCES

Baldini, A., Nota, A., Tripodi, D., Longoni, S., & Cozza, P. (2013). Evaluation of the correlation between dental occlusion and posture using a force platform. *Clinics*, *68*(1), 45–49. http://doi.org/10.6061/clinics/2013(01)OA07

Bracco, P., Deregibus, A., & Piscetta, R. (2004). Effects of different jaw relations on postural stability in human subjects. *Neuroscience Letters*, *356*(3), 228–30. http://doi.org/10.1016/j.neulet.2003.11.055

Browne, P., Clark, G. Yang, Q., & Nakano, M. (1993). Sternocleidomastoid muscle inhibiton induced by trigeminal stimulation. *Journal of Dental Research*, *72*(11), 1503–1508.

Cuccia, A., & Caradonna, C. (2009). The relationship between the stomatognathic system and body posture. *Clinics*, *64*(1), 61–66. http://doi.org/10.1590/S1807-59322009000100011

Cuccia, A. (2011). Interrelationships between dental occlusion and plantar arch. *Journal of Bodywork and Movement Therapies*, *15*(2), 242–50. http://doi.org/10.1016/j.jbmt.2010.10.007

Daly, P., Preston, C. B., & Evans, W. G. (1982). Postural response of the head to bite opening in adult males. *American Journal of Orthodontics*, *82*(2), 157–60. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/6961786

De Leeuw, L, & Klasser, G. (2013). *Orofacial Pain. Guidelines for Assessment, Diagnosis, and Management*. 5h edition, Chicago, IL: Quintessence Publishing Co, Inc.

Devoize, L., Doméjean, S., Melin, C., Raboisson, P., Artola, A., & Dallel, R. (2010). Organization of projections from the spinal trigeminal subnucleus oralis to the spinal cord in the rat: A neuroanatomical substrate for reciprocal orofacial–cervical interactions. *Brain Research*, *1343*, 75–82. http://doi.org/10.1016/j.brainres.2010.04.076

Dylina, T. J. (2001). A common-sense approach to splint therapy. *The Journal of Prosthetic Dentitry*, *86*(5), 539–545.

Ferrario, V., Chiarella, B., Taroni, A., & Schmitz, H. (1996). Occlusion and center of foot pressure variation: Is there a relationship ? *The Journal of Prosthetic Dentitry*, *76*(3), 302–308.

Flavel, S., Nordstrom, M., & Miles, T. S. (2003). Postural stability of the human mandible during locomotion. *Journal of Biomechanics*, *36*(6), 759–764. http://doi.org/10.1016/S0021-9290(03)00009-5

Fujimoto, M., Hayakawa, I., Hirano, S., & Watanabe, I. (2001). Changes in gait stability induced by alteration of mandibular position. *Journal of Medicine and Dental Sciences*, *48*, 131–136.

Gangloff, P., Louis, J., & Perrin, P. (2000). Dental occlusion modifies gaze and posture stabilization in human subjects. *Neuroscience Letters*, *293*, 203–206.

Hermens, H., Freriks, B., Disselhorst-Klug, C., & Rau, G. (2000). Development of recommendations for SEMG sensors and sensor placement procedures. *Journal of Electromyography and Kinesiology*, *10*(5), 361–74. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/11018445

Hosoda, M., Masuda, T., Isozaki, K., Takayanagi, K., Sakata, K., Takakuda, K., & Morita, S. (2007).

Effect of occlusion status on the time required for initiation of recovery in response to external disturbances in the standing position. *Clinical Biomechanics (Bristol, Avon)*, *22*(3), 369–73. http://doi.org/10.1016/j.clinbiomech.2006.11.001

Ishijima, T., Hirai, T., Koshino, H., Konishi, Y., & Yokoyama, Y. (1998). The relationship between occlusal support and physical exercise ability. *Journal of Oral Rehabilitation*, *25*(6), 468–71. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/9687121

Julià-Sánchez, S., Álvarez-Herms, J., Gatterer, H., Burtscher, M., Pagès, T., & Viscor, G. (2015). Dental Occlusion Influences the Standing Balance on an Unstable Platform. *Motor Control*, *19*(4), 341–354. http://doi.org/10.1123/mc.2014-0018

Julià-Sánchez, S., Álvarez-Herms, J., Gatterer, H., Burtscher, M., Pagès, T., & Viscor, G. (2016). The influence of dental occlusion on the body balance in unstable platform increases after high intensity exercise. *Neuroscience Letters*, *617*, 116–121. http://doi.org/10.1016/j.neulet.2016.02.003

Kandel, E. (2013). *Principles of Neural Science*. (A. Kandel, Eric; Schwartz, James; Jessell, Thomas; Sielgelbaum, Steven; Hudspeth, Ed.) (5th ed.). McGraw-Hill.

Lee, S., Park, Y., Park, H., Bae, H., Yu, M., Choi, H., & Hwang, N. (2014). Effect of the Mandibular Orthopedic Repositioning Appliance (MORA) on Forearm Muscle Activation and Grasping Power during Pinch and Hook Grip. *Journal of Physical Therapy Science*, *26*(2), 195–7. http://doi.org/10.1589/jpts.26.195

Maurer, C., Stief, F., Jonas, A., Kovac, A., Groneberg, D. A., Meurer, A., & Ohlendorf, D. (2015). Influence of the lower jaw position on the running pattern. *PLoS ONE*, *10*(8), 1–16. http://doi.org/10.1371/journal.pone.0135712

Michelotti, A., Buonocore, G., Manzo, P., Pellegrino, G., & Farella, M. (2011). Dental occlusion and posture: An overview. *Progress in Orthodontics*, *12*(1), 53–58. http://doi.org/10.1016/j.pio.2010.09.010

Milani, R., De Perière, D., Lapeyre, L., & Pourreyron, L. (2000). Relationship between Dental Occlusion and Posture. *Cranio*, *18*(2), 127–133. http://doi.org/10.1080/08869634.2000.11746124

Miles, T., Flavel, S., & Nordstrom, M. a. (2004). Control of human mandibular posture during locomotion. *The Journal of Physiology*, *554*(Pt 1), 216–26. http://doi.org/10.1113/jphysiol.2003.050443

Ohlendorf, D., Seebach, K., Hoerzer, S., Nigg, S., & Kopp, S. (2014). The effects of a temporarily manipulated dental occlusion on the position of the spine: A comparison during standing and walking. *Spine Journal*, *14*(10), 2384–2391. http://doi.org/10.1016/j.spinee.2014.01.045

Okeson, J. (2008). *Management of Temporomandibular Disorders and Occlusion*. (J. Dojan, Ed.) (Sixth). Elsevier.

Perinetti, G. (2006). Dental occlusion and body posture: no detectable correlation. *Gait & Posture*, *24*(2), 165–8. http://doi.org/10.1016/j.gaitpost.2005.07.012

Perinetti, G., Türp, J. C., Primožič, J., Di Lenarda, R., & Contardo, L. (2011). Associations between the masticatory system and muscle activity of other body districts. A meta-analysis of surface electromyography studies. *Journal of Electromyography and Kinesiology : Official Journal of the International Society of Electrophysiological Kinesiology*, *21*(6), 877–84. http://doi.org/10.1016/j.jelekin.2011.05.014

Tardieu, C., Dumitrescu, M., Giraudeau, A., Blanc, J.-L., Cheynet, F., & Borel, L. (2009). Dental occlusion and postural control in adults. *Neuroscience Letters*, *450*(2), 221–4. http://doi.org/10.1016/j.neulet.2008.12.005

Tecco, S., Polimeni, A., Saccucci, M., & Festa, F. (2010). Postural loads during walking after an imbalance of occlusion created with unilateral cotton rolls. *BMC Research Notes*, *3*, 141. http://doi.org/10.1186/1756-0500-3-141

Tecco, S., Tetè, S., D'Attilio, S. M., & Festa, F. (2008). The analysis of walking in subjects with and without temporomandibular joint disorders. A cross-sectional analysis. *Minerva Stomatologica*, *57*(9), 399–411. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/18923375

Wang, K.; Ueno, T.; Taniguchi, H.; Ohyama, T. (1996). Influence on isometric muscle contraction during shoulder abduction by changing occlusal situation. *Bulletin of Tokyo Medical Dentist University*, *43*, 1–12.

Yin, C., Lee, Y., & Lee, Y. (2007). Neurological influences of the temporomandibular joint. *Journal of Bodywork and Movement Therapies*, *11*(4), 285–294. http://doi.org/10.1016/j.jbmt.2006.11.007

CHAPTER VIII - Effects of dental occlusion on body sway, upper body muscle activity and shooting performance in pistol shooters

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Status: Accepted for publication on the “Journal of Applied Bionics and Biomechanics”; Impact Factor: 1.769

ABSTRACT

Occlusal splints have been shown to reduce body sway in static position and increase muscle activity in the upper limbs. However, how dental occlusion status affects sports performance remains unclear. Here, we investigated whether occlusal splints that reposition the temporomandibular joint (TMJ) influenced body posture, muscle activity, and performance in 10-meter pistol shooters. Thirteen national level male shooters (age= 38.8 ± 10.9yrs) were recruited for this study. An occlusal splint (OS) and a placebo splint (PS) were fabricated for each of the subjects. Surface electromyography (EMG) was assessed in the upper limb that holds the pistol while the subjects were standing on a force platform. The subjects performed two series of 10 shots for each of the three experimental conditions (OS, PS, no splint – N) in randomized order. Results revealed similar centre of pressure (COP) parameters in all conditions, despite a reduction in the average oscillation area caused by the OS. There were also no significant differences in EMG activity between conditions in the five upper limb muscles monitored. Consistent with this, shooting performance was similar in all conditions, despite a reduction in shot dispersion in subjects using OS. Thus, changes in dental occlusion status induced by OS do not affect body posture, upper limb EMG muscle activity, or shot performance in healthy male pistol shooters.

Keywords: Occlusal splint, temporomandibular joint, dental occlusion, body sway, proprioception, surface EMG

INTRODUCTION

Human posture refers to the position of the body that maintains balance in static conditions, including the spatial relations between its anatomical segments. Posture involves constant adjustments to respond to continuous oscillations in the upright position (Kandel, 2013). These adjustments require muscle activation and are controlled by the central nervous system (CNS), which integrates a variety of sensory inputs (visual, vestibular, proprioceptive) from a complex system of sensors.

Previous studies have suggested that dental occlusion status influences posture control (Baldini, et al., 2004; Cuccia & Caradonna, 2009; Huggare et al., 1992). Dental occlusion is the relationship between the maxillary (upper) and mandibular (lower) teeth when they approach each other during chewing or at rest (Okeson, 2008). It was proposed that changes in dental occlusion affect body posture via output signals transmitted by the trigeminal nerve, which is associated to mandibular proprioception (Tardieu et al., 2009). The altered signal is then transmitted to the CNS, which in turn transfers it to the entire body system via spinal and autonomic nerves (Milani et al., 2000). Moreover, changes in occlusion status induced by cotton rolls or occlusion splints (OS) demonstrated that posture can be affected by manipulations of the temporomandibular joint (TMJ) (Baldini et al., 2013; Bracco et al., 2004; Gangloff et al., 2000; Julià-Sánchez et al., 2016; Milani et al., 2000; Sakaguchi et al., 2007) For instance, by using cotton rolls to change the mandibular position, Baldini showed that dental occlusion has a significant influence on body sway (Baldini et al., 2013). Another report reached similar conclusions by using a force platform to measure the effects of three different mandibular positions on body posture (Bracco et al., 2004). However, some studies failed to demonstrate a relationship between dental occlusion and body posture (Ferrario et al., 1996; Perinetti et al., 2006).

