UNIVERSIDADE FEDERAL DE SÃO CARLOS
CENTRO DE CIÊNCIAS BIOLÓGICAS E DA SAÚDE
PROGRAMA DE PÓS-GRADUAÇÃO EM FISIOTERAPIA

EFEITOS DO KINESIO TAPING NA CINEMÁTICA ESCAPULAR E PROPRIOCEPÇÃO DO OMBRO APÓS FADIGA MUSCULAR

GISELE GARCIA ZANCA

São Carlos

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Gisele Garcia Zanca

Tese apresentada ao Programa de Pós-Graduação em Fisioterapia da Universidade Federal de São Carlos como parte dos requisitos para a obtenção do título de Doutora em Fisioterapia, área de concentração Processos de Avaliação e Intervenção em Fisioterapia.

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RESUMO

O complexo do ombro depende altamente de seus estabilizadores dinâmicos e do controle sensório-motor para manutenção de sua estabilidade funcional. Sabe-se que a fadiga muscular altera a cinemática da escápula e causa déficits proprioceptivos, o que pode contribuir para as disfunções do ombro. Kinesio taping (KT) é uma bandagem elástica que vem sendo amplamente utilizada na reabilitação e prevenção de lesões. Diversos efeitos são atribuídos ao KT, dentre eles a facilitação muscular e a melhora do *feedback* proprioceptivo. Sendo assim, o objetivo principal desta tese foi investigar os efeitos do KT na cinemática escapular e propriocepção do ombro após um protocolo de fadiga muscular. Esta tese é composta por três estudos. O estudo I foi desenvolvido na fase de adequação metodológica do estudo II e teve como objetivo investigar a relação entre os movimentos da elevação e retração da clavícula e o sinal EMG capturado em três posicionamento de eletrodo: o posicionamento tradicional (entre C7 e o acrômio) e dois posicionamentos propostos na literatura para a avaliação das fibras claviculares do trapézio. Este estudo concluiu que, embora avalie as fibras que se inserem no acrômio, o sinal capturado no posicionamento tradicional apresenta forte correlação com os movimentos da clavícula, sendo representativo em sujeitos saudáveis. O estudo II teve como objetivo investigar os efeitos do KT para facilitação do trapézio inferior na cinemática escapular tridimensional durante a elevação do braço, em atletas arremessadores saudáveis, após um protocolo de fadiga constituído por arremessos. Embora tenha sido encontrada uma menor intensidade de fadiga do serrátil anterior com o uso do KT com tensão, comparado a uma técnica sem tensão, não houve efeito na cinemática escapular. Além disso, as alterações na cinemática escapular após a fadiga, embora significativas, foram de pequena amplitude, não sendo consideradas clinicamente importantes. Este achado foi atribuído a um possível mecanismo de adaptação destes atletas que, portanto, não se beneficiam do uso do KT. O estudo III avaliou os efeitos do KT aplicado sobre o músculo deltóide no senso de posição articular durante a elevação do ombro, em sujeitos saudáveis, após fadiga muscular. Foi observado um aumento no erro durante os testes de reposicionamento ativo após o protocolo de fadiga, nos maiores ângulos de elevação, mas sem efeito do KT. Os resultados destes estudos não suportam o uso do KT para prevenir ou minimizar os efeitos da fadiga muscular na cinemática escapular de atletas arremessadores e na propriocepção do ombro de indivíduos saudáveis.

Palavras-chave: eletromiografia; biomecânica; fisioterapia; esportes

ABSTRACT

The shoulder joint complex highly depends on dynamic stabilization and sensorimotor control to maintain its functional stability. It is known that muscle fatigue causes scapular kinematics alterations and proprioceptive deficits, and both are related with shoulder injuries. Kinesio taping (KT) is an elastic taping that has been widely used in rehabilitation and injuries preventions. Several effects have been attributed to KT, including muscle facilitation and improvement of proprioceptive feedback. Therefore, the main purpose of this thesis was to investigate the effects of KT on scapular kinematics and shoulder proprioception following a muscle fatigue protocol. This thesis is composed of three studies. The objective of the study I was to investigate the relationship between clavicular movements (elevation and retraction) and the EMG signal recorded on three electrode sites: the traditional positioning (between C7 and the acromion) and two different sites proposed for clavicular fibers evaluation. It was concluded that, although the traditional electrode positioning record the signal from fibers inserted on the acromion, its signal presents high correlation with clavicular movement. Therefore, it can be considered representative in healthy subjects. The study II aimed to investigate the effects of KT for lower trapezius facilitation on three-dimensional scapular kinematics of healthy overhead athletes, following a fatigue protocol consisted of repetitive throwing. Regardless a lower fatigue intensity of serratus anterior when KT was applied with tension compared to no tension, there was no effect of taping on scapular kinematics. Furthermore, although there were statistically significant alterations on scapular kinematics following muscle fatigue, the changes were small and were not considered clinically relevant.

This finding was attributed to a possible adaptive mechanism of overhead athletes, who, therefore, do not beneficiate with the use of KT. The study III investigated the effects of KT applied over the deltoid muscle on shoulder joint position sense of healthy subjects, following a fatigue protocol, during arm elevation. There was an increase in the repositioning errors following the fatigue protocol, but there was no effect of the taping. The findings of these studies do not support the use of KT to prevent or minimize the effects of muscle fatigue on scapular kinematics of healthy overhead athletes and shoulder proprioception of healthy subjects.

Keywords: electromyography; biomechanics; physical therapy; sports

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APRESENTAÇÃO

Esta tese é apresentada segundo as normas do Programa de Pós-Graduação em Fisioterapia e do Regimento Geral da Pós-Graduação da UFSCar. Inicialmente, será apresentada uma contextualização sobre os temas dos estudos incluídos na tese. Em seguida, serão apresentados os manuscritos resultantes dos três estudos desenvolvidos, na formatação dos periódicos em que foram submetidos. Os estudos são apresentados em inglês e precedidos por uma síntese em português, conforme determina o Regimento Geral da Pós-Graduação da UFSCar (Resolução COPG Nº 007 de 18 de dezembro de 2013). Por fim, serão apresentadas as atividades que foram desenvolvidas durante o período do doutorado.

CONTEXTUALIZAÇÃO

O complexo do ombro é composto pela escápula, úmero e clavícula, formando articulações que funcionam de maneira integrada, resultando em uma grande amplitude de movimento e proporcionando o amplo alcance da mão no espaço em atividades de vida diária e esportivas (Terry e Chopp, 2000). Devido à pequena estabilidade proporcionada pelas estruturas ósseas, o ombro é altamente dependente dos estabilizadores dinâmicos e do controle sensório-motor (Nyland, Caborn e Johnson, 1998). Desequilíbrios neste complexo sistema podem resultar em importantes déficits funcionais para o membro superior (Kibler, Kuhn, *et al.*, 2013).

O controle do movimento escapular é essencial para a adequada congruência da cavidade glenóide com a cabeça do úmero, proporcionando uma base estável para o movimento do úmero e favorecendo a relação comprimento-tensão dos músculos do manguito rotador, responsáveis pela estabilização dinâmica da articulação glenoumeral (Phadke, Camargo e Ludewig, 2009). Durante o movimento de elevação do braço, a articulação escapulotorácica apresenta um padrão de movimento em rotação superior e inclinação posterior (Ludewig *et al.*, 2009). A rotação interna/externa da escápula depende do plano de elevação, pois proporciona seu ajuste à curvatura do tórax no plano transverso, mas geralmente ocorre uma diminuição da rotação externa no final da amplitude de elevação (Ludewig *et al.*, 2009). Os movimentos da escápula em relação ao tórax são uma combinação dos movimentos que ocorrem na articulação esternoclavicular e na articulação acromioclavicular. Durante a elevação do braço, a clavícula apresenta um padrão de movimento de elevação, retração e rotação posterior (Ludewig *et al.*, 2009). Devido ao posicionamento da escápula em relação à clavícula na articulação acromioclavicular, dois terços da amplitude de elevação da clavícula resultam em inclinação anterior da escápula em relação ao tórax e um terço em rotação superior da escápula (Teece *et al.*, 2008). A retração da clavícula resulta em rotação externa da escápula e a rotação posterior da clavícula resulta em inclinação posterior e rotação superior da escápula (Teece *et al.*, 2008).

A rotação posterior da clavícula é causada pelo tensionamento dos ligamentos coracoclavicular e acromioclavicular, quando os músculos escapulotorácicos geram o movimento de rotação superior da escápula (Ludewig *et al.*, 2009). Os movimentos de retração e elevação são gerados pela ação da porção superior do músculo trapézio, que se insere no terço distal da clavícula (Johnson *et al.*, 1994). O aumento de ativação do trapézio superior vem sendo encontrada em sujeitos com síndrome do impacto (Ludewig e Cook, 2000; Cools *et al.*, 2004; Cools *et al.*, 2007). Este aumento tem sido relacionado ao aumento da elevação clavicular e consequente aumento da inclinação anterior da escápula nesta população (Ludewig e Braman, 2011). Entretanto, estes estudos avaliaram o sinal eletromiográfico (EMG) do trapézio superior entre C7 e o acrômio, ou seja, sobre as fibras que se inserem no acrômio e não na clavícula (Mercer, 2002). Sendo assim, foi desenvolvido o estudo I ("*EMG of upper trapezius − Electrode sites and association with clavicular kinematics*"), cujo objetivo foi investigar a relação entre os movimentos de elevação e retração da clavícula e o sinal EMG capturado em três posicionamento de eletrodo: o posicionamento tradicional, entre C7 e o acrômio, e dois posicionamentos propostos na literatura para a avaliação das fibras claviculares do trapézio. Este estudo foi apresentado no exame de qualificação e publicado no periódico *Journal of Electromyography and Kinesiology* (Zanca *et al.*, 2014).

Além do trapézio superior, o trapézio inferior e o músculo serrátil anterior têm papel importante para o adequado movimento escapular durante a elevação do braço. O serrátil anterior é responsável pelo movimento da escápula nos três planos, realizando a rotação superior, inclinação posterior e rotação externa (Phadke, Camargo e Ludewig, 2009). O trapézio inferior realiza a rotação externa da escápula, é um importante sinergista do serrátil anterior para a rotação superior da escápula, além de promover sua estabilização medial, contrabalanceando o deslocamento lateral causado pela ação do serrátil (Johnson *et al.*, 1994; Fey *et al.*, 2007). Embora ainda não esteja claro se há uma relação de causa e efeito entre as lesões no ombro e alterações no padrão de movimento escapular, a chamada discinese escapular, parece estar presente em diversas disfunções do ombro (Ludewig e Reynolds, 2009; Kibler, Ludewig, *et al.*, 2013).

O efeito da fadiga muscular na cinemática tridimensional da escápula vem sendo investigado por se tratar de um fator que pode predispor atletas e trabalhadores que realizam movimentos repetitivos com os membros superiores às disfunções do ombro. Vários estudos avaliaram a cinemática escapular após protocolos de fadiga envolvendo atividades como rotação lateral do ombro (Tsai, Mcclure e Karduna, 2003; Ebaugh, Mcclure e Karduna, 2006b; Chopp, Fischer e Dickerson, 2011; Joshi *et al.*, 2011), elevação do braço (Mcquade, Dawson e Smidt, 1998), *push up and plus* em isometria (Borstad, Szucs e Navalgund, 2009) e atividades repetitivas acima da cabeça (Ebaugh, Mcclure e Karduna, 2006a; Chopp, Fischer e Dickerson, 2011). Embora a população de atletas arremessadores esteja exposta a um maior risco de lesões no ombro, devido às grandes amplitudes de movimento, velocidade e repetição do movimento de arremesso (Wilk *et al.*, 2009), foi encontrado apenas um estudo na literatura avaliando a cinemática tridimensional do ombro nesta população, o qual utilizou um protocolo de fadiga para os rotadores laterais do ombro (Joshi *et al.*, 2011). Entretanto, considerando que os efeitos da fadiga na cinemática escapular são dependentes da atividade realizada durante o protocolo de fadiga (Ebaugh, Mcclure e Karduna, 2006b; Chopp, Fischer e Dickerson, 2011), estudos avaliando os efeitos de um protocolo de fadiga envolvendo o movimento de arremesso poderiam contribuir para um melhor entendimento dos efeitos da fadiga na cinemática tridimensional da escápula destes atletas.

Além de alterações na cinemática escapular, sabe-se que a fadiga muscular também altera o controle sensório-motor do ombro (Myers *et al.*, 1999; Tripp *et al.*, 2004; Bowman *et al.*, 2006). A ação coordenada dos músculos estabilizadores do ombro, que proporciona o adequado movimento das articulações envolvidas, é altamente dependente do sistema de controle sensório-motor (Myers, Wassinger e Lephart, 2006). O sistema sensório-motor envolve a integração sensorial, motora, central e os componentes de processamento envolvidos na manutenção da estabilidade articular funcional (Riemann e Lephart, 2002b). As informações sensoriais (propriocepção) se originam nos mecanorreceptores presentes na pele, ligamentos, músculos, tendões e se integram no sistema nervoso central com outros impulsos somatossensoriais, vestibulares e visuais, gerando uma resposta eferente (controle neuromuscular) (Myers e Lephart, 2000). A propriocepção é geralmente descrita em três submodalidades: o senso de posição articular, que se refere à apreciação e interpretação da posição do segmento corporal; a cinestesia, que consiste na capacidade de identificar o movimento articular; e o senso de força, que consiste na capacidade de perceber e interpretar forças aplicadas ou geradas em uma articulação (Riemann e Lephart, 2002a). Diversos estudos demonstraram que a fadiga muscular diminui a acuidade proprioceptiva do ombro (Voight *et al.*, 1996; Carpenter, Blasier e Pellizzon, 1998; Myers *et al.*, 1999; Iida *et al.*, 2014). Alterações no *feedback* proprioceptivo podem gerar déficits na resposta neuromuscular, aumentando os riscos de lesões no ombro (Myers *et al.*, 1999).

A aplicação de bandagens é amplamente utilizada para auxiliar na reabilitação e prevenção de lesões no ombro (Selkowitz *et al.*, 2007; Hsu *et al.*, 2009; Lin, Hung e Yang, 2011; Van Herzeele *et al.*, 2013; Shaheen, Bull e Alexander, 2014). Kinesio taping (KT) é uma bandagem adesiva elástica, criada na década de 1970, que ganhou grande visibilidade nos Jogos Olímpicos de 2008 e vem sendo cada vez mais utilizada por profissionais de reabilitação e do esporte (Williams *et al.*, 2012; Beutel e Cardone, 2014). Esta bandagem é feita de algodão e acrílico e pode ser alongada longitudinalmente em até 40% do seu comprimento de repouso (Kase, Wallis e Kase, 2003). Quando aplicada com tensão, ela tem uma tendência de retornar ao comprimento original, causando uma tensão contínua sobre a pele, à qual são atribuídos seus possíveis efeitos (Kase, Wallis e Kase, 2003). Tem sido sugerido que a tensão do KT eleva a epiderme, promovendo o aumento da circulação sanguínea e linfática (Pekyavaş *et al.*, 2014); diminuição da dor (Thelen, Dauber e Stoneman, 2008); estímulo dos mecanorreceptores cutâneos, promovendo aumento do *feedback* proprioceptivo (Chang *et al.*, 2010; Lin, Hung e Yang, 2011); e inibição ou facilitação muscular, dependendo do sentido de sua aplicação, da inserção à origem ou da origem à inserção, respectivamente (Huang, Cheng e Lin, 2012; Konishi, 2013).

O uso do KT com diversas finalidades vem aumentando significativamente, bem como o número de estudos investigando seus efeitos, com algumas revisões sistemáticas publicadas (Williams *et al.*, 2012; Kalron e Bar-Sela, 2013; Morris *et al.*, 2013; Csapo e Alegre, 2014; Parreira *et al.*, 2014). Uma revisão sistemática recente concluiu que o KT apresenta nenhum ou pequeno efeito na diminuição da dor quando comparado a técnicas *sham*/placebo (Parreira *et al.*, 2014). Outras revisões incluíram estudos que avaliaram diversos efeitos atribuídos ao KT para tratamento e prevenção de lesões do esporte (Williams *et al.*, 2012) e em condições clínicas, incluindo acometimentos musculoesqueléticos, neurológicos e do sistema linfático (Kalron e Bar-Sela, 2013; Morris *et al.*, 2013). De forma geral, todas concluíram que ainda não há evidências suficientes sobre a eficácia do KT. Recentemente, Csapo et al. (Csapo e Alegre, 2014) publicaram uma meta-análise incluindo 19 estudos sobre o efeito do KT na força muscular. Os autores discutem que, embora o KT não altere significantemente a força muscular, os efeitos na ativação muscular ainda não são claros, com alguns estudos encontrando aumento da ativação após sua aplicação (Słupik *et al.*, 2007; Hsu *et al.*, 2009; Huang *et al.*, 2011; Lin, Hung e Yang, 2011; Csapo *et al.*, 2012; Huang, Cheng e Lin, 2012).

Parece possível que uma alteração na ativação muscular seja benéfica para o adequado controle articular, mesmo que isso não reflita em alterações significativas na força muscular. Embora não estejam claros os efeitos do KT na ativação muscular, tem sido especulado que seu estímulo nos aferentes cutâneos poderia alterar o recrutamento de unidades motoras (Firth *et al.*, 2010; Konishi, 2013). Outro mecanismo sugerido é que a aplicação do KT com tensão no sentido da origem à inserção muscular causa uma tensão na fáscia, estimulando o aumento da contração muscular (Hammer, 2007).

Com relação aos efeitos do KT na propriocepção, os estudos encontrados até o momento apresentam resultados conflitantes, com dados de melhora do senso de posição articular do ombro (Lin, Hung e Yang, 2011) e no senso de força de preensão da mão (Chang *et al.*, 2010), enquanto outro estudo, que avaliou o tornozelo, não identificou mudanças no senso de posição (Halseth *et al.*, 2004). Sendo assim, mais estudos são necessários mais estudos para investigar estes efeitos, atribuídos ao estímulo que a tensão do KT causa nos mecanorreceptores cutâneos (Williams *et al.*, 2012).

Sugere-se que os possíveis efeitos do KT na facilitação muscular e propriocepção poderiam auxiliar a contrabalancear os efeitos que a fadiga muscular causa na cinemática escapular e propriocepção do ombro, contribuindo potencialmente para a prevenção de lesões. Sendo assim, foram desenvolvidos os estudos II e III. O estudo II, intitulado "*Effects of Kinesio taping on scapular kinematics of overhead athletes following muscle fatigue*", investigou os efeitos do KT aplicado sobre o trapézio inferior na cinemática tridimensional da escápula de atletas arremessadores após um protocolo de fadiga. Considerando que os efeitos da fadiga na cinemática escapular são dependentes da tarefa executada (Ebaugh, Mcclure e Karduna, 2006b; Chopp, Fischer e Dickerson, 2011), foi utilizado um protocolo de fadiga constituído por arremessos consecutivos. O estudo III investigou os efeitos do KT no senso de posição articular do ombro após fadiga muscular. Este estudo foi desenvolvido durante o estágio de pesquisa no exterior, no *Orthopaedic Biomechanics Laboratory,* Departamento de Fisiologia Humana da *University of Oregon*, sob orientação do Prof. Dr. Andrew Karduna e resultou no manuscrito intitulado "*Kinesio taping does not reduce fatigue induced deficits in shoulder proprioception*".

Referências

Beutel, B. G., & Cardone, D. A. (2014). Kinesiology taping and the world wide web: a quality and content analysis of internet-based information. *Int J Sports Phys Ther, 9*(5), 665-673.

Borstad, J. D., Szucs, K., & Navalgund, A. (2009). Scapula kinematic alterations following a modified push-up plus task. *Hum Mov Sci, 28*(6), 738-751.

Bowman, T. G., Hart, J. M., McGuire, B. A., Palmieri, R. M., & Ingersoll, C. D. (2006). A functional fatiguing protocol and deceleration time of the shoulder from an internal rotation perturbation. *J Athl Train, 41*(3), 275-279.

Carpenter, J. E., Blasier, R. B., & Pellizzon, G. G. (1998). The effects of muscle fatigue on shoulder joint position sense. *Am J Sports Med, 26*(2), 262-265.

Chang, H. Y., Chou, K. Y., Lin, J. J., Lin, C. F., & Wang, C. H. (2010). Immediate effect of forearm Kinesio taping on maximal grip strength and force sense in healthy collegiate athletes. *Phys Ther Sport, 11*(4), 122-127.

Chopp, J. N., Fischer, S. L., & Dickerson, C. R. (2011). The specificity of fatiguing protocols affects scapular orientation: Implications for subacromial impingement. *Clin Biomech (Bristol, Avon), 26*(1), 40-45.

Cools, A. M., Declercq, G. A., Cambier, D. C., Mahieu, N. N., & Witvrouw, E. E. (2007). Trapezius activity and intramuscular balance during isokinetic exercise in overhead athletes with impingement symptoms. *Scand J Med Sci Sports, 17*(1), 25-33.

Cools, A. M., Witvrouw, E. E., Declercq, G. A., Vanderstraeten, G. G., & Cambier, D. C. (2004). Evaluation of isokinetic force production and associated muscle activity in the scapular rotators during a protraction-retraction movement in overhead athletes with impingement symptoms. *Br J Sports Med, 38*(1), 64-68.

Csapo, R., & Alegre, L. M. (2014). Effects of Kinesio(®) taping on skeletal muscle strength-A meta-analysis of current evidence. *J Sci Med Sport*.

Csapo, R., Herceg, M., Alegre, L. M., Crevenna, R., & Pieber, K. (2012). Do kinaesthetic tapes affect plantarflexor muscle performance? *J Sports Sci, 30*(14), 1513-1519.

Ebaugh, D. D., McClure, P. W., & Karduna, A. R. (2006a). Effects of shoulder muscle fatigue caused by repetitive overhead activities on scapulothoracic and glenohumeral kinematics. *J Electromyogr Kinesiol, 16*(3), 224-235.

Ebaugh, D. D., McClure, P. W., & Karduna, A. R. (2006b). Scapulothoracic and glenohumeral kinematics following an external rotation fatigue protocol. *J Orthop Sports Phys Ther, 36*(8), 557-571.

Fey, A. J., Dorn, C. S., Busch, B. P., Laux, L. A., Hassett, D. R., & Ludewig, P. M. (2007). Potential torque capabilities of the trapezius (Vol. 37, pp. 44A-45A): Journal of Orthopaedic and Sports Physical Therapy.

Firth, B. L., Dingley, P., Davies, E. R., Lewis, J. S., & Alexander, C. M. (2010). The effect of kinesiotape on function, pain, and motoneuronal excitability in healthy people and people with Achilles tendinopathy. *Clin J Sport Med, 20*(6), 416-421.

Halseth, T., McChesney, J. W., Debeliso, M., Vaughn, R., & Lien, J. (2004). The effects of kinesio™ taping on proprioception at the ankle. *J Sports Sci Med, 3*(1), 1-7.

Hammer, W. I. (2007). *Functional Soft-tissue Examination and Treatment by Manual Methods* (3rd ed.). Boston: Jones and Bartlett Publishers

Hsu, Y. H., Chen, W. Y., Lin, H. C., Wang, W. T., & Shih, Y. F. (2009). The effects of taping on scapular kinematics and muscle performance in baseball players with shoulder impingement syndrome. *J Electromyogr Kinesiol, 19*(6), 1092-1099.

Huang, C. Y., Hsieh, T. H., Lu, S. C., & Su, F. C. (2011). Effect of the Kinesio tape to muscle activity and vertical jump performance in healthy inactive people. *Biomed Eng Online, 10*, 70.

Huang, T. S., Cheng, W. C., & Lin, J. J. (2012). Relationship between trapezius muscle activity and typing speed: taping effect. *Ergonomics, 55*(11), 1404-1411.

Iida, N., Kaneko, F., Aoki, N., & Shibata, E. (2014). The effect of fatigued internal rotator and external rotator muscles of the shoulder on the shoulder position sense. *J Electromyogr Kinesiol, 24*(1), 72-77.

Johnson, G., Bogduk, N., Nowitzke, A., & House, D. (1994). Anatomy and actions of the trapezius muscle. *Clin Biomech (Bristol, Avon), 9*(1), 44-50.

Joshi, M., Thigpen, C. A., Bunn, K., Karas, S. G., & Padua, D. A. (2011). Shoulder external rotation fatigue and scapular muscle activation and kinematics in overhead athletes. *J Athl Train, 46*(4), 349-357.

Kalron, A., & Bar-Sela, S. (2013). A systematic review of the effectiveness of Kinesio Taping--fact or fashion? *Eur J Phys Rehabil Med, 49*(5), 699-709.

Kase, K., Wallis, J., & Kase, T. (2003). *Clinical Therapeutic Applications of the Kinesio Taping Method* (2nd ed.). Tokyo, Japan: Ken Ikai.

Kibler, W. B., Kuhn, J. E., Wilk, K., Sciascia, A., Moore, S., Laudner, K., et al. (2013). The disabled throwing shoulder: spectrum of pathology-10-year update. *Arthroscopy, 29*(1), 141-161.e126.

Kibler, W. B., Ludewig, P. M., McClure, P. W., Michener, L. A., Bak, K., & Sciascia, A. D. (2013). Clinical implications of scapular dyskinesis in shoulder injury: the 2013 consensus statement from the 'Scapular Summit'. *Br J Sports Med, 47*(14), 877-885.

Konishi, Y. (2013). Tactile stimulation with kinesiology tape alleviates muscle weakness attributable to attenuation of Ia afferents. *J Sci Med Sport, 16*(1), 45-48.

Lin, J. J., Hung, C. J., & Yang, P. L. (2011). The effects of scapular taping on electromyographic muscle activity and proprioception feedback in healthy shoulders. *J Orthop Res, 29*(1), 53-57.

Ludewig, P. M., & Braman, J. P. (2011). Shoulder impingement: biomechanical considerations in rehabilitation. *Man Ther, 16*(1), 33-39.

Ludewig, P. M., & Cook, T. M. (2000). Alterations in shoulder kinematics and associated muscle activity in people with symptoms of shoulder impingement. *Phys Ther, 80*(3), 276-291.