In recent years, research addressing the importance of body posture for athletic performance in pistol shooting (Ball et al.,2003; Era et al., 1996; Ihalainen et al., 2016; Mon et al., 2014; Mononen et al.2007; Sattlecker et al, 2014) has suggested that posture is one of the main factors affecting performance in this sport (Dadswell et al.,2013). For instance, it was shown that the movement of centre of pressure determines the movement of the gun-body system, with anterior-posterior body sway accounting for 8% of the variability in horizontal accuracy, and mediolateral body sway accounting for 40% of vertical accuracy variance (Dadswell et al., 2013). Moreover, pistol movement control and a steady upper limb posture were important for shot accuracy (Dadswell et al., 2013; Tang et al., 2008). However, other reports found contradictory results (Ball et al., 2003; Mononen et al., 2007). Thus, whether body posture affects performance in pistol shooting remains unknown. In addition, despite the potential ergogenic role of OS in improving balance control and COP for optimal sports performance, to date, only one study has explored this question in the context of pistol shooting (Gangloff et al., 2000). Notably, this report shows that OS improve balance control and performance in pistol shooting athletes.

Numerous analyses show that OS have ergogenic effects on body strength, and a positive association between OS and muscle activity in the upper body during isometric tasks has been well established (Alexander, 1999; Chakfa et al., 2002; Lee et al., 2014; Lee et al., 2013). Given that a stable arm is essential for shot accuracy, and that postural tremor during aiming significantly affects performance (Tang et al., 2008), it is plausible that OS may improve performance in shooting sports by increasing strength in the upper body muscles. In the present study, we examined the acute effects of OS on body sway, upper limb muscle activity, and shot accuracy in healthy 10m-pistol-shooting athletes.

METHODS

Subjects

Thirteen national level shooters were recruited (age= 38.8 ± 10.9yrs; weight= 79.7 ± 10.7 kg; height= 1.75 ± 0.1 m) for this study. A dental examination performed by an expert dental practitioner conducted according to the clinical guidelines published by the American Academy of Orofacial Pain (De Leeuw & Klasser, 2013) confirmed that none of the subjects had a temporomandibular joint (TMJ) disorder. A complete maxillary and mandibular arch impression were casted and then an occlusal splint (OS) and a placebo splint (PS) were fabricated (Fig.8) for each subject. The OS repositioned the TMJ in a centric relation (CR) position, which is considered the most stable position for the mandible. (Okeson, 2008) The CR is achieved when the TMJ condyles are in their most anterior-superior position in the articular fossae, which encourages them to seat stably in a congruent skeletal arrangement (Okeson, 2008). This research was approved by the ethics committee of the Faculdade de Motricidade Humana for use of human research.

Figure 8. Occlusal devices used. A – Occlusal splints; B – Placebo splint

Instrumentation

Centre of pressure (COP) position was used to evaluate body sway. COP parameters were quantified using a force platform (Biosignalplux, Lisbon, Portugal) with a dimension of 4500 x 4500 mm. The force platform was positioned directly below the subjects, in the area where they could stand in their favourite position (Fig. 9). Muscular activity of the upper limb that holds the pistol was monitored by using surface electromyography (EMG) with bipolar surface electrodes (Biosignalplux, Lisbon, Portugal). The muscles monitored were as follow: medium deltoid, upper trapezius, biceps brachii, flexor digitorum superficialis, and extensor digitorum. The preparation of the skin and electrode placement was described elsewhere (Criswell, 2011; Perotto, 2011). To assess the precise timing of the shot, an accelerometer was used (Biosignalplux, Lisbon, Portugal) and placed on the anterior portion of the gun barrel (Tang et al., 2008) (Fig. 9). The data from the force platform, EMG, and accelerometer were synchronized and recorded simultaneously at 1000hz with a specific software (OpenSignals, Biosignalplux, Lisbon, Portugal).

Shooting performance was indicated by scores, from 0 to 10.9, consistent with the scoring protocol used in international shooting competitions. For record scoring, an electronic target and control unit were used (SIUS AG, Effretikon, Switzerland).

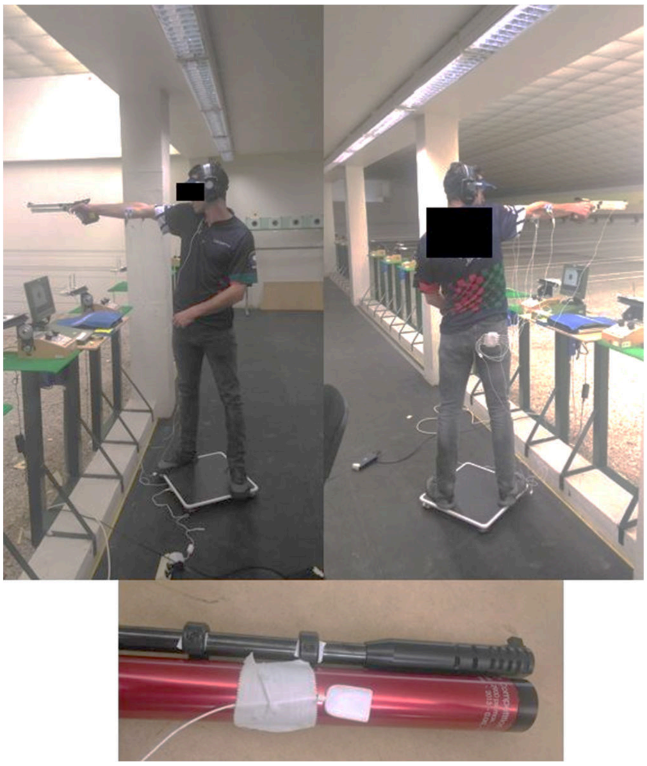
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Figure 9. Position of the shooter on the force platform and placement of the accelerometer on the gun barrel

Experimental protocol

Testing took place in an indoor national-class competition 10m-shooting range. Each subject was briefed individually on the testing procedure, and after the experimenter answered every question, the subjects were asked to sign the informed consent form. All subjects used their own personal pistols.

The experimental procedure began with a warm-up of 10 shots to allow the subjects to get accustomed to the sensors and to find a stable stance position on the force platform. Next, the subjects performed two series of 10 shots for each condition (OS, PS, and N) in a randomized order. A rest period of three minutes was allowed between series. The total number of shots per condition (20) is in agreement with procedures used in previous studies (Ball et al., 2003; Dadswell et al., 2013).

Signal processing and analysis

The EMG signal was amplified with a band pass filter (25-500Hz), common-mode rejection ratio (CMRR) of 110dB and a gain of 1000. The signal was then digitally filtered (20-500Hz), rectified, smoothed through low pass filter (12Hz, fourth-order Butterworth digital filter) and amplitude-normalized using the peak 100ms EMG signal on the normal condition of each subject. Normalized average EMG was determined for each muscle, series, and condition using time windows before the shot (500ms, 20ms), after the shot (100ms), and including the shot (300ms) (Fig. 10).

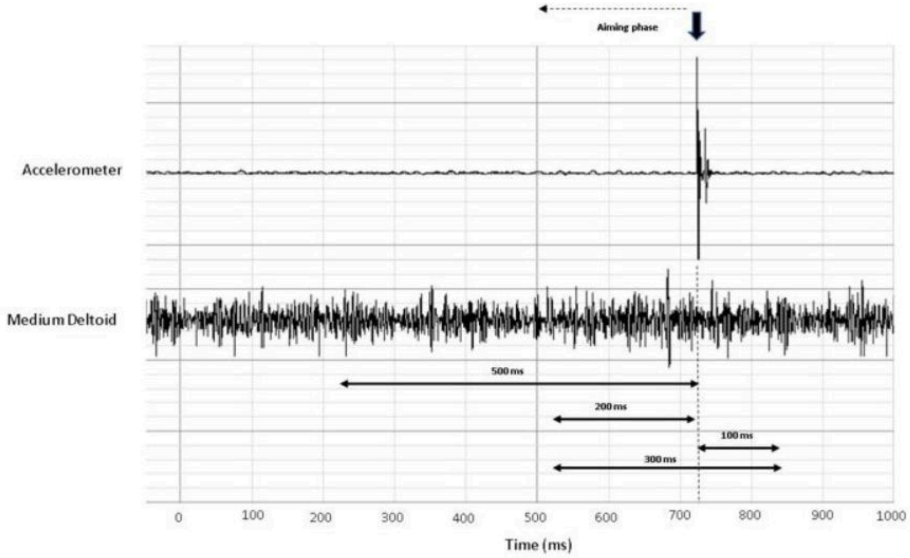

Figure 10. Representative data of accelerometer and EMG analysis during a shooting task. The onset of the shot was determined by the abrupt change in the accelerometer trace.

The signal from the force platform was passed through a digital amplifier with a gain of 400 and processed with a low pass filter (12Hz, second-order Butterworth digital filter). The same time windows were used to perform COP parameters analysis. All the processing and analyses of the signals were performed with Matlab software (version 2013a, Mathworks Inc., Natick Massachusetts, USA) by using a customized routine.

Statistical analysis

Data from all the COP parameters, EMG, and shooting scores were tested for normality using the Shapiro-Wilk test. When the data showed a normal distribution, a repeated measures ANOVA test was applied. For data with a non-normal distribution, a Friedman test was used. The significance level was set at 5%. All statistical analyses were processed in IBM SPSS Statistics 22.0 (IBM Corporation, New York, USA).

RESULTS

The results for the COP parameters and EMG muscle activity measurements are presented in Table 9. No significant differences were found in body sway for any of the conditions, as assessed with COP parameters. Moreover, the EMG measurements revealed no differences in muscular activity between conditions in every muscle analysed. The mean shooting scores for each condition (OS = 9.46 ± 1.06; N= 9.51 ± 0.91 and PS = 9.47 ± 0.99) show that neither the OS nor the PS affected shooting performance (p= 0.212). A coefficient of variation was calculated for the shooting scores (OS = 12.24 ± 1.30; N= 15.37 ± 1.77 and PS = 12.11 ± 1.21) to determine whether there were any changes in shot dispersion. However, no significant differences were detectable between conditions (p=0.069).

DISCUSSION

Over recent decades, a number of studies reported that changes in vertical dimension of occlusion affects strength and body posture (Chakfa et al., 2002; Lee et al., 2013; Motoyoshi, et al., 2003; Pae et al., 2013), and it has been suggested that OS may improve static posture (Cuccia & Caradonna, 2009; Julià-Sánchez et al., 2015; Milani et al., 2000; Tardieu et al., 2009), possibly by reducing mediolateral sway (Bracco et al., 2004).