Ludewig, P. M., Phadke, V., Braman, J. P., Hassett, D. R., Cieminski, C. J., & LaPrade, R. F. (2009). Motion of the shoulder complex during multiplanar humeral elevation. *J Bone Joint Surg Am, 91*(2), 378-389.

Ludewig, P. M., & Reynolds, J. F. (2009). The association of scapular kinematics and glenohumeral joint pathologies. *J Orthop Sports Phys Ther, 39*(2), 90-104.

McQuade, K. J., Dawson, J., & Smidt, G. L. (1998). Scapulothoracic muscle fatigue associated with alterations in scapulohumeral rhythm kinematics during maximum resistive shoulder elevation. *J Orthop Sports Phys Ther, 28*(2), 74-80.

Mercer, S. R. (2002). Surface electrode placement and upper trapezius (Vol. 4, pp. 50-53): European Journal of Physiotherapy.

Morris, D., Jones, D., Ryan, H., & Ryan, C. G. (2013). The clinical effects of Kinesio® Tex taping: A systematic review. *Physiother Theory Pract, 29*(4), 259-270.

Myers, J. B., Guskiewicz, K. M., Schneider, R. A., & Prentice, W. E. (1999). Proprioception and neuromuscular control of the shoulder after muscle fatigue. *J Athl Train, 34*(4), 362-367.

Myers, J. B., & Lephart, S. M. (2000). The role of the sensorimotor system in the athletic shoulder. *J Athl Train, 35*(3), 351-363.

Myers, J. B., Wassinger, C. A., & Lephart, S. M. (2006). Sensorimotor contribution to shoulder stability: effect of injury and rehabilitation. *Man Ther, 11*(3), 197-201.

Nyland, J. A., Caborn, D. N., & Johnson, D. L. (1998). The human glenohumeral joint. A proprioceptive and stability alliance. *Knee Surg Sports Traumatol Arthrosc, 6*(1), 50-61.

Parreira, P. o. C., Costa, L. a. C., Hespanhol Junior, L. C., Lopes, A. D., & Costa, L. O. (2014). Current evidence does not support the use of Kinesio Taping in clinical practice: a systematic review. *J Physiother, 60*(1), 31-39.

Pekyavaş, N. O., Tunay, V. B., Akbayrak, T., Kaya, S., & Karataş, M. (2014). Complex decongestive therapy and taping for patients with postmastectomy lymphedema: A randomized controlled study. *Eur J Oncol Nurs*.

Phadke, V., Camargo, P., & Ludewig, P. (2009). Scapular and rotator cuff muscle activity during arm elevation: A review of normal function and alterations with shoulder impingement. *Rev Bras Fisioter, 13*(1), 1-9.

Riemann, B. L., & Lephart, S. M. (2002a). The sensorimotor system, part I: the physiologic basis of functional joint stability. *J Athl Train, 37*(1), 71-79.

Riemann, B. L., & Lephart, S. M. (2002b). The Sensorimotor System, Part II: The Role of Proprioception in Motor Control and Functional Joint Stability. *J Athl Train, 37*(1), 80-84.

Selkowitz, D. M., Chaney, C., Stuckey, S. J., & Vlad, G. (2007). The effects of scapular taping on the surface electromyographic signal amplitude of shoulder girdle muscles during upper extremity elevation in individuals with suspected shoulder impingement syndrome. *J Orthop Sports Phys Ther, 37*(11), 694-702.

Shaheen, A. F., Bull, A. M., & Alexander, C. M. (2014). Rigid and Elastic taping changes scapular kinematics and pain in subjects with shoulder impingement syndrome; an experimental study. *J Electromyogr Kinesiol*.

Słupik, A., Dwornik, M., Białoszewski, D., & Zych, E. (2007). Effect of Kinesio Taping on bioelectrical activity of vastus medialis muscle. Preliminary report. *Ortop Traumatol Rehabil, 9*(6), 644-651.

Teece, R. M., Lunden, J. B., Lloyd, A. S., Kaiser, A. P., Cieminski, C. J., & Ludewig, P. M. (2008). Three-dimensional acromioclavicular joint motions during elevation of the arm. *J Orthop Sports Phys Ther, 38*(4), 181-190.

Terry, G. C., & Chopp, T. M. (2000). Functional anatomy of the shoulder. *J Athl Train, 35*(3), 248-255.

Thelen, M. D., Dauber, J. A., & Stoneman, P. D. (2008). The clinical efficacy of kinesio tape for shoulder pain: a randomized, double-blinded, clinical trial. *J Orthop Sports Phys Ther, 38*(7), 389-395.

Tripp, B. L., Boswell, L., Gansneder, B. M., & Shultz, S. J. (2004). Functional Fatigue Decreases 3-Dimensional Multijoint Position Reproduction Acuity in the Overhead-Throwing Athlete. *J Athl Train, 39*(4), 316-320.

Tsai, N. T., McClure, P. W., & Karduna, A. R. (2003). Effects of muscle fatigue on 3-dimensional scapular kinematics. *Arch Phys Med Rehabil, 84*(7), 1000-1005.

Van Herzeele, M., van Cingel, R., Maenhout, A., De Mey, K., & Cools, A. (2013). Does the application of kinesiotape change scapular kinematics in healthy female handball players? *Int J Sports Med, 34*(11), 950-955.

Voight, M. L., Hardin, J. A., Blackburn, T. A., Tippett, S., & Canner, G. C. (1996). The effects of muscle fatigue on and the relationship of arm dominance to shoulder proprioception. *J Orthop Sports Phys Ther, 23*(6), 348-352.

Wilk, K. E., Obma, P., Simpson, C. D., Cain, E. L., Dugas, J. R., & Andrews, J. R. (2009). Shoulder injuries in the overhead athlete. *J Orthop Sports Phys Ther, 39*(2), 38-54.

Williams, S., Whatman, C., Hume, P. A., & Sheerin, K. (2012). Kinesio taping in treatment and prevention of sports injuries: a meta-analysis of the evidence for its effectiveness. *Sports Med, 42*(2), 153-164.

Zanca, G. G., Oliveira, A. B., Ansanello, W., Barros, F. C., & Mattiello, S. M. (2014). EMG of upper trapezius - Electrode sites and association with clavicular kinematics. *J Electromyogr Kinesiol, 24*(6), 868-874.

ESTUDO I

EMG OF UPPER TRAPEZIUS − ELECTRODE SITES AND ASSOCIATION WITH CLAVICULAR KINEMATICS

Artigo publicado no periódico *Journal of Electromyography and Kinesiology*

Síntese

O trapézio superior tem sido amplamente estudado e o aumento de sua ativação relacionado a alterações na cinemática clavicular em sujeitos com disfunções de ombro. Entretanto, o posicionamento de eletrodo mais utilizado para capturar a eletromiografia (EMG) do trapézio superior é no ponto médio entre C7 e o acrômio, posicionando o eletrodo sobre as fibras que se inserem no acrômio ao invés das fibras claviculares. Sendo assim, o objetivo deste estudo foi investigar a relação entre os movimentos de elevação e retração da clavícula e o sinal EMG capturado em três posicionamento de eletrodo: o posicionamento tradicional (segundo as recomendações do SENIAM) e dois posicionamentos propostos na literatura para a avaliação das fibras claviculares (um entre o occípito e C7, no nível de C3; e outro 20% lateral ao ponto médio entre C3 e o ponto mais lateral da clavícula). Além disso, este estudo também teve como objetivo secundário determinar a posição que gera maior amplitude de ativação EMG durante contrações isométricas voluntárias máximas (CIVM), para cada posicionamento de eletrodo, para ser utilizada para normalização do sinal. O sinal EMG foi captado simultaneamente nos três posicionamentos de eletrodo em 20 sujeitos saudáveis, durante CIVM em cinco posições diferentes e durante os movimentos de elevação do ombro e abdução do braço no plano da escápula. A cinemática da clavícula foi avaliada utilizando um sistema de rastreamento eletromagnético durante as contrações dinâmicas. A posição de abdução do ombro com rotação contralateral e inclinação ipsilateral da cabeça apresentou o maior pico de ativação EMG nos três posicionamentos de eletrodo durante as CIVM e foi utilizada para a normalização do sinal coletado durante os movimentos. A análise de correlação cruzada entre o sinal EMG e a cinemática clavicular apresentou altas correlações entre todos os posicionamentos de eletrodos e os movimentos da clavícula. Entretanto, o posicionamento tradicional, entre C7 e o acrômio, parece capturar um sinal mais informativo em sujeitos saudáveis.

Abstract

The upper trapezius (UT) has been widely studied and related to alterations in clavicular kinematics in subject with shoulder disorders. However, the most common electrode site used to capture UT EMG is between C7 and the acromion, placing the electrodes over the acromial fibers rather than clavicular ones. Therefore, this study aimed to investigate the relationship between clavicular movements (elevation and retraction) and UT EMG recorded from three electrode sites (traditional electrode positioning and two different sites proposed for clavicular fibers evaluation). Furthermore, the position associated with the highest EMG during maximal isometric voluntary contractions (MVIC), for each electrode site, was determined for normalization purposes. EMG was simultaneously captured in the three electrode sites of 20 healthy subjects, during MVIC at five different positions and during shoulder elevation and abduction in scapular plane. Clavicular kinematics was recorded using an electromagnetic tracking system during the dynamic contractions. Shoulder abduction with head rotation and lateral flexion elicited the highest EMG amplitude on the three electrode sites and was used to normalize the signals. A cross-correlation analysis showed high correlations between all electrode sites and clavicular movements. However, the traditional electrode site seems to record more informative signals in healthy subjects.

1. Introduction

The trapezius muscle has been widely studied, considering its important role in shoulder stabilization (Phadke et al., 2009). This muscle is typically divided into three different portions: the upper trapezius, that originates from the superior nuchal line to the ligamentum nuchae above C7 spinal process and attaches the posterior border of the distal third of the clavicle; the middle trapezius, that originates at C7 and T1 spinal process and inserts on acromion and the spine of the scapula; and the lower trapezius, that comprises the fascicles originated from spinal processes below T1 and inserted in the deltoid tubercle of the scapula (Johnson et al., 1994).

Due to its insertion on the distal clavicle, the upper trapezius has a torque capability to produce clavicular elevation and retraction relative to the thorax (Johnson et al., 1994; Fey et al., 2007). Considering that clavicle is a rigid structure, all movements occurring at the sternoclavicular joint influence the movements of the scapula relative to the thorax. The coupled movements of scapula and clavicle were described by Teece et al. (2008). Since the scapula is positioned at 60º of internal rotation relative to the clavicle (Ludewig et al., 2009), when the clavicle is elevated, 1/3 of the motion results in scapulothoracic upward rotation and 2/3 results in scapulothoracic anterior tilt (Teece et al., 2008). For this reason, the increased electromyographic (EMG) activity of the upper trapezius found in subjects with shoulder impingement (Ludewig and Cook, 2000; Cools et al., 2004, 2007) has been related to the increase in clavicular elevation and, consequently, increased scapular anterior tilt observed in these patients (Ludewig and Braman, 2011).

The above mentioned studies have captured the surface EMG signal on the line between the acromion and C7 spinous process, which has been widely used in the literature and recommended by SENIAM (Hermens et al., 2000). However, a dissection study demonstrated that this positioning results in the electrodes being placed over the trapezius fibers inserted on the acromion (Mercer, 2002). Therefore, for a better understanding of the alterations in upper trapezius activation and their relationship with clavicular movements, it would be important to consider the electrical signal generated also from the fibers inserted on clavicle. Two different electrode positioning were used by previous studies to record EMG from trapezius fibers inserted on clavicle (Johnson and Pandyan, 2005; Holtermann et al., 2009; Szucs and Borstad, 2013). However, these studies had different purposes than investigating the relationship between upper trapezius activation and clavicular movements. Therefore, it is still unknown if the electrical activity captured on those sites does relate with the clavicular movements.

Thus, the objective of this study was to investigate the relationship between clavicular elevation and retraction recorded during shoulder abduction and elevation movements and EMG recorded on three electrode sites (two positions described for trapezius clavicular portion and the traditional location, between C7 and the acromion). Furthermore, considering the importance of an adequate normalization procedure for EMG analysis (De Luca, 1997), this study also aimed to determine the position that elicits the highest EMG during maximal isometric voluntary contractions (MVIC) in each electrode site.

2. Methods

2.1. Participants

Twenty healthy subjects (10male and 10 female) were evaluated. Mean age (± standard deviation) for the participants was 23.84±2.57 years, mean stature was 1.62±3.9m and mean body mass was 67.9±13.2 kg. The participants presented no shoulder or neck pain, had normal shoulder range of motion, no history of surgery in the upper limbs or neurological disease. This study was approved by the Ethics Committee of the University and was conducted according to the Helsinki Statement. All participants signed an informed consent to participate.

2.2. Instrumentation

Surface EMG data was collected using an8-channel Bagnoli EMG System (DelSys, Boston, USA),which provided voltage gain of 1000, bandwidth of 20–450 Hz, and noise ≤1.2 μV (RMS). Active double differential electrodes (#DE 3.1, DelSys, Boston, USA), with three parallel bars (1 mm x 1 cm) geometry, 1 cm of distance between them, and contact material composed of 99.9% Ag were used. The electrodes had input impedance of 10^{15} ohms in parallel, with 0.2 pF; common mode rejection ratio of 92 dB; noise ≤1.2 uV (RMS); and preamplifier gain of 10. The EMG system was interfaced with a computer via a 16-channel, 12-bit A/D card (Computer Boards, Inc., Middleboro, MA) and recorded using the MotionMonitor software (Innovative Sports Training, Chicago IL, USA). The sampling rate was set at 2000 Hz per channel.

Three-dimensional kinematics data from the thorax, clavicle and humerus were collected at 100 Hz with the Flock of Birds electromagnetic tracking system (Ascension Technology Corporation, Burlington, VT) integrated with the Motion Monitor software. The manufacturer has reported an accuracy (root-mean-square, RMS) of 0.15° for orientation and 0.8 mm for position within 76 cm of the transmitter.

2.3. Procedures

The EMG surface electrodes were placed on three sites (Fig. 1-A). The electrode 1 (E1) was placed according to the SENIAM recommendations (Hermes et al., 1999), at midway between C7 spinous process and the acromion. The electrode 2 (E2) was located between the occiput and C7, at the level of C3 (Johnson and Pandyan, 2005). The position of the electrode 3 (E3) was based on the study of Holtermann et al. (2009). They described the electrode site as at the main superior muscle bulk, 20% lateral to the midpoint between the origin and insertion of the muscle fibers. Considering that the origin of the clavicular portion of the trapezius muscle extends from the superior nuchal line to the level of the C6 spinous process (Johnson et al., 1994), this electrode was positioned at 20% lateral to the midpoint between C3 and the most lateral point of the clavicle. The positioning was confirmed by asking the subject to elevate the shoulder against manual resistance while the examiner palpated to check if the electrode was located on the muscle bulk.

The electrodes were positioned with the bars perpendicular to the muscle fibers, using double sided adhesive interfaces (DelSys, Boston, USA). Before electrode fixation, the skin was shaved and cleaned with alcohol in order to reduce resistance and ensure good signal conduction. A reference electrode was positioned on the contralateral wrist.

Five positions previously described in the literature to perform MVIC for EMG normalization of upper trapezius (McLean et al., 2003; Ekstrom et al., 2005; Holtermann et al., 2009) were tested (Figure 1B-F), in order to determine which position would elicit the highest amplitude of activation at each electrode site. For all positions, participants were seated and performed three MVIC (5-s each) against manual resistance of the examiner while received standardized verbal encouragement. Before recording the first MVIC trial at each position, the participants received an explanation about the positioning and the direction they should exert maximal effort. After that, a familiarization trial was performed in order to verify the participants' understanding about the procedures. There was 1-min rest between the contractions, and the order was randomized for each participant.

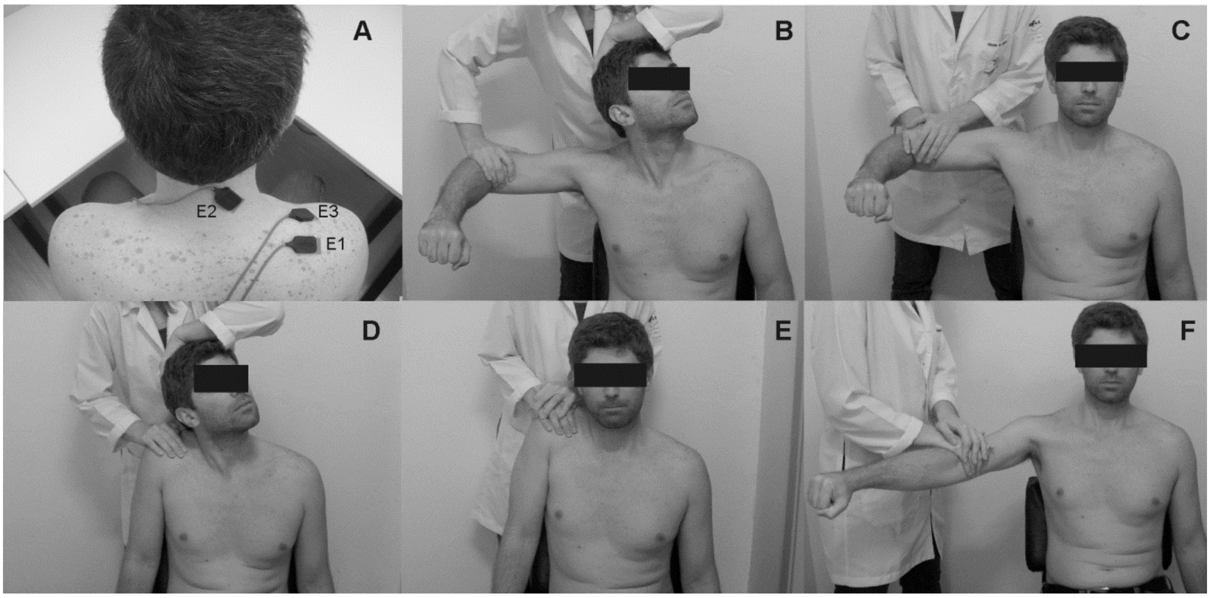

Fig. 1 Electrode sites (A), and the positions used to test maximal isometric contractions: shoulder abduction with head rotation and lateral flexion (B); shoulder abduction (C); shoulder elevation with head rotation and lateral flexion (D); shoulder elevation (E); and scaption (F).

After MVIC recordings, the sensors for kinematics evaluation were placed on specific anatomical segments using adhesive tape. The first sensor was placed on sternum, just inferior to sternal notch; the second one, on the medial and most prominent portion of the clavicle; and the third one was fixed on a thermoplastic cuff and attached to the distal humerus using a Velcro® strap. A fourth sensor was attached to a stylus used to palpate and digitize the anatomical landmarks, in order to determine the anatomical coordinate systems following the International Society of Biomechanics recommendations (Wu et al., 2005). For the thorax, the anatomical landmarks were C7 and T8 spinous processes, sternal notch and xiphoid process. For the clavicle, superior and inferior sternoclavicular joint and posterior and anterior acromioclavicular joint landmarks were used to define the long axis. A third point, necessary to create a vertical plane, was digitized using a plastic made triangle, with adjustable length (Ludewig et al., 2004). Landmarks for the humerus were medial and lateral epycondiles and the center of the humeral head, estimated by rotating the arm passively in 20 different positions (An et al., 1990).

Participants were evaluated in standing position, during arm elevation in scapular plane and shoulder elevation movements. The movements were performed in approximately 3 s, from the start position to the maximum range of motion, following verbal time cues of the examiner. For shoulder abduction, scapular plane was determined as 45º anterior to the frontal plane, with the humerus at 90º of abduction in relation to the thorax. The plane of movement was guided by a wood apparatus, where the participants were instructed to maintain light touch of the fingers, with the elbow extended and the thumb pointing up. For the shoulder elevation movements, participants were instructed to raise their shoulder slowly, with the arm besides the trunk. This movement was evaluated aiming to emphasizes the clavicular elevation movement.

2.4. Data processing

EMG data were processed using a customized program generated in MatLab software (version 7.6.0, MathWorks Inc., Natick, USA). The EMG signals were band-pass filtered from 30 Hz to 450 Hz, with a fourth order, zero-lag, Butterworth filter. Band-stop filters were applied at 60 Hz and harmonics, in order to reduce the main noise artifact from the electromagnetic tracking system (Hsu et al., 2009; Phadke and Ludewig, 2013).

The analyses of the MVIC were performed excluding the first and the last second, in a 3-s window. Root mean square (RMS) was calculated using a 20-ms moving window with 50% overlap. Noise subtraction was performed by calculating the square root of the squared measured EMG amplitude minus the squared amplitude of the noise (Hansson et al., 1997). The highest RMS was determined from each MVIC trial and used for statistical analysis.

The movements of the clavicle and the humerus relative to the thorax were described following the ISB recommendations (Wu et al., 2005). Clavicular movements were described using a Cardan angle sequence of protraction/retraction about the y-axis and elevation/depression about the x-axis, and long-axis rotation about the z-axis.The humeral movements were described using an Euler angle sequence, with humeral rotation about the thoracic y-axis to define the plane of elevation; elevation about the humeral x-axis, and internal/external rotation about the humeral y-axis.

2.5. Data analyses

Statistical analyses were performed using SPSS for Windows 17.0 software (SPSS Inc, Chicago, IL, USA), considering a significance level of 5%, with Bonferroni correction when necessary. The intraclass correlation coefficient (ICC 3,1) was calculated in order to determine the same day trial-to-trial reliability for each evaluated position of MVIC. Repeated-measures ANOVA were conducted to compare the peak EMG amplitude among the five MVIC positions. In the presence of significant difference, Tukey's post hoc test was performed for pairwise comparison. The criteria used to determine the best MVIC position for EMG normalization was based on the study of Ekstrom et al. (2005): the position should elicit the highest EMG amplitude (statistically significant) and have high test-retest reliability (ICC>0.80). When more than one position attended these criteria, the position which elicited the maximum activation for the majority of the subjects was considered for normalization purposes. Following the determination of the best MVIC position for each electrode site, the correspondent peak RMS was used to normalize the signal captured during the movements.

A zero-lag cross-correlation analysis was applied, using Matlab, to verify the relationship between clavicular elevation and retraction movements and the EMG activation (RMS) for each electrode site, during the movements of shoulder abduction and shoulder elevation. The mean and peak of normalized RMS from each electrode site were compared between shoulder abduction and elevation movements using Wilcoxon tests. The RMS was also compared between the electrode sites, for each movement, using Kruskal-Wallis one-way analysis of variance on ranks, followed by Mann–Whitney tests with Bonferroni correction for multiple comparisons. The range of motion of clavicular elevation and retraction were compared between shoulder elevation and abduction using paired *t*-tests.

3. Results

3.1. Maximal isometric voluntary contractions

Table 1 shows the results from MVIC at the five tested positions. For E1, the three positions with shoulder abduction presented the highest peak RMS compared to those with shoulder elevation ($p<0.001$), with no difference between them ($p>0.05$). Fifty five percent of the subjects presented the maximal activation at shoulder abduction with head rotation and lateral flexion, 15% at shoulder abduction and 30% at shoulder abduction in scapular plane. The highest EMG amplitude for E2 was observed at both positions with head rotation and lateral flexion ($p<0.01$ when compared to the other positions), combined either with shoulder abduction (75% of the participants) or elevation (20% of the participants). For E3, shoulder abduction with head rotation and lateral flexion presented the highest EMG amplitude ($p<0.05$) and 50% of the participants presented the peak RMS at this position. The test-retest reliability was high for all of the above-cited positions. Therefore, considering that shoulder abduction with head rotation and lateral flexion elicited significantly higher activation at the three electrode positions and the peak RMS for the majority of the participants, it was considered the best position to normalize the EMG signal for all the electrode sites.

Table 1
Mean peak RMS (mV) and the corresponding values normalized by the MVIC; percentage of subjects in which the maximum EMG amplitude was obtained; and test–retest reliability for the three electrode sites.

	Shoulder abduction with head rotation and lateral flexion	**Shoulder abduction**	**Shoulder elevation with head rotation and lateral flexion**	**Shoulder elevation**	**Shoulder abduction in scapular plane**
Electrode 1					
Mean peak RMS (SD)	3.67 (0.93) [a]	3.59 (1.03) [a]	2.58 (0.98) [b]	3.19 (1.08)	3.63 (1.11) [a]
% MVIC (SD)	89.56 (5.55)	85.97 (9.71)	60.12 (14.97)	73.05 (114.74)	87.08 (9.97)
% Subjects with maximum RMS	55	15	0	0	30
ICC	0.93	0.94	0.95	0.91	0.93
Electrode 2					
Mean peak RMS (SD)	2.20 (1.01) [a]	1.38 (0.85)	1.86 (0.99) [a]	1.27 (0.97)	1.44 (0.85)
% MVIC (SD)	88.75 (7.37)	52.47 (19.74)	70.73 (17.12)	45.38 (20.56)	52.76 (18.57)
% Subjects with maximum RMS	75	0	20	0	5
ICC	0.89	0.92	0.90	0.96	0.73
Electrode 3					
Mean peak RMS (SD)	3.30 (0.75) [c]	2.90 (0.82)	2.76 (0.98)	2.65 (1.01)	2.85 (0.88)
% MVIC (SD)	90.82 (5.53)	78.55 (15.44)	70.99 (19.94)	67.99 (19.36)	75.94 (15.33)
% Subjects with maximum RMS	50	25	10	10	5
ICC	0.94	0.93	0.88	0.93	0.89

[a] Highest RMS compared to the other positions ($p<0.05$), with no difference between them ($p>0.05$).
[b] Lowest RMS compared to the other positions ($p<0.05$).
[c] Highest RMS compared to the other positions ($p<0.05$).

3.2. EMG and kinematics during shoulder abduction and elevation movements

Figure 2 presents typical data of EMG activation and clavicular kinematics from a representative subject. Cross-correlation between EMG and clavicular elevation and retraction was high or very high for all electrode sites (Table 2). The EMG amplitude captured at E1 was the highest, followed by E3 and E2 ($p<0.001$), for both shoulder abduction and elevation movements. Peak RMS from all electrode sites was higher during shoulder elevation than during shoulder abduction, with no difference for the mean RMS (Table 3).