Consistent with this, a functional correlation between the trigeminal nerve and the upper limb systems was recently proposed (Ferrario et al., 2003; Sforza et al., 2006). Moreover, increased strength (Alexander, 1999; Chakfa et al., 2002; Lee et al., 2013) and higher EMG muscle activation in the upper limbs have been detected in subjects using OS during isometric tasks (Lee et al., 2014). However, other similar studies report conflicting results (Greenberg et al., 1981; Schubert et al. , 1984; Williams et al., 1983; Yates et al.,1984). To address this question, we investigated how OS influence body sway, upper limb muscle activation, and shot accuracy in male pistol shooting athletes. Our results clearly show that changes in occlusion status induced by customised OS do not affect any of these variables. Specifically, no significant changes in a range of body sway parameters were detected in subjects using the OS. Shooting performance and muscle activity measured by surface EMG in five upper limb muscles also remained unchanged in the OS condition.

Arm strength, and particularly grip strength, may be essential for pistol shooting because they affect arm stability and/or tremor (Ebben, 2006; Tang et al.,2008). Recently, a growing number of studies has assessed the effects of OS on strength and muscle activity in the upper limbs (Dang et al.,2012; Lee et al., 2014, 2013; Wang et al., 1996) and other body regions (Ceneviz et al., 2006; Ferrario et al., 2001; Perinetti et al., 2011). Our results contradict two previous reports showing that isometric grip strength and upper body muscle activity are increased in subjects using OS (Alexander, 1999; Lee et al., 2014). However, these studies assessed maximal muscle contractions tests, whereas in pistol shooting the upper arm muscles must maintain a steady position for a period of time, which requires a sustained (and not a maximal) isometric muscle contraction. Another study previously investigated whether OS that repositions the TMJ to CR affect body sway in pistol and rifle shooters (Gangloff et al., 2000).

In this study, subjects using OS show an improvement in shooting performance and balance control (Gangloff et al., 2000), which contradicts our data. Methodological differences may explain this discrepancy in outcomes. First, in our study, all subjects were pistol shooters, whereas Gangloff (Gangloff et al., 2000) included both pistol and rifle shooters in their sample. As rifle shooters have smaller body sway areas than pistol shooters (Mon et al., 2014), this may have skewed the results. Second, the control condition (no-splint) in our study was a relaxed position (the subjects' “natural” position), but in Gangloff (Gangloff et al., 2000) the subjects were asked to clench their teeth in the control condition.

Table 9. Results of COP parameters and EMG on the three experimental conditions. AP – anterior-posterior; ML – medium lateral; OS – Occlusal splint; N – Normal condition; PS – Placebo splint

Variables (unit)	500 ms				200 ms				100 ms				300 ms			
COP parameters	OS	N	PS	*P value*	OS	N	PS	*P value*	*OS*	N	PS	*P value*	*OS*	N	PS	*P value*
Total distance (cm)	55.29 ± 24.38	53.49 ± 21.21	55.61 ± 22.22	0.583	35.46 ± 15.90	34.21 ± 13.50	35.59 ± 14.17	0.682	26.53 ± 10.73	26.02 ± 9.92	27.50 ± 10.34	0.583	44.53 ± 18.80	43.17 ± 16.54	45.27 ± 17.25	0.633
AP distance (cm)	33.16 ± 15.83	32.74 ± 15.06	31.88 ± 13.15	0.695	21.25 ± 10.68	21.04 ± 9.90	20.41 ± 8.76	0.754	25.82 ± 7.41	15.85 ± 7.11	16.07 ± 6.38	0.968	26.67 ± 12.80	26.49 ± 12.07	26.33 ± 10.67	0.976
ML distance (cm)	40.64 ± 23.39	38.29 ± 21.43	41.15 ± 25.05	0.394	26.00 ± 14.91	24.31 ± 13.49	26.18 ± 15.88	0.464	19.61 ± 10.16	18.64 v 10.03	20.11 ± 11.72	0.531	32.80 ± 17.75	30.85 ± 16.66	33.18 ± 18.59	0.492
AP amplitude oscillation (cm)	0.72 ± 0.24	0.65 ± 0.20	0.71 ± 0.17	0.538	0.45 ± 0.20	0.39 ± 0.15	0.43 ± 0.12	0.687	0.43 ± 0.37	0.53 ± 0.36	0.57 ± 0.49	0.068	0.71 ± 0.40	0.75 ± 0.37	0.83 ± 0.51	0.199
ML amplitude oscillation (cm)	0.53 ± 0.41	0.48 ± 0.21	0.45 ± 0.21	0.710	0.35 ± 0.33	0.31 ± 0.18	0.29 ± 0.16	0.926	0.49 ± 0.46	0.62 ± 0.55	0.59± 0.55	0.368	0.69 ± 0.59	0.79 ± 0.59	0.72 ±0.61	0.584
Oscillation area (cm^2)	0.25 ± 0.13	0.48 ± 0.95	0.42 ± 0.46	0.472	0.10 ± 0.76	0.37 ± 0.01	0.34 ± 0.55	0.338	0.24 ± 0.39	0.71 ± 0.95	0.34 ± 0.66	0.472	0.22 ± 0.21	0.38 ± 0.41	0.30 ± 0.65	0.435
Total oscillation velocity (cm/s)	0.056 ± 0.024	0.053 ± 0.021	0.056 ± 0.022	0.583	0.035 ± 0.01	0.034 ± 0.01	0.036 ± 0.01	0.682	0.027 ± 0.01	0.026 ±0.01	0.028 ± 0.01	0.583	0.044 ± 0.02	0.043 ± 0.02	0.012 ± 0.02	0.589
AP oscillation velocity (cm/s)	0.033 ± 0.02	0.033 ± 0.02	0.032 ± 0.01	0.740	0.021 ± 0.01	0.021 ± 0.001	0.020 ± 0.001	0.754	0.016 ± 0.01	0.015 ± 0.01	0.016 ± 0.01	0.968	0.027 ± 0.01	0.026 ± 0.01	0.026 ± 0.01	0.959
ML oscillation velocity	0.041 ± 0.024	0.04 ± 0.02	0.04 ± 0.02	0.413	0.026 ± 0.01	0.024 ±0.01	0.026 ± 0.01	0.464	0.019 ± 0.01	0.019 ± 0.01	0.020 ± 0.01	0.531	0.033 ± 0.02	0.031 ± 0.02	0.033 ± 0.02	0.470
EMG (%)																
Medium deltoid	53.03 ± 10.16	53.92 ± 7.45	51.03 ± 9.75	0.376	50.62 ± 12.19	50.50 ± 10.84	50.93 ± 10.66	0.412	49.66 ± 12.74	48.96 ± 10.81	50.05 ± 11.13	0.663	50.31 ± 11.92	49.50 ± 10.18	50.68 ± 10.19	0.630
Upper trapezius	38.87 ± 16.38	41.78 ± 14.48	39.47 ± 15.57	0.058	38.44 ± 16.35	41.71 ± 14.87	39.09 ± 15.60	0.060	38.61 ± 16.37	41.59 ± 15.19	36.60 ± 16.03	0.185	38.11 ± 15.98	41.16 ± 14.49	38.62 ± 15.27	0.054
Biceps brachii	31.58 ± 12.37	34.26 ± 11.33	32.87 ± 12.22	0.088	31.66 ± 12.82	34.27 ± 11.74	33.36 ± 12.88	0.197	32.56 ± 12.75	35.30 ± 11.86	34.11 ± 12.80	0.188	37.91 ± 12.63	34.38 ± 11.61	33.47 ± 12.72	0.129
Flexor digitorum	30.16 ± 22.72	28.70 ± 22.65	31.31 ± 22.61	0.666	30.29 ± 22.72	28.59 ± 22.64	31.37 ± 22.58	0.158	31.85 ± 21.55	30.74 ± 21.75	33.35 ± 21.19	0.071	30.41 ± 22.68	28.87 ± 22.59	31.49 ± 22.52	0.657
Extensor digitorum	28.28± 12.77	29.04 ± 12.86	28.34 ± 12.59	0.980	28.52 ± 12.28	29.23 ± 13.20	28.46 ± 12.93	0.657	29.96 ± 14.15	28.27 ± 12.74	28.21 ± 12.86	0.08	28.67 ± 13.14	29.12 ± 12.83	27.60 ± 12.59	0.911

It is important to note that the large between-individuals' variability in our results (Table 9) may compromise the detection of an effect. Indeed, except for the 500ms time window, subjects using OS showed a tendency to have reduced oscillation areas when compared to the control and PS conditions, but with no statistical differences, similar to a previous study (Sforza et al., 2006). This methodological limitation could be overcome by using a larger sample.

In pistol shooting, visual cues necessary for maintaining postural control are somewhat compromised because the visual system is focused on aiming (Herpin et al., 2010). Thus, during shooting tasks posture control requires additional inputs from other sensory systems, such as proprioception and vestibular signals. Moreover, since shooters are in a bipedal position, the CNS has various degrees of freedom throughout the body to achieve the postural stability and accurate upper arm positioning critical for performance. It is, therefore, possible that shooting athletes develop specific motor-control strategies, mostly based on vestibular and proprioception cues, that are less sensitive to new physiological inputs, such as those triggered by changes in dental occlusion induced by OS. Consistent with this, a 4-week longitudinal study revealed that the effects of OS on postural activity were only noticeable a few days after the subjects started wearing the splints (Milani et al.,2000), and this could explain why we could not detect any significant changes in body sway parameters in our study. Shooting athletes may have a specific motor control strategy for maintaining balance that requires an adaptation period to incorporate physiological changes induced by OS (before producing any noticeable changes in posture).

One other factor that could have played an important role in the outcomes of this study is jaw clenching. It has been demonstrated that clenching has an effect on muscle activity (Ebben et al., 2010), grip strength (Ebben et al.,2008) and posture (Baldini et al., 2013; Sakaguchi et al., 2007). Moreover, involuntary clenching of the jaw has been showed to occur in physical activities where strength is involved (Yokoyama, 1998). Supporting this notion is a study that assessed posture in subjects while clenching their jaw in CR position (Sakaguchi et al., 2007). Results in this study revealed that COP trajectory length was shorter in CR position, meaning that body posture was more stable. In our study, we did not control the clenching of the jaw, but we recognize that it may have occurred. This is a limitation of our study. Also, this variable is not controlled in many of the studies addressing the relationship between dental occlusion and body posture (Baldini et al., 2013; Bracco et al., 2004; Cuccia & Caradonna, 2009;Ferrario et al., 1996; Perinetti, 2006; Motoyoshi et al., 2003). This could explain why the literature is inconclusive, since it's challenging to distinguish the effects of dental occlusion from clenching.

CONCLUSIONS

This study suggests that body sway, upper limb muscle activity, and shot performance are not affected by dental occlusion status. However, the high between-subject variability in our results could have masked changes caused by OS. Future studies would benefit from a longitudinal design focusing on the medium/long-term effects of using OS on balance sway, muscle activity and shot performance. Likewise, further research should also focus on jaw clenching and dental occlusion and how the balance between these variables could affects body posture. This research would significantly contribute to our understanding of how TMJ positions influence body postural control and performance outcomes in sports.

Acknowledgments

The authors would like to express their gratitude to the Portuguese Shooting Federation for providing the access to the shooting range and all the necessary logistics, and to the athletes for their contribution and participation in this study.