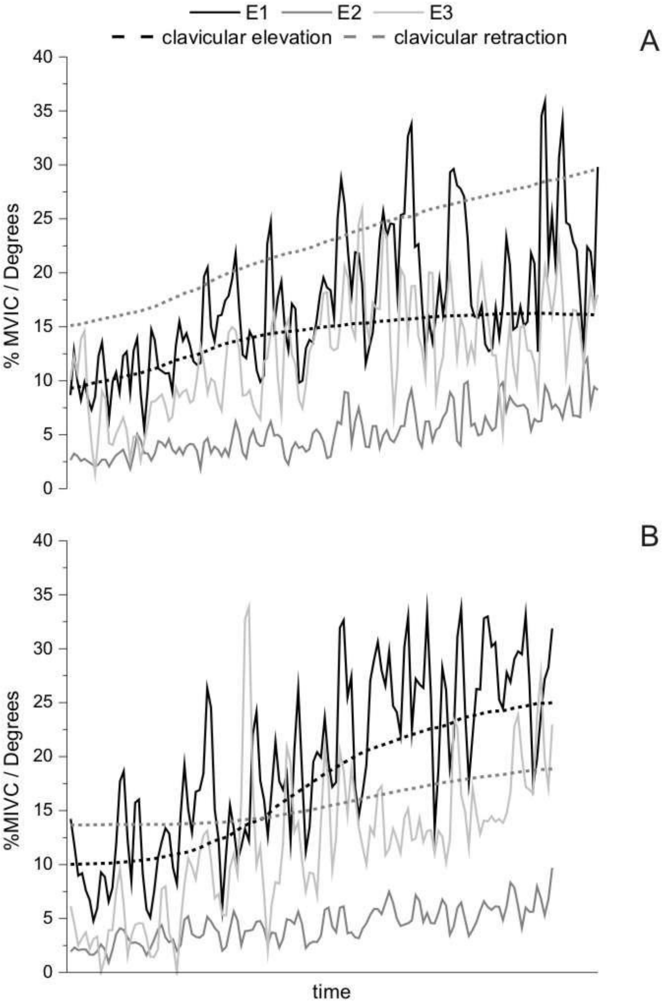

Fig. 2 Data of upper trapezius EMG activity at the three electrode sites and clavicular elevation and retraction movements from one representative subject during shoulder abduction in scapular plane (A) and shoulder elevation (B).

Table 2

Median (25% - 75%) values of cross-correlation coefficients between the EMG amplitude (RMS) obtained at each electrode site and the movements of clavicular elevation and retraction, during shoulder abduction in scapular plane and shoulder elevation.

	Electrode 1	**Electrode 2**	**Electrode 3**
Shoulder abduction			
Clavicular elevation	0.95 (0.88 - 0.96)	0.92 (0.87 - 0.95)	0.90 (0.88 - 0.92)
Clavicular retraction	0.95 (0.94 - 0.96)	0.95 (0.93 - 0.96)	0.93 (0.88 - 0.95)
Shoulder elevation			
Clavicular elevation	0.89 (0.86 - 0.92)	0.90 (0.88 - 0.91)	0.86 (0.81 - 0.91)
Clavicular retraction	0.80 (0.78 - 0.86)	0.86 (0.78 - 0.91)	0.75 (0.68 - 0.82)

Table 3
Median (25% - 75%) values of mean and peak RMS (% MVIC) obtained during shoulder abduction in scapular plane and shoulder elevation, for the three electrode sites.

	Electrode 1	**Electrode 2**	**Electrode 3**
Mean RMS[a]			
Abduction	24.32 (17.55 - 35.06)	8.45 (5.92 - 10.71)	15.51 (9.25 - 19.48)
Elevation	21.16 (13.52 - 27.67)	8.16 (6.21 - 10.31)	11.44 (6.91 - 18.26)
Peak RMS[a, b]			
Abduction	51.86 (40.99 - 64.54)	20.19 (13.53 - 26.87)	38.81 (26.61 - 47.99)
Elevation	57.84 (46.52 - 75.15)	22.98 (16.88 - 34.35)	41.05 (26.32 - 62.62)

[a] Significant differences between the three electrode sites for both movements ($p<0.017$).
[b] Peak RMS higher during elevation than abduction for all electrode sites ($p<0.05$).

Clavicular range of motion was different between the evaluated movements ($p<0.001$). The range of clavicular retraction was higher during shoulder abduction (15.17±6.31°) than during shoulder elevation (4.49±4.75°), while clavicular elevation was higher during shoulder elevation (19.99±7.03°) than abduction (4.30±2.98°) ($p<0.05$).

4. Discussion

The results of this study showed high correlations between the EMG signal from the three evaluated electrode sites and clavicular elevation and retraction, indicating that all upper trapezius portions are involved in clavicular movements. Johnson et al. (1994) described that all the fascicles from occiput to C7 are inserted transversely on the lateral clavicle or acromion and therefore cannot directly elevate the clavicle, by suspension. However, fibers inserted on clavicle can exert a medial moment about the sternoclavicular joint and elevate the clavicle and scapula by clavicular upward rotation (Johnson et al., 1994). Johnson and Padyan (2005) suggested that due to their size, the action of the uppermost fibers (E2) would have a minor biomechanical importance, while the acromial fibers (E1) could contribute to clavicular elevation also by producing a moment about the sternoclavicular joint.

The upper trapezius has been considered to have functional and neuromuscular subdivisions (Lindman et al., 1990; Jensen et al., 1996; Holtermann et al., 2009). Lindman et al. (1990) showed that the lower portion of upper trapezius present more fibers type I than the occiptal and clavicular portions, which could be considered respectively correspondent to the E2 and E3 sites in the present study. Jensen et al. (1996) found different EMG activation levels on three electrode sites, one at the line between C7 and the acromion, one anterior and one posterior to that, during maximal isometric contractions.

Although the findings from dynamic contractions shows the same relationship between all electrode sites and clavicular movements, the findings from MVIC trials are consistent with the concept of functional subdivisions of upper trapezius. While shoulder abduction with head rotation and lateral flexion was considered the best position for EMG normalization of all the electrode sites, there were some specificities for each of them, mainly between the electrode sites proposed to evaluate fibers inserted on clavicle (E2 and E3). The highest amplitude at E2 was captured at positions with head rotation and lateral flexion, independent of the arm position. Considering its location, E2 may have captured electrical activity mainly from the fascicles originated from the superior nuchal line to C3. These fascicles present a small volume and cross-sectional area (Johnson et al., 1994) and, therefore, may be more related to head movement control (Lindman et al., 1990). This may also explain the lowest activity recorded by E2 during the dynamic shoulder abduction and elevation compared to the other electrode sites. Since during these evaluations the participants' head was in neutral position, these fibers might not be highly involved, acting only isometrically to maintain head posture.

For E3, shoulder abduction with head rotation and lateral flexion elicited the highest EMG activation among the five MVIC positions. This electrode may have captured the signal from all fascicles of the uppermost trapezius, including the fascicles originated from C3 to C6, which can contribute in a greater proportion to clavicle elevation and retraction due to their larger cross-sectional area (Johnson et al., 1994). During shoulder elevation, the predominant clavicular movement is the elevation. However, when the shoulder is abducted to 90º, besides elevating the clavicle also retracts (Ludewig et al., 2009). As both clavicular retraction and elevation are directly and indirectly produced by the trapezius clavicular portion, respectively (Johnson et al., 1994), this can explain the highest EMG amplitude elicited at this position.

Regarding E1, there was no difference in peak RMS between the three MVIC positions at shoulder abduction, although the highest amplitude for the majority of the participants occurred at abduction associated with head rotation and lateral flexion, corroborating with a previous study (Ekstrom et al., 2005). Conversely, shoulder elevation with head rotation and lateral flexion, traditionally described as the manual muscle test for the upper trapezius (Kendall et al., 2005), presented the lowest EMG amplitude for the E1.

The different results observed in isometric and dynamic testing may be related to inherent differences between the two contractions. During dynamic contractions, the muscle fibers length changes, consequently changing the source of the EMG signal, since the surface electrode is fixed on the skin, which does not change in length during muscle contraction (De Luca, 1997). Furthermore, the isometric contractions were performed in maximal effort, while the dynamic ones were at submaximal effort. These differences may result in distinct recruitment patterns.

The E1 recorded the highest activity for both dynamic contractions. The anatomical line of action of the acromial fibers of the trapezius was described as ideally suited for scapular stabilization, by offsetting the lateral translation caused by the serratus anterior muscle (Johnson et al., 1994). Therefore, it could be expected to find a higher recording at E1 during shoulder abduction. However, the peak RMS was higher during shoulder elevation, for all electrode sites. A trend of a greater activity of the acromial fibers during shrugging and less during shoulder abduction and adduction was also found by another study, under controlled loading condition (Johnson and Pandyan, 2005). This finding strengthens that the signal captured at E1 may not be influenced by cross-talk from the supraspinatus muscle, since this muscle would present higher activation during shoulder abduction, to stabilize the humeral head. Cross-talk between the trapezius portions should also be considered, but some procedures were adopted to minimize that. Electrodes were positioned according to previous studies (Johnson et al., 2005; Holtermann et al., 2009; Szucs and Borstad, 2013), using double differential electrodes with three parallel bars of 10 mm^2 of detection area and 1 cm of distance between them, to reduce the pick-up area (De Luca, 1997).

It is also important to consider that other mechanisms than muscle activity can contribute to clavicular motions. Ebaugh et al. (2005) have evaluated shoulder kinematics during active and passive arm elevation and found that, despite a small decrease in the amplitude of clavicular retraction and elevation motion, the overall pattern was the same in both conditions. They suggested that mechanisms as the passive tension in the coracoclavicular and acromioclavicular ligaments could contribute to that (Fung et al., 2001).

Overall, the EMG recorded in all electrode sites presented high correlations with clavicular movements, but the fibers inserted on acromion seem to have a major role. This can be due to the greater cross-sectional area of the acromial portion, which can result in greater capacity to exert torque for clavicular elevation, even indirectly (Johnson and Pandyan, 2005). Although the most used electrode positioning is confirmed to represent the activation pattern of the upper portion of trapezius, the EMG activity of trapezius fibers inserted on the clavicle should also be measured, considering that it might present alterations in pathologic conditions, as impingement syndrome. For this purpose, E3 location may be the most adequate, since it may capture the signal from all the fascicles that insert on the clavicle, while E2 seems to be more related to head movements.

5. Conclusion

Although the signal recorded at the three electrode locations presented high correlation with clavicular elevation and retraction, the traditional positioning (between C7 and the acromion) seems to be the best for recording the EMG activity of the upper portion of trapezius muscle in healthy subjects. However, the evaluation of the clavicular portion should not be discarded when investigating subjects in pathologic conditions. Furthermore, the position of shoulder abduction with the contralateral rotation and the ipsilateral flexion of the head was the best one to normalize the signal obtained from all electrode sites, since it elicited the highest activation in the majority of the subjects.

References

An KN, Korinek SL, Kilpela T, Edis S. Kinematic and kinetic analysis of push-up exercise. Biomedical Sciences Instrumentation 1990;26:53-7.

Cools AM, Witvrouw EE, Declercq GA, Vanderstraeten GG, Cambier DC. Evaluation of isokinetic force production and associated muscle activity in the scapular rotators during a protraction-retraction movement in overhead athletes with impingement symptoms. British Journal of Sports Medicine 2004;38(1):64–8.

Cools AM, Declercq GA, Cambier DC, Mahieu NN, Witvrouw EE. Trapezius activity and intramuscular balance during isokinetic exercise in overhead athletes with impingement symptoms. Scandinavian Journal of Medicine & Science in Sports 2007;17(1):25–33.

Ebaugh DD, McClure PW, Karduna AR. Three-dimensional scapulothoracic motion during active and passive arm elevation. Clinical Biomechanics 2005;20(7):700-9.

De Luca C. The use of surface electromyography in biomechanics. Journal of Applied Biomechanics 1997;13(2):135-163.

Ekstrom RA, Soderberg GL, Donatelli RA. Normalization procedures using maximum voluntary isometric contractions for the serratus anterior and trapezius muscles during surface EMG analysis. Journal of Electromyography and Kinesiology 2005;15(4):418-28.

Fey AJ, Dorn CS, Busch BP, Laux LA, Hassett DR, Ludewig PM. Potential torque capabilities of the trapezius [abstract]. Journal of Orthopaedic and Sports Physical Therapy 2007;37(1):A44-5.

Fung M, Kato S, Barrance PJ, Elias JJ, McFarland EG, Nobuhara K, Chao EY. Scapular and clavicular kinematics during humeral elevation: a study with cadavers. Journal of Shoulder and Elbow Surgery 2001;10(3):278–85.

Hansson G-Å, Asterland P, Skerfving S. Acquisition and analysis of whole-dayelectromyographic field recordings. In: Hermens HJ, Hägg G, Freriks B, editors. European applications of surface electromyography. Stockholm: SENIAM /Roessingh Research and Development; 1997:19–27.

Hermens HJ, Freriks B, Disselhorst-Klug C, Rau G. Development of recommendations for SEMG sensors and sensor placement procedures. Journal of Electromyography and Kinesiology 2000;10(5):361–74.