REFERENCES

Alexander, C. (1999). *A Study on the Effectiveness of a Self-Fit Mandibular Repositioning Appliance on Increasing Human Strength and Endurance Capabilities*. University of Tennessee.

Baldini, A., Nota, A., Tripodi, D., Longoni, S., & Cozza, P. (2013). Evaluation of the correlation between dental occlusion and posture using a force platform. *Clinics*, *68*(1), 45–49. http://doi.org/10.6061/clinics/2013(01)OA07

Ball, K., Best, R., & Wrigley, T. (2003). Inter- and intra-individual analysis in elite sport: Pistol shooting. *Journal of Applied Biomechanics*, *19*(1), 28–38.

Ball, K., Best, R., & Wrigley, T. (2003). Body sway, aim point fluctuation and performance in rifle shooters: inter- and intra-individual analysis. *J. Sports Sci.*, *21*(7), 559–566. http://doi.org/10.1080/0264041031000101881

Bracco, P., Deregibus, A., & Piscetta, R. (2004). Effects of different jaw relations on postural stability in human subjects. *Neuroscience Letters*, *356*, 228–230. http://doi.org/10.1016/j.neulet.2003.11.055

Ceneviz, C., Mehta, N., Forgione, A., Sands, M. J., Abdallah, E., Lobo, S., & Mavroudi, S. (2006). The immediate effect of changing mandibular position on the EMG activity of the masseter, temporalis, sternocleidomastoid, and trapezius muscles. *Cranio*, *24*, 237–244. http://doi.org/10.1179/crn.2006.038

Chakfa, A., Mehta, N., Forgione, A., Al-Badawi, E., Lobo, S., & Zawawi, K. (2002). The effect of stepwise increases in vertical dimension of occlusion on isometric strength of cervical flexors and deltoid muscles in nonsymptomatic females. *Cranio : The Journal of Craniomandibular Practice*, *20*(4), 264–73. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/12403184

Criswell, E. (2011). *Cram's introduction to surface electromyography*. (E. Criswell, Ed.) (2nd ed.). Jones and Bartlett.

Cuccia, A., & Caradonna, C. (2009). The relationship between the stomatognathic system and body posture. *Clinics*, *64*(1), 61–66. http://doi.org/10.1590/S1807-59322009000100011

Dadswell, C., Payton, C., Holmes, P., & Burden, A. (2013). Biomechanical analysis of the change in pistol shooting format in modern pentathlon. *Journal of Sports Sciences*, *3112*(March), 1294–1301. http://doi.org/10.1080/02640414.2013.777762

Dang, T., Minh, H., Thanh, H., & Van, T. (2012). Analyzing surface EMG signals to determine relationship between jaw imbalance and arm strength loss. *Biomedical Engineering Online*, *11*(1), 55. http://doi.org/10.1186/1475-925X-11-55

De Leeuw, L, & Klasser, G. (2013). *Orofacial Pain. Guidelines for Assessment, Diagnosis, and Management*. 5h edition, Chicago, IL: Quintessence Publishing Co, Inc.

Ebben, W. (2006). A brief review of concurrent activation potentiation: theoretical and practical constructs. *Journal of Strength and Conditioning Research / National Strength & Conditioning Association*, *20*(4), 985–91. http://doi.org/10.1519/R-19375.1

Ebben, W., Leigh, D., & Geiser, C. (2008). The effect of remote voluntary contractions on knee extensor torque. *Medicine and Science in Sports and Exercise*, *40*(10), 1805–1809. http://doi.org/10.1249/MSS.0b013e31817dc4ad

Ebben, W., Petushek, E., Fauth, M., & Garceau, L. (2010). EMG analysis of concurrent activation potentiation. *Medicine and Science in Sports and Exercise*, *42*(3), 556–562. http://doi.org/10.1249/MSS.0b013e3181b66499

Era, P., Konttinen, N., Mehto, P., Saarela, P., & Lyytinen, H. (1996). Postural stability and skilled performance-a study On top-Level and naive rifle shooters. *Journal of Biomechanics*, *29*(3), 301–306. http://doi.org/10.1016/0021-9290(95)00066-6

Ferrario, V., Chiarella, B., Taroni, A., & Schmitz, H. (1996). Occlusion and center of foot pressure variation: Is there a relationship ? *The Journal of Prosthetic Dentitry*, *76*(3), 302–308.

Ferrario, V., Sforza, C., Dellavia, C., & Tartaglia, G. (2003). Evidence of an influence of asymmetrical occlusal interferences on the activity of the sternocleidomastoid muscle. *Journal of Oral Rehabilitation*, *30*(1), 34–40. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/12485381

Ferrario, V., Sforza, C., Serrao, G., Fragnito, N., & Grassi, G. (2001). The influence of different jaw positions on the endurance and electromyographic pattern of the biceps brachii muscle in young adults with different occlusal characteristics. *Journal of Oral Rehabilitation*, *28*(8), 732–9. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/11556954

Gangloff, P., Louis, J., & Perrin, P. (2000). Dental occlusion modifies gaze and posture stabilization in human subjects. *Neuroscience Letters*, *293*, 203–206.

Greenberg, M., Cohen, S., Springer, P., Kotwick, J., & Vegso, J. (1981). Mandibular position and upper body strength: a controlled clinical trial. *The Journal of the American Dental Association*, *103*, 576–579.

Herpin, G., Gauchard, G., Lion, A., Collet, P., Keller, D., & Perrin, P. (2010). Sensorimotor specificities in balance control of expert fencers and pistol shooters. *Journal of Electromyography and Kinesiology*, *20*(1), 162–169. http://doi.org/10.1016/j.jelekin.2009.01.003

Huggare, J., Raustia, A., & Makofsky, H. (1992). Head Posture and Cervicovertebral and Craniofacial Morphology in Patients with Craniomandibular Dysfunction. *CRANIO®*, *10*(3), 173–179. http://doi.org/10.1080/08869634.1992.11677908

Ihalainen, S., Kuitunen, S., Mononen, K., & Linnamo, V. (2016). Determinants of elite-level air rifle shooting performance. *Scandinavian Journal of Medicine and Science in Sports*, *26*(3), 266–274. http://doi.org/10.1111/sms.12440

Julià-Sánchez, S., Álvarez-Herms, J., Gatterer, H., Burtscher, M., Pagès, T., & Viscor, G. (2015). Dental Occlusion Influences the Standing Balance on an Unstable Platform. *Motor Control*, *19*(4), 341–354. http://doi.org/10.1123/mc.2014-0018

Julià-Sánchez, S., Álvarez-Herms, J., Gatterer, H., Burtscher, M., Pagès, T., & Viscor, G. (2016). The influence of dental occlusion on the body balance in unstable platform increases after high intensity exercise. *Neuroscience Letters*, *617*, 116–121. http://doi.org/10.1016/j.neulet.2016.02.003

Kandel, E. (2013). *Principles of Neural Science*. (A. Kandel, Eric; Schwartz, James; Jessell, Thomas; Sielgelbaum, Steven; Hudspeth, Ed.) (5th ed.). McGraw-Hill.

Lee, S., Hong, M., Park, M., & Choi, S. (2013). Effect of the Mandibular Orthopedic Repositioning Appliance on Trunk and Upper Limb Muscle Activation during Maximum Isometric Contraction. *Journal of Physical Therapy Science*, *25*(11), 1387–9. http://doi.org/10.1589/jpts.25.1387

Lee, S., Park, Y., Park, H., Bae, H., Yu, M., Choi, H., & Hwang, N. (2014). Effect of the Mandibular Orthopedic Repositioning Appliance (MORA) on Forearm Muscle Activation and Grasping Power during Pinch and Hook Grip. *Journal of Physical Therapy Science*, *26*(2), 195–7. http://doi.org/10.1589/jpts.26.195

Milani, R., De Perière, D., Lapeyre, L., & Pourreyron, L. (2000). Relationship between dental occlusion and posture. *Cranio : The Journal of Craniomandibular Practice*, *18*(2), 127–34. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/11202823

Mon, D., Zakynthinaki, M., Cordente, C., Barriopedro, M., & Sampedro, J. (2014). Body sway and performance at competition in male pistol and rifle Olympic shooters. *Biomedical Human Kinetics*, *6*, 56–62. http://doi.org/10.2478/bhk-2014-0010

Mononen, K., Konttinen, N., Viitasalo, J., & Era, P. (2007). Relationships between postural balance, rifle stability and shooting accuracy among novice rifle shooters. *Scandinavian Journal of Medicine and Science in Sports*, *17*(2), 180–185. http://doi.org/10.1111/j.1600-0838.2006.00549.x

Motoyoshi, M., Shimazaki, T., Hosoi, K., Wada, M., & Namura, S. (2003). Stresses on the cervical column associated with vertical occlusal alteration. *European Journal of Orthodontics*, *25*(2), 135–8. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/12737211

Okeson, J. (2008). *Management of Temporomandibular Disorders and Occlusion*. (J. Dojan, Ed.) (Sixth). Elsevier.

Pae, A., Yoo, R., Noh, K., Paek, J., & Kwon, K. (2013). The effects of mouthguards on the athletic ability of professional golfers. *Dental Traumatology : Official Publication of International Association for Dental Traumatology*, *29*(1), 47–51. http://doi.org/10.1111/j.1600-9657.2012.01123.x

Perinetti, G. (2006). Dental occlusion and body posture: no detectable correlation. *Gait & Posture*, *24*(2), 165–8. http://doi.org/10.1016/j.gaitpost.2005.07.012

Perinetti, G., Türp, J. C., Primožič, J., Di Lenarda, R., & Contardo, L. (2011). Associations between the masticatory system and muscle activity of other body districts. A meta-analysis of surface electromyography studies. *Journal of Electromyography and Kinesiology : Official Journal of the International Society of Electrophysiological Kinesiology*, *21*(6), 877–84. http://doi.org/10.1016/j.jelekin.2011.05.014

Perotto, A. (2011). *Anatomical Guide for the Electromyographer - The limbs and trund*. *Journal of anatomy* (Fifth, Vol. 186). Springfield, Illinois, USA: Charles C. Thomas. http://doi.org/10.1097/00002060-199505000-00020

Sakaguchi, K., Mehta, N., Abdallah, E., Forgione, A., Hirayama, H., Kawasaki, T., & Yokoyama, A.

(2007). Examination of the relationship between mandibular position and body posture. *Cranio - Journal of Craniomandibular Practice*, *25*(4), 237–249. http://doi.org/10.1179/crn.2007.037

Sattlecker, G., Buchecker, M., Müller, E., & Lindinger, S. J. (2014). Postural Balance and Rifle Stability During Standing Shooting on an Indoor Gun Range Without Physical Stress in Different Groups of Biathletes. *International Journal of Sports Science and Coaching*, *9*(1), 171–184. http://doi.org/10.1260/1747-9541.9.1.171

Schubert, M., Guttu, R., Hunter, L., Hall, R., & Thomas, R. (1984). Changes in shoulder and leg strength in athletes wearing mandibular orthopedic repositioning appliances. *The Journal of the American Dental Association*, *108*, 334–337.

Sforza, C., Tartaglia, G., Solimene, U., Morgun, V., Kaspranskiy, R., & Ferrario, V. (2006). Occlusion, Sternocleidomastoid muscle activity and Body Sway : A Pilot Study in Male Astronauts. *The Journal of Craniomandibular Practice*, *24*(1), 43–49.