Holtermann A, Roeleveld K, Mork P, Grönlund C, Karlsson J, Andersen L, et al. Selective activation of neuromuscular compartments within the human trapezius muscle. Journal of Electromyography and Kinesiology 2009;19(5):896-902.

Hsu YH, Chen WY, Lin HC, Wang WTJ, Shih YF. The effects of taping on scapular kinematics and muscle performance in baseball players with shoulder impingement syndrome. Journal of Electromyography and Kinesiology 2009;19(6):1092-9.

Jensen C, Westgaard RH. Functional subdivision of the upper trapezius muscle during maximal isometric contractions. Journal of Electromyography and Kinesiology 1995;5(4):227-38.

Johnson G, Bogduk N, Nowitzke A, House D. Anatomy and actions of the trapezius muscle. Clinical Biomechanics 1994;9(1):44-50.

Johnson GR, Pandyan AD. The activity in the three regions of the trapezius under controlled loading conditions − an experimental and modelling study. Clinical Biomechanics 2005;20(2):155-61.

Kendall FP, McCreary EK, Provance PG, Rodgers MM, Romani WA. Muscles: testing and function, with posture and pain. 5th ed. Philadelphia: Lippincott Williams & Wilkins, 2005.

Lindman R, Eriksson A, Thornell LE. Fiber type composition of the human male trapezius muscle: enzyme-histochemical characteristics. The American Journal of Anatomy 1990;189(3):236-44.

Ludewig PM, Behrens SA, Meyer SM, Spoden SM, Wilson LA. Three-dimensional clavicular motion during arm elevation: reliability and descriptive data. Journal of Orthopaedic and Sports Physical Therapy 2004;34(3):140-9.

Ludewig PM, Braman JP. Shoulder impingement: biomechanical considerations in rehabilitation. Manual Therapy 2011;16(1):33-9.

Ludewig PM, Cook TM. Alterations in shoulder kinematics and associated muscle activity in people with symptoms of shoulder impingement. Physical Therapy 2000;80(3):276–91.

Ludewig PM, Phadke V, Braman JP, Hassett DR, Cieminski CJ, LaPrade RF. Motion of the shoulder complex during multiplanar humeral elevation. Journal of Bone and Joint Surgery 2009;91(2):378–89.

McLean L, Chislett M, Keith M, Murphy M, Walton P. The effect of head position, electrode site, movement and smoothing window in the determination of a reliable maximum voluntary activation of the upper trapezius muscle. Journal of Electromyography and Kinesiology 2003;13(2):169–80.

Mercer SR. Surface electrode placement and upper trapezius. European Journal of Physiotherapy 2002;4(2):50-3.

Phadke V, Camargo PR, Ludewig PM. Scapular and rotator cuff muscle function during arm elevation: A review of normal function and alterations with shoulder impingement. Brazilian Journal of Physical Therapy 2009;13(1):1-9.

Phadke V, Ludewid PM. Study of the scapular muscle latency and deactivation time in people with and without shoulder impingement. Journal of Electromyography and Kinesiology 2013;23(2): 469-75.

Szucs KA, Borstad JD. Gender differences between muscle activation and onset timing of the four subdivisions of trapezius during humerothoracic elevation. Human Movement Science 2013; 32(6):1288-98.

Teece RM, Lunden JB, Lloyd AS, Kaiser AP, Cieminski CJ, Ludewig PM. Three-dimensional acromioclavicular joint motions during elevation of the arm. Journal of Orthopaedic and Sports Physical Therapy 2008;38(4):181-90.

Wu G, van der Helm FC, Veeger HE, Makhsous M, Van Roy P, Anglin C, Nagels J, Karduna AR, McQuade K, Wang X, Werner FW, Buchholz B. ISB recommendation on definitions of joint coordinate systems of various joints for the reporting of human joint motion - Part II: shoulder, elbow, wrist and hand. Journal of Biomechanics 2005;38(5):981-92.

ESTUDO II

EFFECTS OF KINESIO TAPING ON SCAPULAR KINEMATICS OF OVERHEAD ATHLETES FOLLOWING MUSCLE FATIGUE

Síntese

A fadiga muscular é considerada um fator potencial para o desenvolvimento de disfunções no ombro de atletas arremessadores. Diversos estudos investigaram os efeitos da fadiga na cinemática escapular, mas seus efeitos dependem da tarefa realizada durante o protocolo de fadiga. Devido à importância do trapézio inferior para o coordenado movimento escapular e sua atuação como sinergista do serrátil anterior, o objetivo deste estudo foi investigar os efeitos de um técnica de KT para facilitar a ação do trapézio inferior na cinemática escapular de atletas arremessadores, após um protocolo de fadiga no movimento de arremesso. Foram avaliados 28 atletas saudáveis, em um desenho cruzado, aleatorizado, com mascaramento do sujeito. Os participantes foram avaliados em três sessões, com uma semana de intervalo entre elas: controle (sem intervenção), KT (KT aplicado com tensão) e *sham* (KT aplicado sem tensão). A cinemática escapular tridimensional foi avaliada utilizando um sistema de rastreamento eletromagnético e o sinal EMG foi coletado nas porções clavicular e acromial do trapézio superior, trapézio inferior e serrátil anterior, durante a elevação do braço no plano da escápula, antes e após o protocolo de fadiga. Nas sessões KT e *sham*, a bandagem foi aplicada antes do protocolo de fadiga e removida após a reavaliação. A diminuição da frequência mediana do serrátil anterior foi significativamente menor na sessão KT comparada à sessão *sham*, indicando uma menor intensidade de fadiga muscular. Entretanto, não houve diferença nos efeitos da fadiga na cinemática escapular entre as sessões. Embora tenham sido encontradas diferenças significativas na cinemática escapular após o protocolo de fadiga, elas foram de pequena amplitude, consideradas sem relevância clínica. Foi concluído que atletas arremessadores saudáveis apresentam um mecanismo de adaptação, não modificando a cinemática escapular mesmo após um protocolo de fadiga intenso e que, portanto, não se beneficiam do uso do KT com o objetivo de auxiliar o movimento escapular.

Abstract

The aim of this study was to investigate the effects of Kinesio taping (KT) applied over the lower trapezius on scapular kinematics of healthy overhead athletes, following a fatigue protocol. Twenty-eight athletes were evaluated in a crossover, single-blind, randomized design, in three sessions: control (no taping), KT (KT with tension) and sham (KT without tension). Scapular tridimensional kinematics and EMG of clavicular and acromial portions of the upper trapezius, lower trapezius and serratus anterior were evaluated during arm elevation and lowering, before and after a fatigue protocol involving repetitive throwing. Median power frequency decline of serratus anterior was significantly lower in the KT session compared to sham, indicating lower muscle fatigue intensity. However, the effects of muscle fatigue on scapular kinematics were not different between taping conditions. Although significant changes were found in scapular kinematics following muscle fatigue, they presented small effect sizes and were not considered relevant. It was concluded that healthy overhead athletes present an adaptive mechanism that prevent scapular movement pattern disruption and, therefore, they do not beneficiate with the use of KT.

1. Introduction

The overhead throwing places high forces in the shoulder complex due to the wide range of motion and high speed that is performed, predisposing overhead athletes to shoulder injuries (Wilk *et al.*, 2009). Proper scapular movement and control is essential to provide a stable basis for humeral movement and adequately transfer the generated kinetic energy from the trunk to the arm during throwing (Sciascia *et al.*, 2012).

The serratus anterior and lower trapezius form an important force couple for coordinated scapular movement. The serratus anterior produces scapular upward rotation, posterior tilting and external rotation (Phadke *et al.*, 2009). The lower trapezius is a scapular external rotator, an important synergist of serratus anterior for scapular upward rotation and promotes scapular medial stabilization, resisting to the lateral displacement caused by serratus anterior action (Johnson *et al.*, 1994; Phadke *et al.*, 2009). Decreased activity of lower trapezius has been found in overhead athletes with impingement symptoms (Cools *et al.*, 2004; Cools *et al.*, 2007) and it may be suggested that it is be related to the increased scapular internal rotation and decreased upward rotation found during arm elevation in subjects with shoulder impingement (Ludewig and Reynolds, 2009). These muscles are highly active during the throwing movement (Escamilla and Andrews, 2009) and, therefore, predisposed to fatigue during competitive and training activities. Several studies have investigated the effects of muscle fatigue on scapular kinematics, but the findings depend on the task performed during the fatigue protocol (Ebaugh *et al.*, 2006b; a; Borstad *et al.*, 2009; Chopp *et al.*, 2011; Joshi *et al.*, 2011). A fatigue protocol simulating overhead throwing could more accurately represent the scapular kinematics alterations caused by fatigue in overhead athletes during sports practice.

Different taping techniques have been proposed to assist scapular function and change muscle activation aiming at shoulder injuries rehabilitation and prevention (Hsu *et al.*, 2009;

Lin *et al.*, 2011; Van Herzeele *et al.*, 2013; Shaheen *et al.*, 2014). Kinesio taping (KT) is a technique that uses an elastic adhesive tape with several purposes, including change of muscle activation, pain relief, increase of blood and lymphatic flow circulation and proprioception improvement (Kase *et al.*, 2003; Williams *et al.*, 2012). KT causes minimal movement restriction and continual skin traction, stimulating cutaneous mechanoreceptors, which has been suggested to drive a facilitatory effect to the muscle (Firth *et al.*, 2010; Konishi, 2013).

Hsu et al (Hsu *et al.*, 2009) have shown that a KT technique for muscle facilitation increased lower trapezius muscle activation during arm lowering and scapular posterior tilt during arm elevation in baseball players with impingement symptoms. Considering these positive effects, we hypothesized that KT for lower trapezius could facilitate this muscle action during throwing, assisting serratus anterior function and minimizing scapular alterations following muscle fatigue, potentially contributing for shoulder injury prevention. Therefore, the purpose of this study was to investigate the effects of KT for lower trapezius facilitation in scapular kinematics and muscle activation of healthy overhead athletes following a fatigue protocol involving the throwing movement.

2. Methods

2.1. Participants

Twenty-eight healthy overhead athletes (19 males and 9 females) with mean (±SD) age 20.7 (±2.5) years, mean height 172 (±11) cm and mean body mass 71 (±13.8) kg, participated in this study. All participants were involved in regular sports training of handball (n=20), baseball (n=4) or softball (n=4) for an average 5.5 (±3.9) years and participated in university-level competitions. Inclusion criteria were participation in regular sports training and no symptoms involving the shoulder. Exclusion criteria were shoulder injuries in the last year, previous shoulder surgery and shoulder dislocation. This study was conducted in agreement with the declaration of Helsinki and approved by the Ethics Committee of the University. Subjects signed an informed consent form.

2.2. Overview of the experiments

This investigation used a repeated-measures, crossover, sham-controlled, single-blind (subject) study design. Participants were evaluated in three sessions: control (no taping), KT (KT with tension) and sham (KT without tension), randomized by a random-number generator. In each session, scapular three-dimensional kinematics and EMG of clavicular and acromial portions of upper trapezius, lower trapezius and serratus anterior of the dominant arm were evaluated during arm elevation in scapular plane, before and after a fatigue protocol. The initial evaluation was performed without taping, in all the sessions. Following that, the taping was applied or not, depending on the session, the subjects performed the fatigue protocol and were reassessed. There was one-week interval between sessions, in order to avoid cumulative effects of the taping (Hsu *et al.*, 2009) or muscle fatigue (Myers *et al.*, 1999). Participants were instructed not to perform upper-body exercises for the 24 hours prior to each session.

2.3. Instrumentation

Surface EMG data were collected using an 8-channel Bagnoli EMG System (DelSys, Boston, USA), which provided voltage gain of 1000, bandwidth of 20–450 Hz and noise ≤1.2 μV (RMS). Active double differential electrodes (#DE 3.1, DelSys, Boston, USA), with three parallel bars (1 mm x 1 cm) geometry, 1 cm of distance between them, and contact material composed of 99.9% Ag were used. The electrodes had input impedance of 10^{15} ohms in parallel, with 0.2 pF; common mode rejection ratio of 92 dB; noise ≤1.2 uV (RMS); and preamplifier gain of 10. The EMG system was interfaced with a computer via a 16-channel, 12-bit A/D card (Computer Boards, Inc., Middleboro, MA) and recorded using the MotionMonitor software (Innovative Sports Training, Chicago IL, USA). The sampling rate was set at 2000 Hz per channel.

Three-dimensional kinematics data from the thorax, scapula and humerus were collected at 100 Hz with the Flock of Birds electromagnetic tracking system (Ascension Technology Corporation, Burlington, VT) integrated with the Motion Monitor software. The manufacturer has reported an accuracy (RMS) of 0.15º for orientation and 0.8 mm for position within 76 cm of the transmitter.

2.4. Procedures

2.4.1. Three-dimensional kinematics and EMG acquisition

The EMG electrodes were positioned perpendicular to muscle fibers, attached to the skin with a double-sided adhesive interface and a strip of Transpore tape. Before electrode positioning, the skin was shaved and cleaned with alcohol in order to reduce resistance and ensure good signal conduction. A reference electrode was positioned on the contralateral wrist. The electrodes for the acromial portion of upper trapezius and lower trapezius were positioned according to the SENIAM recommendations (Hermens *et al.*, 2000), at midway between C7 spinous process and the acromion and at 2/3 on the line from scapular root spine and T8 spinous process, respectively. The electrode for the clavicular portion of upper trapezius was positioned 20% lateral do the midpoint between C3 and the most lateral point of the clavicle (Zanca *et al.*, 2014). The serratus anterior electrode was placed on the level of xiphoid process, in the lateral trunk, 45° rising to dorsal (Anders *et al.*, 2004).