Tang, W., Zhang, W., Huang, C., Young, M., & Hwang, I. (2008). Postural tremor and control of the upper limb in air pistol shooters. *Journal of Sports Sciences*, *26*(14), 1579–1587. http://doi.org/10.1080/02640410802287063

Tardieu, C., Dumitrescu, M., Giraudeau, A., Blanc, J., Cheynet, F., & Borel, L. (2009). Dental occlusion and postural control in adults. *Neuroscience Letters*, *450*(2), 221–4. http://doi.org/10.1016/j.neulet.2008.12.005

Wang, K., Ueno, T., Taniguchi, H., & Ohyama, T. (1996). Influence on isometric muscle contraction during shoulder abduction by changing occlusal situation. *Bulletin of Tokyo Medical Dentist University*, *43*, 1–12.

Williams, M., Chaconas, S.., & Bader, P. (1983). The effect of mandibular position position on appendage muscle strength. *The Journal of Prosthetic Dentitry*, *49*(4), 560–567.

Yates, J., Koen, T., Semenick, D., & Kuftinec, M. (1984). Effect of a mandibular orthopedic repositioning appliance on muscular strength. *The Journal of the American Dental Association*, *108*, 331–333.

Yokoyama, Y. (1998). Involuntary Teeth Clenching during Physical Exercise. *Journal of the Japan Prosthodontic Society*, *42*, 90–101.

CHAPTER IX – General Discussion

The initial idea that prompted the development of this thesis was the lack of knowledge identified in the literature, regarding the acute neuromuscular effects of using oral appliances. There is empirical knowledge, based on dentists clinical practice, that the use of oral appliances influences the human body, particularly posture and muscle strength. However, such knowledge lacked proper evidence. Therefore, this thesis aimed to determine the acute effects of oral appliances, focusing on the areas identified by empirical knowledge, as well as by research performed beforehand. Accordingly, this thesis had the objective to analyse how oral appliances - in this case OS - could affect strength and posture in healthy subjects. The choice for OS was grounded on the premises that it could shift the TMJ in a known and reproducible position, as well as cause less discomfort for the subject's, due to its small thickness, unlike other oral appliances. To accomplish these objectives, five studies were carried out. Their main findings will next be summarized, while providing a discussion that joins these studies together. The limitations of this thesis will also be discussed, as well as recommendations for future research and practical implications.

1. Summary of main findings

The main results of this thesis demonstrated that the use of OS has a positive impact regarding strength in healthy untrained subjects. Contrary findings occurred in the studies that assessed body posture, since no changes were found in the analysed variables for both studies. These results aid to accomplish the objectives defined in the Introduction. Moreover, they provide support for confirmation or dismissal of the hypothesis formulated in this thesis, as highlighted in Table 10.

The opening area of research on this thesis was related to acute strength changes induced by OS and for this purpose there were three studies focused on the subject. The first study of this thesis was a systematic review, which examined nine studies after applied the search strategy and quality assessment. Although few studies were included, the results from this systematic review support the notion that OS provides a positive impact on untrained healthy subjects for isometric upper body strength tasks. Other forms of strength evaluation (isokinetic, muscle power) focused on both upper and lower body quadrants and were unanimous in the lack of changes when using OS. Curiously, the studies that reported no variations in strength while using OS were performed with trained healthy subjects, while the studies that reported changes were completed with untrained healthy subjects.

Table 10. Highlights of studies results

Study	Objectives	Findings	Hypothesis
1 (chapter IV)	1. Evaluate the body of evidence available on the efficiency of OS in producing changes in strength in healthy participants; 2. Determine the most used protocols and assessed parameters	There is a trend towards a positive interaction between OS and increased muscle strength in upper limb isometric strength tests, for untrained healthy subjects, with moderate to large effect size. Training level and the type of muscle contraction appears to be important factors for the relationship between OS and strength.	
2 (chapter V)	1. Determine the acute effects of using OS on strength in upper limbs, using an isokinetic task; 2. Access how the use of OS affects EMG signals of the main muscles involved in the tasks;	In healthy untrained subjects, OS increased significantly peak torque and peak muscular activation (measured with EMG) for the two upper body movements. No placebo effect was present.	Both hypotheses for this study were confirmed: a) The use of OS affected arm strength in a significant manner; b) EMG signals in upper body muscles was significantly altered with OS.
3 (chapter VI)	1) To determine if the use of a mandible controlled position mouthguard would affect acute measurements of strength and power in trained athletes; 2) To ascertain and compare if OS are associated with positive changes when compared to other thicker mouthpieces.	In healthy trained subjects, OS did not change strength and power in a power movement. When using the mouthguard that promoted the same changes in TMJ as the OS, there was a significant increase in peak acceleration and peak force. No placebo effect was present.	Only the second hypothesis of this study was confirmed: b) The use of custom made mouthguards has a positive effect on strength. The first hypothesis (a) was rejected, since the use of OS did not affect strength in a power movement.
4 (chapter VII)	1. To determine the effect of using OS on dynamic posture;	No differences were found for horizontal and vertical body sway during both gait and running. Results presented a high inter-subject variability.	Both hypotheses for this study were rejected, since the use of OS did not reduce body oscillation in gait and running.
5 (chapter VIII)	1) To establish if OS would affect static posture, upper limb activation and performance during pistol shooting in trained athletes	No differences were found for body sway, upper limb EMG activity and shot performance between conditions. Results revealed a reduction of oscillation area when using OS. It is possible that the high degree of variability could have masked significant differences. The coefficient of variation of shot performance also displayed a reduction of shot dispersion when using OS, but with no statistical changes.	All the three hypotheses of this study were rejected, since body sway, muscle activity and scoring accuracy were not altered by using OS.

Hence, it appears that training level is an important factor that influences the association between OS and muscle strength. Also interesting is the fact that the positive effect of OS on strength was only observed on isometric muscle contractions. Despite the results of this systematic review appear to demonstrate a positive trend in the use of OS for improving isometric strength and no influence when strength was developed on dynamic contractions, this must be considered preliminary data. This is due to the scarce number of studies on the topic and also to some methodological limitations we identified. Only more research testing the effectiveness of OS on different forms of strength manifestation can properly help answer the question regarding the acute effects of OS on strength.

In the second study, we investigate the immediate effects of OS on dynamic isokinetic strength and muscular activation. This study took into consideration a gap on the research, identified in the systematic review, regarding the lack of studies that focus on the association between OS and isokinetic strength, in untrained healthy adults. The testing procedures focus on two often used movements in everyday life as well as in sports – shoulder abduction/adduction and external/internal rotation. Results from this study showed an increase in strength, measured with the peak torque, but also an increase in muscular activation, assessed with surface EMG of muscles that have an agonist or stabilizer role in these movements. No placebo effect was shown.

The possible explanations for the findings of the second study were discussed in chapter V, but we would highlight the importance of using an equilibrated splint to start a chain of events, that worked together in order to generate an ergogenic effect of shoulder muscles strength. This chain of events is probably caused by a mixture of factors. The OS tested in this study repositioned the TMJ in CR position, known for increase occlusal stability. A higher stability of the TMJ causes an increase in masseter muscle activity during strength testing, provoked by an involuntary mandible contraction (Yokoyama, 1998). This involuntary action may increase acute H-reflex activity and improve strength in distal body parts (Buscà et al., 2016; Ebben, 2006; Miyahara et al., 1996). Hence, we hypothesize that this ergogenic effect occurs due to changes in spinal excitability in the subjects who were untrained, which have smaller H-reflex amplitudes than trained subjects (Aagaard et al., 2002; Nielsen et al., 1993), and therefore can benefit from increases reflex excitability. As we pointed out in chapter IV, previous researches suggests that the use of OS was ineffective for improving muscle performance during isokinetic muscle contractions. However, we must remember that the isokinetic studies mentioned in this systematic review presented results solely on athletes or physically active subjects, while the study we present in chapter V was performed with untrained subjects. This topic should be confirmed in future research using electrical stimulation and H-reflex testing to investigate the effects of using OS on spinal excitability and strength in trained and untrained subjects. Additionally, the trapezius and sternocleidomastoid muscles, who play an important part on fixating the scapula and clavicle, are also connected to interact and suffer influence from variations in VDO (Ferrario et al., 2003; Miralles et al., 2002). These muscles act as stabilizers and they are necessary to increase muscle action, so the increase in EMG activity registered in the study could derive from the changes caused by the OS.

Regarding the third study, it focused on the assessment of how OS could affect muscle power, which was identified in the systematic review as a topic with a paucity of studies. The only study we included in our systematic review that evaluated the influence of OS in power development, was performed with a stretch-shortening cycle action of the lower limbs (counter-movement jump) (Golem, 2012). The third study was an experimental within-subjects design with randomized trials, focusing on a ballistic bench press throw, which is a power movement. The focus remained on testing upper body strength in trained athletes. Particularly, in this study rugby players were recruited as participants, since they are athletes accustomed to strength training. A customized mouthguard was also tested in this study since rugby players are mandated to wear one for teeth and injury prevention. The customized mouthguard provided the same manipulation of the TMJ as OS did, but it was thicker and therefore created a greater VDO than OS. Results of this study revealed that when using the customized mouthguard there was a significant increase in peak acceleration and peak force. No placebo effect was detected. The discussion of this study in chapter VI provides some clues on how the customized mouthguards made the ergogenic effect on a ballistic and power movement possible. We theorize that the ergogenic effect of the customized mouthguard was related to a combination of repositioning the TMJ in CR position, increasing VDO and also the presence of involuntary clenching. Other studies found similar results (Dunn-Lewis et al., 2012), but further research is warranted to confirm these ergogenic effects. Another important finding from this third study was the fact that OS did not improve strength in the trained athletes that were included in the study. This appears to confirm that the training level of the subject is a factor that influences the ergogenic aid of using OS, as mentioned in the first study. Accordingly, the results of this third study also help to support the premise put forward in study two, that ergogenic effects occur due to changes in H-reflex amplitude, produced by a natural clenching upon performance tests. Thus, this can only happen in untrained subjects, which have smaller H-reflex amplitudes than athletes and therefore can have this reflex activity enhanced. Nevertheless, this should be confirmed in future research.

The results of the third study also gave us some clues on how oral appliances can be used to create an ergogenic effect on trained athletes. The use of customized mouthguards, that placed the TMJ in a similar position than OS, but were thicker and therefore increased VDO in a significant manner, as demonstrated in the study, appears to provide some answers.

Some research has demonstrated that a rise in VDO correlates with an increase in strength (Arent, McKenna, & Golem, 2010; Dunn-Lewis et al., 2012), suggesting a functional relationship between VDO and body strength, based on neural conduction (Bracco et al., 2004). Considering what we have previously discussed on the importance of H-reflex as a relevant factor for the ergogenic effect of oral appliances, it can be postulated that for athletes that have increased H-reflex amplitude (Aagaard et al., 2002; Nielsen et al., 1993), it is necessary to use oral appliances that increase VDO (like mouthguards). This increase in VDO will increase their functional length (Boero, 1989) in order to perform more efficiently. So, when clenching naturally during strength exercises, the increase in length derived by the VDO can create a more intensive muscle contraction of the masseters and surpass the elevated H-reflex amplitude, elevating even more the H-reflex activity and accordingly create an ergogenic effect of strength enhancement. This hypothesis is based on the studies conducted for this thesis and more research on the issue is necessary, to provide additional information for confirmation or dismissal of this theory.