Following electrode positioning, maximal isometric voluntary contractions (MVIC) were performed in order to determine the peak EMG to be used for signal normalization.

Three MVIC of 5 seconds of duration each, with 30-seconds interval between them were performed for each muscle portion. For clavicular and acromial portions of upper trapezius, MVIC were performed with the subjects seated, the dominant arm at 90° of abduction, head rotation to the opposite side and ipsilateral flexion (Ekstrom *et al.*, 2005; Zanca *et al.*, 2014). For lower trapezius, participants were tested in prone, with the arm elevated, aligned with the muscle fibers (Ekstrom *et al.*, 2005). The serratus anterior MVIC were performed at seated position, 90° of arm flexion and resistance applied to scapular protraction (Ekstrom *et al.*, 2005).

The sensors for kinematics evaluation were fixed on specific anatomical segments using double-sided adhesive tape. The first sensor was placed on sternum, just inferior to the sternal notch, the second one on the flat surface of the posterior acromion process, and the third one was fixed on a thermoplastic cuff and attached to the distal humerus using adhesive tape. A fourth sensor was attached to a stylus and used to palpate and digitize the anatomical landmarks, in order to determine the anatomical coordinate systems following the International Society of Biomechanics (ISB) recommendations (Wu *et al.*, 2005). For the thorax, the anatomical landmarks were C7 and T8 spinous processes, sternal notch and xiphoid process. For the scapula, the landmarks were the root of the spine of the scapula, the posterolateral angle of the acromion and the inferior angle of the scapula. Landmarks for the humerus were medial and lateral epycondiles and the center of the humeral head, estimated by rotating the arm passively in 20 different positions, in short arc of motions, to determine the pivot point (An *et al.*, 1990).

For kinematics and EMG data collection, the participants performed three trials of arm elevation in scapular plane, determined as 45° anterior to the frontal plane at 90° of humeral elevation in relation to the thorax. The participants were evaluated in standing position and performed each phase of the movement (arm elevation and lowering, from the start position to the maximum range of motion, returning to the initial position) in approximately 3 seconds, following verbal time cues of the examiner. The plane of movement was guided by a wood apparatus, where the participants were instructed to maintain light touch of the fingers, with the elbow extended and the thumb pointing up.

2.4.2. Taping techniques

In both taping sessions (sham and KT), a Y-shaped strip of Kinesio Tex Gold Standard (Kinesio USA, LLC, Albuquerque, NM), 5 cm width, was applied over the lower trapezius, from origin to insertion (Figure 1) (Hsu *et al.*, 2009). In the KT session, the tape size was measured from T12 spinal process to the root spine of the scapula, while the subject stayed with the arm at the trunk side, relaxed. The base of the tape was applied with the subject at this position, initiating at T12 in the direction to the root spine of the scapula. The subject was then instructed to move the arm into horizontal adduction overhead. At this position, the tape was applied involving the lower trapezius, ending on the root spine of the scapula, with light tension (approximately 25%) (Kase *et al.*, 2003). For the sham application, the tape size was measured with the participant's arm at horizontal adduction overhead and the tape was applied at this same position, with no tension. The subjects were blinded to the intervention they were receiving, only informed that the study was testing two different techniques, with no further details.

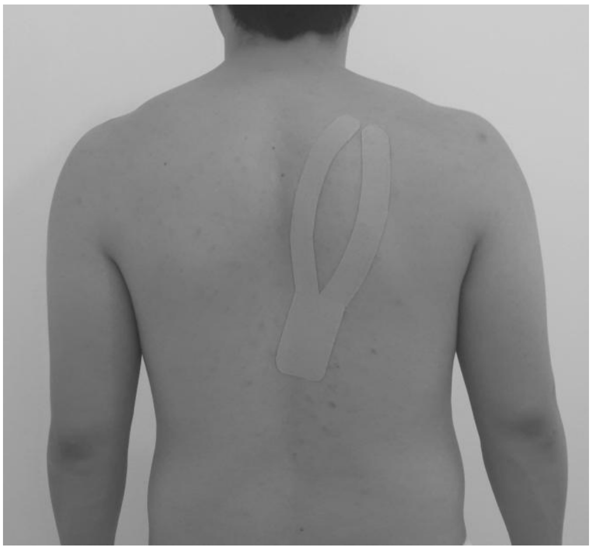

Figure 1. Taping application over the lower trapezius.

2.4.3. EMG fatigue quantification

Immediately before and after the fatigue protocol, the participants performed a submaximal isometric contraction at 90° of shoulder flexion with extended elbow, holding a weighted bag corresponding to 15% MVIC of flexion (Chopp *et al.*, 2011). The MVIC for this purpose was assessed in the first session, using a digital dynamometer model DDK (Kratos, São Paulo, Brazil). Participants performed three MVIC of 5 seconds each, with 1 minute of rest between them. The corresponding 15% MVIC was calculated and the same weight was used in all the sessions.

2.4.4. Fatiguing protocol

The functional fatiguing protocol consisted of consecutive throwing while sitting on a chair, in order to isolate the upper body and ensure shoulder fatigue (Bowman *et al.*, 2006). The athletes were instructed to throw a rubber ball (8 cm of diameter and 80 g of mass) against a wall at approximately 2.5 meters of distance, with enough force and speed to the ball return to their hands.

Before starting the fatigue protocol, the subjects received instructions about the modified Borg's Rate of Perceived Exertion Scale (Borg, 1990). This scale has been used for fatigue determination considering the close relationship between subjective perception and EMG indicatives of muscle fatigue (Hummel *et al.*, 2005). Subjects were asked at each one-minute interval to indicate their level of fatigue on the shoulder and scapular region, in a scale from 0 to 10. The fatigue protocol was interrupted when they reached a rating equal or higher than 8 (Fuller *et al.*, 2009). Subjects were not aware about this criteria.

2.5. Data reduction

The kinematics data were described following the ISB recommendations (Wu *et al.*, 2005). Scapular movements relative to the thorax were described using a Cardan angle sequence of internal/external rotation about the y-axis, upward/downward rotation about the x-axis and anterior/posterior tilt about the z-axis. The humeral movements were described using an Euler angle sequence, with humeral rotation about the thoracic y-axis to define the plane of elevation; elevation about the humeral x-axis, and internal/external rotation about the humeral y-axis. Scapular orientation at humerothoracic elevation angles of 30°, 60°, 90° and 120°, during arm elevation and lowering, was averaged across the three trials, before and after the fatigue protocol. This method present excellent within-day reliability, with standard error of measurement ranging from 1.23° to 1.85° for internal rotation, from 1.58° to 3.07° for upward rotation and from 0.86° to 1.49° for scapular tilting (Haik *et al.*, 2014).

EMG data were processed using a customized program generated in MatLab software (version 7.6.0, MathWorks Inc., Natick, USA). The EMG signals were band-pass filtered from 30 Hz to 450 Hz, with a fourth order, zero-lag, Butterworth filter. Band-stop filters were applied at 60 Hz and harmonics, in order to reduce the main noise artifact originated from the electromagnetic tracking system (Hsu *et al.*, 2009; Zanca *et al.*, 2014).

Root mean square (RMS) was calculated for the MVIC and arm elevation trials as previously described (Zanca *et al.*, 2014). The RMS was averaged in windows of 30° of humerothoracic elevation, from 30° to 120 and expressed as a percentage of peak RMS during MVIC. EMG evaluation of serratus anterior and trapezius present excellent within-day reliability, with standard error of the measure ranging from 1 to 1.7% of MVIC (Seitz and Uhl, 2012).

The median power frequency (MPF) was calculated from EMG collected during the submaximal isometric contractions. Following data filtering, a Fast Fourier Transformation algorithm was applied to the signal from the second to the fourth seconds, in order to establish a power density spectrum. The percent change of MPF for each muscle was determined by subtracting the final MPF from the initial MPF and dividing this value by the initial MPF. A minimum decline of 8% in the MPF has been considered an indicator of local muscle fatigue (Oberg *et al.*, 1990; Ebaugh *et al.*, 2006a; Borstad *et al.*, 2009).

2.6. Data analysis

Statistical analyses were performed using SPSS version 22 (IBM, Chicago, IL). The MPF change and the fatigue protocol duration time were compared between taping conditions using one-way repeated-measures analyses of variance (ANOVA). Three-way repeated-measures ANOVAs were run for arm elevation and lowering, in order to analyze the effects of taping on scapular kinematics and muscle activation, with the within-subject factors: taping condition (KT, sham and control), humeral angle (30º, 60º, 90º e 120º) and time (pre and post fatigue). Mauchly's test of sphericity was performed for all measures and Greenhouse–Geisser correction was used if this assumption was violated. Significance level was set as 5%. When a significant interaction was found, the simple effects were calculated using the Sidak correction for multiple comparisons (Cardinal and Aitken, 2005). The effect size was calculated using Cohen's d statistic, considering ≤0.2 small, 0.5 moderate and >0.8 large (Cohen, 1988).

3. Results

3.1. Muscle fatigue quantification

There was no difference in the fatiguing protocol duration time between sessions (p=0.42), with a mean (± standard error) of 8.8 (±1.1) minutes for the control session, 9.7 (±1.3) minutes for the sham session and 9.2 (±1.4) minutes for the KT session. The MPF decline of serratus anterior was significantly lower in the KT condition compared to the sham (p=0.02; d=0.59; Figure 2). There was no significant difference between taping conditions for MPF change of all the trapezius portions (p>0.05).

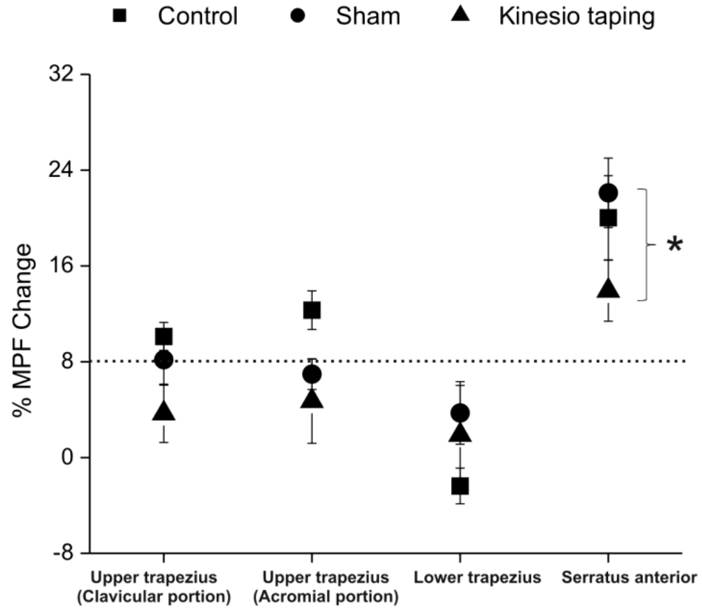

Figure 2. Median power frequency (MPF) percent change following the fatigue protocol, for each taping condition.
The dotted line represent the fatigue threhsold considered (>8% of MPF decline).
*Statistical significance (p=0.02) between sham and Kinesio taping conditions.

3.2. Scapular three-dimensional kinematics

There was no main effect or interaction involving taping ($p>0.05$) (Figure 3). A significant interaction of time by humeral angle was found for upward and internal rotation during arm elevation ($p<0.001$) and for tilting during arm elevation ($p=0.001$) and lowering ($p=0.005$). Simple effects analyses showed significant changes following fatigue for upward rotation at 30°, 90° and 120° of humeral elevation; internal rotation at 30° and 60° of humeral elevation; and for posterior tilting at 30° of humeral elevation during arm elevation and 30° and 60° of humeral elevation during arm lowering (Table 1). A main effect of time was found for internal rotation during arm lowering ($p=0.038$).