The other area of research on this thesis was the possible acute influence of using OS in balance. Recent studies have put forward some evidence that body posture can be altered through changes in TMJ (Baldini et al., 2013; Michelotti et al., 2011). Research has demonstrated that this relationship is due to the influence that changes in TMJ cause in afferent information, mediated by the trigeminal nerve (Julià-Sánchez et al., 2015). The trigeminal nerve possesses a neural connection to the vestibular nuclei, that is responsible for body equilibrium (Devoize et al., 2010). So, it is feasible that a neural connection is present in TMJ, that may be affected by changes in occlusion. This neural connection may explain how modifications in dental occlusion cause deviations in afferent information, mediated by the trigeminal nerve, and subsequently affect the vestibular nuclei which mediates and controls body posture and equilibrium. For further examining this issue, two studies focused on this specific topic.

The fourth study of this thesis explored how dynamic balance could be altered by OS. In order to accomplish this, we analysed 3D kinematics of gait and running on a treadmill performed by healthy subjects. Results demonstrated that mean horizontal and vertical sway was not changed with the use of OS and no placebo effect was present. Mean results presented a high standard deviation for the analysed conditions, which suggests an elevated degree of variability. This high variability implies that there were very diverse movement patterns among the subjects and this variation could have masked any changes caused by the OS.

Regarding the fifth and final study, it focused on static balance, by analysing body sway and how it could affect a specific sports performance. Shooting was the selected sport for this study, since it has been demonstrated that balance control is relevant to performance

(Dadswell, Payton, Holmes, & Burden, 2013), but also because it would allow us to examine how OS would affect upper body muscle activity in a sports context, specifically in the arm that holds the pistol. This analysis was performed because arm muscles must contract and maintain a steady position to reduce arm fluctuation while aiming. This action represents an isometric muscle contraction to some extent, which has been proved to benefit from OS, as demonstrated in study 1. The results of this study revealed that OS did not create any significant change in body sway parameters, EMG muscle activity and shooting accuracy.

A detailed analysis of the variables demonstrated that mean oscillation area was reduced for all of the time windows analysed in OS condition, but no statistical differences were found, probably due to the high variability in mean values for the examined conditions. The fourth and fifth study are parallel in their findings, since both revealed no significant deviations in balance for both dynamic and static conditions. Also, common to these studies is the fact that the results showed a high degree of between subjects' variability. This provides some clues to help explain why body posture was not altered significantly when using OS. It is possible that OS affects each participant in a specific manner, which is related to his individual and intrinsic characteristics. Accordingly, the variability and effect of OS in each participant is different and when mean averages are calculated and compared, this could affect the results and mask possible effects caused by OS, on an individual level. Additional research on this topic is necessary, focusing on individual analysis, to ascertain and provide additional knowledge on the effects of OS on dynamic and static balance.

The limitations of each individual study have already been discussed in their respective chapters. Another limitation could have influenced the results of two of the experimental studies. With regards to studies 2 (Chapter V) and 3 (Chapter VI), it is assumed, based on the existing literature, that clenching is a natural response during strength exercises (Dunn-Lewis et al., 2012) and that occurs in an involuntary manner (Yokoyama, 1998). Additionally, a recent study has established that jaw clenching when using an OS was related to an increase in activity in brain areas associated with motor coordination, when comparing to a normal condition (Ariji, Koyama, Sakuma, Nakayama, & Ariji, 2015). In our studies, no data was recorded on this variable and subjects were given no specific instructions involving clenching. Future studies could determine the strength of the relationship between clenching force and the repositioning of the TMJ, with the aid of an OS.

Moreover, the results of this thesis should be limited to the population evaluated in each study. It is possible that groups of subjects with different characteristics, such as female participants, athletes from other sports, participants with TMJ disorders and / or more elderly may yield different results.

2. Recommendations for future research

Our recommendations for future studies are based on four main ideas. The first one is related to the difference in the ergogenic effect caused by OS in untrained and trained subjects. It would be relevant to perform additional studies that could directly compare how OS affects strength in trained and untrained subjects in the same exercises / experimental protocol.

On the other hand, the experimental studies in this thesis, as well as the studies revised in the systematic review focus solely on the acute effects of OS. The human body may require an adaptation period in order to integrate the physiological and neural changes caused by OS, before producing any sizable effects. Consequently, further studies on the effects and importance of OS on the human body should have a longitudinal design, in order to direct their attention to long-term effects and gain a supplementary understanding of how OS affects the human body.

Our studies on human posture, as well as others, have revealed that a great variability of mean results occurs when comparing groups of subjects. They demonstrated that an inter-group analysis overlooks the individual effect that OS could cause on each participant. Hence, we suggest that future studies focusing on changes caused by OS in dynamic and static balance should emphasise an intra-subject comparison, instead of merely comparing mean variable results between groups of subjects. Also, the high degree of variability suggests that future studies should employ different and more specific methods of analysis, specifically nonlinear analysis for feature extraction both in the informational and invariant domain (Bravi et al., 2011), in order to better understand the variability that occurs in body posture when using OS.

Except for study 5, our studies, as most of the studies in the literature on the effects of OS, occurred in experimental controlled conditions, in a controlled environment (laboratory). More research on the effects of OS should focus their experimental protocols on athletic and sports environment, to evaluate how OS would affect variables determinant for performance.

3. Implications for sports practice

The findings in this thesis provide evidence that changing occlusal condition can have a positive influence on strength through the use of an OS, but also highlight the importance of an in-depth understanding of how these changes occur. As seen on the systematic review (Chapter IV), for untrained subjects, there is a trend towards a positive effect of OS, through an increase in upper body muscle strength in isometric strength tasks. This notion is further supported and extended to dynamic contractions by the results in study 2 (Chapter V), which revealed that isokinetic strength in upper body was also increased for untrained subjects while using an OS. These two studies reinforce the notion that for untrained subjects, the use of OS can be beneficial in increasing strength in tasks were upper body strength is relevant.

The use of mouthguards is widespread and mandatory in several sports (boxing, rugby, American football) in order to prevent oral injuries. Study 3 (Chapter VI) endorses the use of customized mouthguards as ergogenic aids. The outcomes of this study have revealed that customized mouthguards, that place the TMJ in a CR position, besides protecting the teeth and preventing facial injury, appear to benefit trained athletes with an increase in peak force and peak acceleration. This is particularly relevant for athletes engaged in contact sports were upper body strength is relevant to performance. In accordance, strength and conditioning specialists, as well as athletes who use these oral devices, are encouraged to seek expert professional dentists for the manufacturing of their mouthguards. Nevertheless, these results cannot be deemed conclusive, since some of the analyzed variables in this study were not affected neither by the use of customized mouthguard or OS.

Body balance control is a key factor in a great variety of sport skills and everyday tasks. The studies included in this thesis did not reveal that using OS promotes changes in body posture in static and dynamic conditions. However, these studies provided valuable clues regarding the course that future studies on the topic should undertake.

CHAPTER X – Conclusions

The studies compiled in this thesis provide information regarding the use of OS, which are oral devices designed to reposition the TMJ, and its effects on the human body. The focus of the studies was on upper body strength and body balance control in static and dynamic positions. The results observed in this thesis revealed that OS can act as an ergogenic aid in enhancing strength for untrained healthy male subjects. Furthermore, mouthguards that reposition the TMJ in an identical position as OS also have a positive effect on strength for trained healthy male subjects (rugby players). Body balance control was not affected by the use of OS, for both static and dynamic conditions.

Future research should continue to explore the effects of OS on the human body, with the support of EMG, kinetic and kinematic assessments and new techniques to explore and interpret data. The focus should rely on the long-term effects caused by the use of OS. Also, the comparison in future studies should be made on an individual basis, since each participant has individual characteristics that may, on a neuromuscular level, respond differently with the use of an OS.

CHAPTER XI – References

Aagaard, P., Simonsen, E., Andersen, J., Magnusson, P., & Dyhre-Poulsen, P. (2002). Neural adaptation to resistance training: changes in evoked V-wave and H-reflex responses. *Journal of Applied Physiology*, *92*(6), 2309–2318. http://doi.org/10.1152/japplphysiol.01185.2001

Adsuar, J., Olivares, P., Parraca, J., Hernández-Mocholí, M., & Gusi, N. (2013). Applicability and test-retest reliability of isokinetic shoulder abduction and adduction in women fibromyalgia patients. *Archives of Physical Medicine and Rehabilitation*, *94*(3), 444–50. http://doi.org/10.1016/j.apmr.2012.08.198

Alexander, C. (1999). *A Study on the Effectiveness of a Self-Fit Mandibular Repositioning Appliance on Increasing Human Strength and Endurance Capabilities*. University of Tennessee.

Allen, C., Dabbs, N., Zachary, C., & Garner, J. (2014). The acute effect of a commercial bite-aligning mouthpiece on strength and power in recreationally trained men. *Journal of Strength and Conditioning Research*, *28*(2), 499–503.

Alomar, X., Medrano, J., Cabratosa, J., Clavero, J. A., Lorente, M., Serra, I., & Salvador, A. (2007). Anatomy of the Temporomandibular Joint. *Seminars in Ultrasound, CT and MRI*, *28*(3), 170–183. http://doi.org/10.1053/j.sult.2007.02.002

Arent, S., McKenna, J., & Golem, D. L. (2010). Effects of a neuromuscular dentistry-designed mouthguard on muscular endurance and anaerobic power. *Comparative Exercise Physiology*, *7*(2), 73–79. http://doi.org/10.1017/S1755254010000231

Ariji, Y., Koyama, S., Sakuma, S., Nakayama, M., & Ariji, E. (2015). Regional brain activity during jaw clenching with natural teeth and with occlusal splints: a preliminary functional MRI study. *CRANIO®*, 1–7. http://doi.org/10.1080/08869634.2015.1097320

Baechle, T. & Earle, R. (2008). *Essentials of Strength Training and Conditioning*. *Journal of athletic training* (3rd ed., Vol. 31). Human Kinetics. http://doi.org/10.1016/S0031-9406(05)66120-2

Bag, A., Gaddikeri, S., Singhal, A., Hardin, S., Tran, B., Medina, J., & Curé, J. (2014). Imaging of the temporomandibular joint: An update. *World Journal of Radiology*, *6*(8), 567. http://doi.org/10.4329/wjr.v6.i8.567

Baker, D., Nance, S., & Moore, M. (2001). The Load That Maximizes the Average Mechanical Power Output During Jump Squats in Power-Trained Athletes. *The Journal of Strength and Conditioning Research*, *15*(1), 92. http://doi.org/10.1519/1533-4287(2001)015<0092:TLTMTA>2.0.CO;2

Baldini, A., Nota, A., Tripodi, D., Longoni, S., & Cozza, P. (2013). Evaluation of the correlation between dental occlusion and posture using a force platform. *Clinics*, *68*(1), 45–49. http://doi.org/10.6061/clinics/2013(01)OA07

Bevan, H., Bunce, P., Owen, N., Bennett, M., Cook, C., Cunningham, D., Newton, R., & Kilduff, L.. (2010). Optimal loading for the development of peak power output in professional rugby players. *Journal of Strength and Conditioning Research*, *24*(1), 43–47.

Blaak, E. (2001). Gender differences in fat metabolism. *Current Opinion in Clinical Nutrition and Metabolic Care*, *4*(6), 499–502. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/11706283

Boero, R. (1989). The physiology of splint therapy_a literature review.pdf. *Angle Orthodontist*, *59*(3), 165–180.

Bracco, P., Deregibus, A., & Piscetta, R. (2004b). Effects of different jaw relations on postural stability in human subjects. *Neuroscience Letters*, *356*, 228–230. http://doi.org/10.1016/j.neulet.2003.11.055

Bravi, A., Longtin, A., & Seely, A. J. E. (2011). Review and classification of variability analysis techniques with clinical applications. *Biomedical Engineering Online*, *10*, 90. http://doi.org/10.1186/1475-925X-10-90

Browne, P., Clark, G., Yang, Q., & Nakano, M. (1993). Sternocleidomastoid muscle inhibiton induced by trigeminal stimulation. *Journal of Dental Research*, *72*(11), 1503–1508.

Buscà, B., Morales, J., Solana-Tramunt, M., Miró, A., & García, M. (2016). Effects of Jaw Clenching While Wearing a Customized Bite-Aligning Mouthpiece on Strength in Healthy Young Men. *Journal of Strength and Conditioning Research*, *30*(4), 1102–10. http://doi.org/10.1519/JSC.0000000000001192

Chakfa, A., Mehta, N., Forgione, A., Al-Badawi, E., Lobo, S., & Zawawi, K. (2002). The effect of stepwise increases in vertical dimension of occlusion on isometric strength of cervical flexors and deltoid muscles in nonsymptomatic females. *Cranio : The Journal of Craniomandibular Practice*, *20*(4), 264–73. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/12403184

Choi, A., Conway, R., Taraschi, V., & Ben-Nissan, B. (2015). Biomechanics and functional distortion of the human mandible. *Journal of Investigative and Clinical Dentistry*, *6*(4), 241–251. http://doi.org/10.1111/jicd.12112

Criswell, E. (2011). *Cram's introduction to surface electromyography*. (E. Criswell, Ed.) (2nd ed.). Jones and Bartlett.

Cuccia, A., & Caradonna, C. (2009). The relationship between the stomatognathic system and body posture. *Clinics*, *64*(1), 61–66. http://doi.org/10.1590/S1807-59322009000100011

Cuccia, A. (2011). Interrelationships between dental occlusion and plantar arch. *Journal of Bodywork and Movement Therapies*, *15*(2), 242–50. http://doi.org/10.1016/j.jbmt.2010.10.007

Dadswell, C., Payton, C., Holmes, P., & Burden, A. (2013). Biomechanical analysis of the change in pistol shooting format in modern pentathlon. *Journal of Sports Sciences*, *3112*(March), 1294–1301. http://doi.org/10.1080/02640414.2013.777762

Daly, P., Preston, C., & Evans, W. (1982). Postural response of the head to bite opening in adult males. *American Journal of Orthodontics*, *82*(2), 157–60. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/6961786

Devoize, L., Doméjean, S., Melin, C., Raboisson, P., Artola, A., & Dallel, R. (2010). Organization of projections from the spinal trigeminal subnucleus oralis to the spinal cord in the rat: A neuroanatomical substrate for reciprocal orofacial–cervical interactions. *Brain Research*, *1343*, 75–82. http://doi.org/10.1016/j.brainres.2010.04.076

Dunn-Lewis, C., Hydren, J., Kraemer, W., Denegar, C., Watts, A., Comstock, B., & Volek, J. S. (2012). The Effects of a Customized Over-the-Counter Mouth Guard on Neuromuscular Force and Power Production in Trained Men and Women. *Journal of Strength and Conditioning Research*, *26*(September 2015), 1085–1093. http://doi.org/10.1519/JSC.0b013e31824b4d5b

Dylina, T. (2001). Dylina - A common-sense approach to splint therapy.pdf. *The Journal of Prosthetic Dentitry*, *86*(5), 539–545.

Ebben, W. (2006a). A brief review of concurrent activation potentiation: theoretical and practical constructs. *Journal of Strength and Conditioning Research / National Strength & Conditioning Association*, *20*(4), 985–91. http://doi.org/10.1519/R-19375.1

Ellis, E., & Throckmorton, G. (2005). Treatment of mandibular condylar process fractures: Biological considerations. *Journal of Oral and Maxillofacial Surgery*, *63*(1), 115–134. http://doi.org/10.1016/j.joms.2004.02.019

Ferrario, V., Chiarella, B., Taroni, A., & Schmitz, H. (1996). Occlusion and center of foot pressure variation: Is there a relationship ? *The Journal of Prosthetic Dentitry*, *76*(3), 302–308.

Ferrario, V., Sforza, C., Dellavia, C., & Tartaglia, G. M. (2003). Evidence of an influence of asymmetrical occlusal interferences on the activity of the sternocleidomastoid muscle. *Journal of Oral Rehabilitation*, *30*(1), 34–40. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/12485381

Ferrario, V., Sforza, C., Serrao, G., Fragnito, N., & Grassi, G. (2001). The influence of different jaw positions on the endurance and electromyographic pattern of the biceps brachii muscle in young adults with different occlusal characteristics. *Journal of Oral Rehabilitation*, *28*(8), 732–9. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/11556954

Flavel, S., Nordstrom, M., & Miles, T. (2003). Postural stability of the human mandible during locomotion. *Journal of Biomechanics*, *36*(6), 759–764. http://doi.org/10.1016/S0021-9290(03)00009-5

Forgione, A., Mehta, N., McQquade, C., & Westcott, W. (1992). Strength and bite, Part 2: Testing isometric strength using a MORA set to a functional criterion. *Cranio*, *10*(1), 13–20.

Forgione, A. (1991). Strength and bite Part I.pdf. *The Journal of Craniomandibular Practice*, *9*(4), 305–315.

Frederick, L.., & Steinkeler, A. (2013). Epidemiology, Diagnosis, and Treatment of Temporomandibular Disorders. *Dental Clinics of North America*, *57*(3), 465–479. http://doi.org/10.1016/j.cden.2013.04.006

Fujimoto, M., Hayakawa, I., Hirano, S., & Watanabe, I. (2001). Changes in gait stability induced by alteration of mandibular position. *Journal of Medicine and Dental Sciences*, *48*, 131–136.

Gangloff, P., Louis, J., & Perrin, P. (2000). Dental occlusion modifies gaze and posture stabilization in human subjects. *Neuroscience Letters*, *293*, 203–206.

Gangloff, P., & Perrin, P. (2002). Unilateral trigeminal anaesthesia modifies postural control in human subjects. *Neuroscience Letters*, *330*(2), 179–82. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/12231441

Garceau, L.., Petushek, E., McKenzie, F., & Ebben, W. (2012). Effect of Remote Voluntary Contractions on Isometric Prime Mover Torque and Electromyography. *Journal of Exercise Physiology*, *15*(4), 40–46. http://doi.org/10.1519/JSC.0b013e3181874564

Golem, D. (2012). *Improving Physical Performance: The Role of Jaw-Repositioning*. Graduate School - New Brunswick.

González-Hernádez, J., García-Ramos, A., Capelo-Ramírez, F., Castaño-Zambudio, A., Marquez, G., Boullosa, D., & Jiménez-Reyes, P. (2017). Mechanical, metabolic, and perceptual acute responses to different set configurations in full squat. *Journal of Strength and Conditioning Research*. http://doi.org/10.1519/JSC.0000000000002117

Greenberg, M., Cohen, S., Springer, P., Kotwick, J., & Vegso, J. (1981). Mandibular position and upper body strength: a controlled clinical trial. *The Journal of the American Dental Association*, *103*, 576–579.

Hanke, B., Motschall, E., & Türp, J. (2007). Association between orthopedic and dental findings: what level of evidence is available? *Journal of Orofacial Orthopedics*, *68*(2), 91–107. http://doi.org/10.1007/s00056-007-0634-0

Hernández, J., Solana, R., Marin, J., Fernández, J., & Ramón, M. (2016). Rest Interval Required for Power Training With Power Load in the Bench Press Throw Exercise. *Journal of Strength and Conditioning Research*, *30*(5), 1265–74. http://doi.org/10.1519/JSC.0000000000001214

Hoffman, J. (2014). *Physiological aspects of sport training and performance* (2nd ed.). Human Kinetics.

Hopkins, W., Marshall, S., Batterham, A., & Hanin, J. (2009). Progressive statistics for studies in sports medicine and exercise science. *Medicine and Science in Sports and Exercise*, *41*(1), 3–12. http://doi.org/10.1249/MSS.0b013e31818cb278

Hosoda, M., Masuda, T., Isozaki, K., Takayanagi, K., Sakata, K., Takakuda, K., … Morita, S. (2007). Effect of occlusion status on the time required for initiation of recovery in response to external disturbances in the standing position. *Clinical Biomechanics (Bristol, Avon)*, *22*(3), 369–73. http://doi.org/10.1016/j.clinbiomech.2006.11.001

Ishijima, T., Hirai, T., Koshino, H., Konishi, Y., & Yokoyama, Y. (1998). The relationship between occlusal support and physical exercise ability. *Journal of Oral Rehabilitation*, *25*(6), 468–71. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/9687121

Johansson, A., Unell, L., Carlsson, G., Söderfeldt, B., & Halling, A. (2003). Gender difference in symptoms related to temporomandibular disorders in a population of 50-year-old subjects. *Journal of Orofacial Pain*, *17*, 29–35.

Julià-Sánchez, S., Álvarez-Herms, J., Gatterer, H., Burtscher, M., Pagès, T., & Viscor, G. (2015). Dental Occlusion Influences the Standing Balance on an Unstable Platform. *Motor Control*, *19*(4), 341–354. http://doi.org/10.1123/mc.2014-0018

Jung, J., Chae, W., & Lee, K. (2013). Analysis of the characteristics of mouthguards that affect isokinetic muscular ability and anaerobic power. *The Journal of Advanced Prosthodontics*, *5*(4), 388–95. http://doi.org/10.4047/jap.2013.5.4.388

Kandel, E. (2013). *Principles of Neural Science*. (A. Kandel, Eric; Schwartz, James; Jessell, Thomas; Sielgelbaum, Steven; Hudspeth, Ed.) (5th ed.). McGraw-Hill.

Kibana, Y., Ishijima, T., & Hirai, T. (2002). Occlusal support and head posture. *Journal of Oral Rehabilitation*, *29*, 58–63.

Klineberg, I., & Jagger, R. G. (2004). *Occlusion and clinical practice : an evidence-based approach*. Wright.

Lee, S., Park, Y., Park, H., Bae, H, Yu, M., Choi, H., & Hwang, N. (2014). Effect of the Mandibular Orthopedic Repositioning Appliance (MORA) on Forearm Muscle Activation and Grasping Power during Pinch and Hook Grip. *Journal of Physical Therapy Science*, *26*(2), 195–7. http://doi.org/10.1589/jpts.26.195

Manfredini, D., Guarda-Nardini, L., Winocur, E., Piccotti, F., Ahlberg, J., & Lobbezoo, F. (2011). Research diagnostic criteria for temporomandibular disorders: a systematic review of axis I epidemiologic findings. *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontology*, *112*(4), 453–462. http://doi.org/10.1016/j.tripleo.2011.04.021

Manns, A., Miralles, R., & Pena, M. C. (1988). The Effect of Different Occlusal Splints on The Electromyographic Activity of Elevator Muscles : A comparative Study. *The Journal of Gnathology*, *7*(1), 61–73.

Michelotti, A., Buonocore, G., Farella, M., Pellegrino, G., Piergentili, C., Altobelli, S., & Martina, R. (2006). Postural stability and unilateral posterior crossbite: is there a relationship? *Neuroscience Letters*, *392*(1–2), 140–4. http://doi.org/10.1016/j.neulet.2005.09.008

Michelotti, A., Buonocore, G., Manzo, P., Pellegrino, G., & Farella, M. (2011). Dental occlusion and posture: An overview. *Progress in Orthodontics*, *12*(1), 53–58. http://doi.org/10.1016/j.pio.2010.09.010

Michiels, I., & Bodem, F. (1992). The deltoid muscle: an electromyographical analysis of its activity in arm abduction in various body postures. *International Orthopaedics*, *16*(3), 268–271. http://doi.org/10.1007/BF00182709

Milani, R., De Perière, D., Lapeyre, L., & Pourreyron, L. (2000). Relationship between dental occlusion and posture. *Cranio : The Journal of Craniomandibular Practice*, *18*(2), 127–34. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/11202823

Miralles, R., Dodds, C., Manns, A., Palazzi, C., Jaramillo, C., Quezada, V., & Cavada, G. (2002). Vertical dimension. Part 2: the changes in electrical activity of the cervical muscles upon varying the vertical dimension. *Cranio : The Journal of Craniomandibular Practice*, *20*(1), 39–47. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/11831343

Miyahara, T., Hagiya, N., Ohyama, T., & Nakamura, Y. (1996). Modulation of human soleus H reflex in association with voluntary clenching of the teeth. *Journal of Neurophysiology*, *76*(3), 2033–41. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/8890312

Myers, T. (2009). *Anatomy Trains: Myofascial Meridians for Manual and Movement Therapists*. (C. Livingstone, Ed.) (2nd ed.). Elsevier.

Nelson, S. (2013). *Wheeler's dental anatomy, physiology and Occlusion*. (Elsevier, Ed.)*Journal of Chemical Information and Modeling* (10th ed., Vol. 53). http://doi.org/10.1017/CBO9781107415324.004

Nielsen, J., Crone, C., & Hultborn, H. (1993). H-reflexes are smaller in dancers from The Royal Danish Ballet than in well-trained athletes. *European Journal of Applied Physiology and Occupational Physiology*, *66*(2), 116–121. http://doi.org/10.1007/BF01427051

Okeson, J. (2008). *Management of Temporomandibular Disorders and Occlusion*. (J. Dojan, Ed.) (Sixth). Elsevier.

Olivo, S., Fuentes, J., Major, P., Warren, S., Thie, N., & Magee, D. J. (2010). The association between neck disability and jaw disability. *Journal of Oral Rehabilitation*, *37*(9), 670–9. http://doi.org/10.1111/j.1365-2842.2010.02098.x

Perinetti, G. (2006). Dental occlusion and body posture: no detectable correlation. *Gait & Posture*, *24*(2), 165–8. http://doi.org/10.1016/j.gaitpost.2005.07.012

Perinetti, G., & Contardo, L. (2009). Posturography as a diagnostic aid in dentistry: a systematic review. *Journal of Oral Rehabilitation*, *36*(12), 922–36. http://doi.org/10.1111/j.1365-2842.2009.02019.x

Perotto, A. (2011). *Anatomical Guide for the Electromyographer - The limbs and trund*. *Journal of anatomy* (Fifth, Vol. 186). Springfield, Illinois, USA: Charles C. Thomas. http://doi.org/10.1097/00002060-199505000-00020

Politti, J., Felice, C., & Valentinuzzi, M. (2003). Arm EMG during abduction and adduction: Hysteresis cycle. *Medical Engineering and Physics*, *25*(4), 317–320. http://doi.org/10.1016/S1350-4533(02)00218-7

Pow, E., Leung, K., & McMillan, A. (2001). Prevalence of symptoms associated with temporomandibular disorders in Hong Kong Chinese. *Journal of Orofacial Pain*, *15*(3), 228–34.

Prosthodontics. (2005). THE GLOSSARY OF PROSTHODONTIC TERMS. *THE JOURNAL OF PROSTHETIC DENTISTRY*, *94*(1), 10–92.

Raadsheer, M., Van Eijden, T., Van Ginkel, F., & Prahl-Andersen, B. (2004). Human jaw muscle strength and size in relation to limb muscle strength and size. *European Journal of Oral Sciences*, *112*(5), 398–405. http://doi.org/10.1111/j.1600-0722.2004.00154.x

Roberts, D., & Tattersall, I. (1974). Skull form and the mechanics of mandibular elevation in mammals. American Museum novitates ; no. 2536. *American Museum Novitates*, (2536), 1–9. Retrieved from http://digitallibrary.amnh.org/handle/2246/2739

Ruivo, R., Pezarat-Correia, P., & Carita, A.. (2012). Elbow and shoulder muscles strength profile in judo athletes. *Isokinetics and Exercise Science*, *20*(1), 41–45. http://doi.org/10.3233/IES-2012-0439

Schleip, R. (2003). Fascial plasticity – a new neurobiological explanation: Part 1. *Journal of Bodywork and Movement Therapies*, *7*(1), 11–19. http://doi.org/10.1016/S1360-8592(02)00067-0

Schleip, R., Klingler, W., & Lehmann-Horn, F. (2005). Active fascial contractility: Fascia may be able to contract in a smooth muscle-like manner and thereby influence musculoskeletal dynamics. *Medical Hypotheses*, *65*(2), 273–7. http://doi.org/10.1016/j.mehy.2005.03.005

Schubert, M., Guttu, R., Hunter, L., Hall, R., & Thomas, R. (1984). Changes in shoulder and leg strength in athletes wearing mandibular orthopedic repositioning appliances. *The Journal of the American Dental Association*, *108*, 334–337.

Spector, M. (2001). Perspective article Musculoskeletal connective tissue cells with muscle : Expression of muscle actin in and contraction of fibroblasts , chondrocytes , and osteoblasts. *WOUND REPAIR AND REGENERATION*, *9*(1), 11–18.

Staubesand, J.; Ly, Y. (1996). Zum Feinbau der Fascia cruris mit besonderer Berucksichtigung epi- und intrafaszialer Nerven. *Manuelle Medizin*, *34*, 196–200.

Strini, P., Machado, N., Gorreri, M., Ferreira, A., Sousa, G., & Fernandes Neto, A. (2009). Postural evaluation of patients with temporomandibular disorders under use of occlusal splints. *Journal of Applied Oral Science : Revista FOB*, *17*(5), 539–43. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/19936539

Tanaka, E., & Koolstra, J. H. (2008). Biomechanics of the Temporomandibular Joint. *Journal of Dental Research*, *87*(11), 989–991. http://doi.org/10.1177/154405910808701101

Tecco, S., Caputi, S., & Festa, F. (2007). Electromyographic activity of masticatory, neck and trunk muscles of subjects with different skeletal facial morphology--a cross-sectional evaluation. *Journal of Oral Rehabilitation*, *34*(7), 478–86. http://doi.org/10.1111/j.1365-2842.2007.01724.x

Tecco, S., Polimeni, A., Saccucci, M., & Festa, F. (2010). Postural loads during walking after an imbalance of occlusion created with unilateral cotton rolls. *BMC Research Notes*, *3*, 141. http://doi.org/10.1186/1756-0500-3-141

Tecco, S., Salini, V., Calvisi, V., Colucci, C., Orso, C., Festa, F., & D'Attilio, M. (2006). Effects of anterior cruciate ligament (ACL) injury on postural control and muscle activity of head, neck and trunk muscles. *Journal of Oral Rehabilitation*, *33*(8), 576–87. http://doi.org/10.1111/j.1365-2842.2005.01592.x

Thoumie, P., & Do, M. (1996). Changes in motor activity and biomechanics during balance recovery following cutaneous and muscular deafferentation. *Experimental Brain Research*, *110*(2), 289–97. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/8836692

Valentino, B., Melito, F., Aldi, B., & Valentino, T. (2002). Correlation between interdental occlusal plane and plantar arches. An EMG study. *Bulletin Du Groupement International Pour La Recherche Scientifique En Stomatologie et Odontologie*, *44*(1), 10–13.

Verban, E., Groppel, J., Pfautsch, E., & Ramseyer, G. (1984). The Effects of a Mandibular Orthopedic Repositioning Applianceon Shoulder Strength. *The Journal of Craniomandibular Practice*, *2*(3), 232–237.

Visscher, C., Lobbezoo, F., de Boer, W., Van der Zaag, J., & Naeije, M. (2001). Prevalence of cervical spinal pain in craniomandibular pain patients. *European Journal of Oral Sciences*, *109*(2), 76–80. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/11347659

Walker, C., & MacLeod, S. (2017). Anatomy and Biomechanics of Condylar Fractures. *Atlas of the Oral and Maxillofacial Surgery Clinics*, *25*(1), 11–16. http://doi.org/10.1016/j.cxom.2016.10.002

Wang, K., Ueno, T., Taniguchi, H., & Ohyama, T. (1996). Influence on isometric muscle contraction during shoulder abduction by changing occlusal situation. *Bulletin of Tokyo Medical Dentist University*, *43*, 1–12.

Williams, M., Chaconas, S.., & Bader, P. (1983). The effect of mandibular position position on appendage muscle strength. *The Journal of Prosthetic Dentistry*, *49*(4), 560–567.

Wood, W., & Tobias, D. L. (1984). EMG response to alteration of tooth contacts on occlusal splints during maximal clenching. *The Journal of Prosthetic Dentistry*, *51*(3), 394–396.

Yahia, L., Pigeon, P., & DesRosiers, E. (1993). Viscoelastic properties of the human lumbodorsal fascia. *Journal of Biomedical Engineering*, *15*(5), 425–9. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/8231161

Yahia, L., Rhalmi, S., Newman, N., & Isler, M. (1992). Sensory innervation of human thoracolumbar fascia. An immunohistochemical study. *Acta Orthopaedica Scandinavica*, *63*(2), 195–7. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/1590057

Yates, J., Koen, T., Semenick, D., & Kuftinec, M. (1984). Effect of a mandibular orthopedic repositioning appliance on muscular strength. *The Journal of the American Dental Association*, *108*, 331–333.

Yokoyama, Y. (1998). Involuntary Teeth Clenching during Physical Exercise. *Journal of the Japan Prosthodontic Society*, *42*, 90–101.

Yunus, N. (2009). Occulusal Splints Therapy : A Review. *Indian Journal of Dental Education*, *2*(1), 33–37.