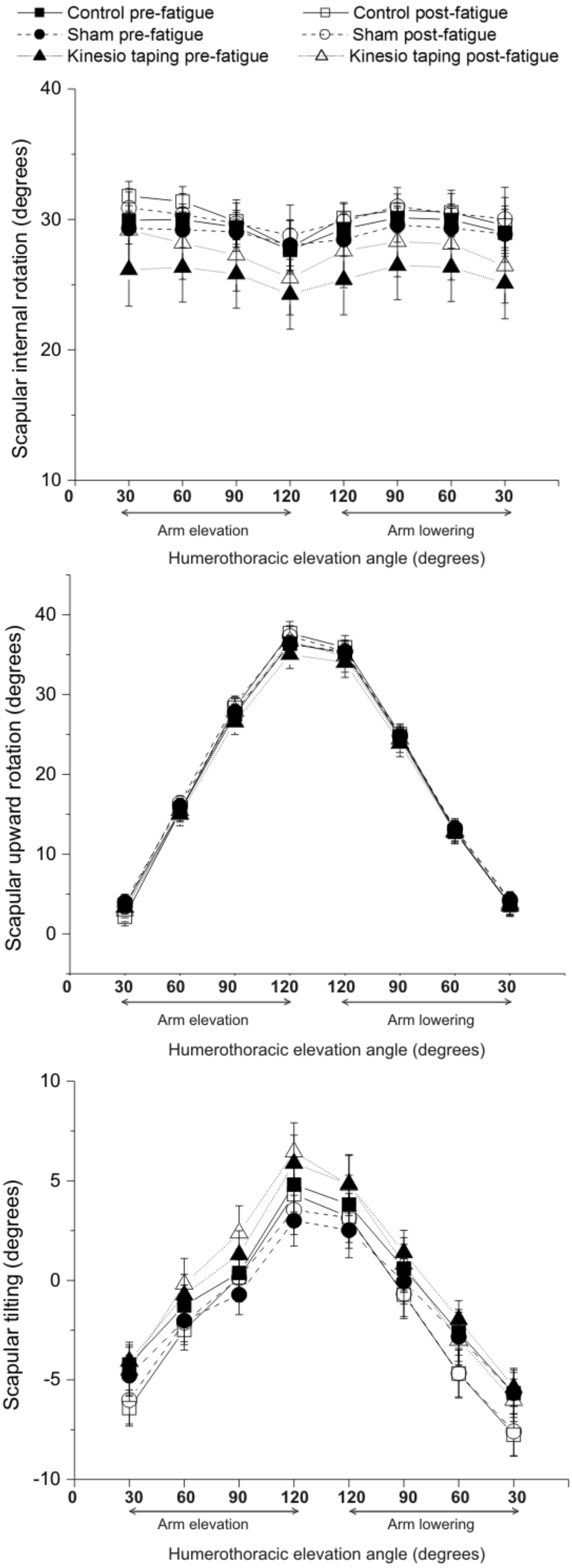

Figure 3. Mean (± standard error) scapular rotations relative to humeral elevation angles, at each taping condition, pre and post fatigue.

Table 1. Mean change (95% confidence interval) of scapular kinematics following the fatigue protocol and Cohen's d effect size.

	Internal rotation		**Upward Rotation**		**Posterior tilting**	
Phase	Mean (95% CI)	d	Mean (95% CI)	d	Mean (95% CI)	d
Elevation						
30°	2.15 (1.27; 3.04)*	0.53	-0.80 (-1.53; -0.06)*	0.24	-1.28 (-2.07; -0.49)*	0.35
60°	1.47 (0.52; 2.42)*	0.34	0.27 (-0.50; 1.03)	0.08	-0.27 (-1.06; 0.53)	0.07
90°	0.85 (-0.20; 1.90)	0.18	1.06 (0.22; 1.90)*	0.27	0.57 (-0.28; 1.42	0.15
120°	0.73 (-0.38; 1.84)	0.14	1.31 (0.36; 2.26)*	0.30	0.21 (-0.68; 1.09)	0.05
Lowering						
120°	1.02 (0; 2.04)[#]	0.22	0.50 (-0.41; 1.40)	0.12	-0.02 (-0.97; 0.93)	<0.01
90°	1.16 (0.20; 2.11)[#]	0.26	0.35 (-0.42; 1.12)	0.10	-0.84 (-1.74; 0.07)	0.20
60°	1.29 (0.35; 2.22)[#]	0.30	0.03 (-0.72; 0.79)	0.01	-1.65 (-2.55; -0.74)*	0.39
30°	1.48 (0.58; 2.38)[#]	0.36	0.04 (-0.68; 0.75)	0.01	-1.55 (-2.44; -0.66)*	0.38

*Significant difference ($p<0.05$) between pre and post fatigue in the simple effect analyses (follow-up for the interaction time by angle).

[#] Significant main effect of time ($p<0.05$).

3.3. Muscle activity

There was no main effect or interaction for taping condition (Figure 4). A significant interaction of time by humeral angle was found for all the muscle portions evaluated. Simple effect analyses showed a significant increase of mean RMS for all the muscle portions following the fatigue protocol, in most of the range of motion (Table 3).

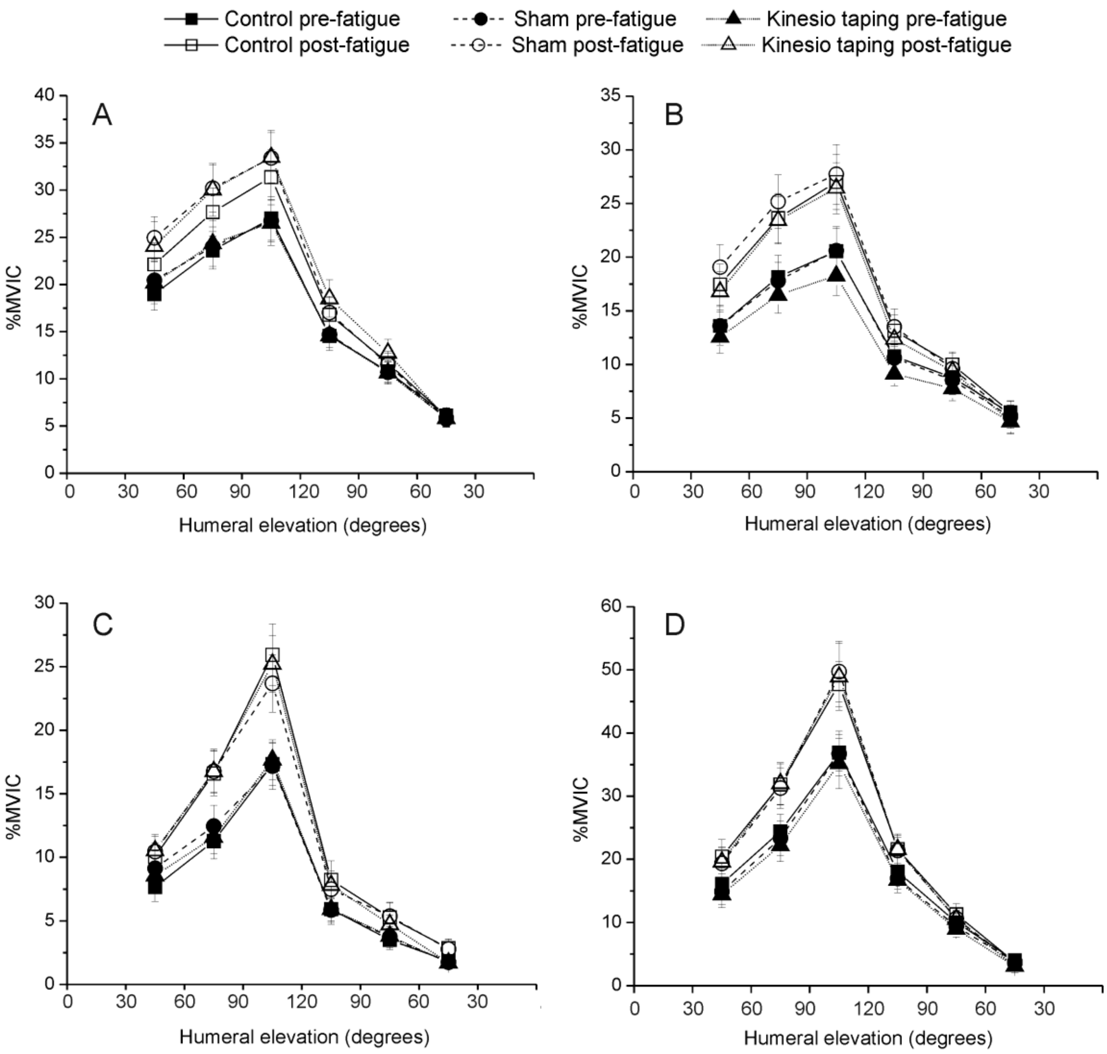

Figure 4. Mean (±standard error) of RMS for (A) acromial portion of upper trapezius, (B) clavicular portion of upper trapezius, (C) lower trapezius and (D) serratus anterior, pre and post fatigue, at each taping condition.

Table 2. Mean change in muscle activation (RMS; %MVIC) following fatigue and Cohen's d effect size for each muscle portion and phase of movement.

	Upper trapezius (clavicular portion)		**Upper trapezius (acromial portion)**		**Lower trapezius**		**Serratus anterior**	
Phase	Mean (95% CI)	d	Mean (95% CI)	d	Mean (95% CI)	d	Mean (95% CI)	d
Elevation								
30°-60°	4.5 (3.3; 5.8)*	0.83	3.8 (2.7; 4.9)*	0.81	1.9 (1.0; 2.8)*	0.45	4.7 (3.5; 5.8)*	0.88
60°-90°	6.6 (5.0; 8.2)*	0.94	5.3 (3.9; 6.7)*	0.85	4.9 (3.7; 6.2)*	0.86	8.4 (6.6; 10.2)*	1.08
90°-120°	7.2 (5.4; 9.1)*	0.91	6.0(4.2; 7.8)*	0.79	7.6 (6.0; 9.1)*	1.08	12.5 (9.8; 15.3)*	1.04
Lowering								
120°-90°	2.3 (0.8; 3.7)*	0.35	2.8 (1.9; 3.7)*	0.72	1.9 (1.0; 2.9)*	0.45	4.3 (3.0; 5.6)*	0.76
90°-60°	1.3 (-0.1; 2.6)	0.21	1.3 (0.5; 2.0)*	0.40	1.4 (0.6; 2.2)*	0.40	1.4 (0.4; 2.4)*	0.31
60°-30°	1.1 (-0.5; 2.8)	0.16	0.1 (-0.5; 0.7)	0.04	0.8 (0.2; 1.4)	0.29	0.1 (-0.9; 1.0)	0.02

*Significant difference ($p<0.05$) between pre and post fatigue in the simple effect analyses (follow-up for the interaction time by angle).

4. Discussion

The hypothesis of this study was partially confirmed, since the serratus anterior presented a lower MPF decline in the KT condition compared to sham, indicating a lower intensity of local muscle fatigue (De Luca, 1984). The sham application used the same material, but no tension was applied, removing the main characteristic of the KT technique. Therefore, the difference found between the taping conditions may be attributed to the recoil effect of KT and its continuous traction on the skin. Previous studies have suggested that cutaneous afferent stimulation provided by KT might change motor unit recruitment (Firth *et al.*, 2010; Konishi, 2013). However, the mechanism that caused a lower fatigue intensity of serratus anterior remains to be elucidated. It could be speculated that KT did facilitate lower trapezius, as occurred in a previous study (Hsu *et al.*, 2009). However, it is not possible to affirm that, since there was no effect of taping condition on muscle activation during arm elevation and EMG was not recorded during the fatigue protocol. It is important to note that, although the fatigue intensity of serratus anterior was lower in KT condition, the mean MPF decline was greater than 8% in all the sessions, i.e., KT did not prevent fatigue development.

Despite the effect on serratus anterior fatigue, there was no effect of taping on scapular kinematics, which presented alterations following muscle fatigue in all sessions. Although statistically significant, these changes presented small effect sizes, except internal rotation at 30° of humeral elevation, which presented a moderate effect size. Furthermore, the mean changes between pre and post fatigue were smaller or very close to the within-day error of measurement reported for scapular kinematics assessment using the same equipment of the present study (Haik *et al.*, 2014). Therefore, these alterations may not be considered relevant. This is an unexpected finding, considering that the fatigue protocol was very intense compared to the actual sport practice of these athletes. The protocol was consisted of consecutive throwing and limited the use of the kinetic chain, imposing higher demand to the shoulder.

Other studies have found none or small alterations in scapular kinematics and position in healthy overhead athletes following muscle fatigue (Crotty and Smith, 2000; Su *et al.*, 2004; Joshi *et al.*, 2011). Two studies have investigated scapular rest position (Crotty and Smith, 2000) and upward rotation (Su *et al.*, 2004) in healthy swimmers and found no alteration following an usual training session. Another study have evaluated scapular tridimensional kinematics in healthy overhead athletes (Joshi *et al.*, 2011). They have found only an increase of 3° in the total range of scapular upward rotation, following a fatigue protocol of shoulder external rotation (Joshi *et al.*, 2011). Previous studies have questioned the clinical importance of changes up to 3° (Ebaugh *et al.*, 2006a; b). Furthermore, an increase in upward rotation could be considered a compensatory, positive change, since it is in the direction of increasing subacromial space.

It may be suggested that healthy overhead athletes present some adaptive mechanism that maintain proper scapular movement, even at fatiguing conditions. In this study, all the muscle portions presented a significant increase in EMG amplitude following the fatigue protocol. The interpretation of these changes for upper trapezius and serratus anterior is difficult, since muscle fatigue also involves an increase in EMG amplitude (De Luca, 1984). However, the lower trapezius presented a small decline in MPF. The lower trapezius is a scapular external rotator (Johnson *et al.*, 1994) and its increased activation at higher angles of elevation may have contributed to maintain the adequate scapular movement in the transverse plane following the fatigue protocol. This hypothesis is reinforced by the moderate increase in scapular internal rotation at 30° of humeral elevation, position at which the lower trapezius presented the lowest increase in muscle activity.

Previous studies have found alterations in the shoulder of asymptomatic overhead athletes that were considered beneficial adaptations for injury prevention and sports performance, as a decrease in the functional strength rotators ratio and an increase in torque fluctuation (Zanca *et al.*, 2011; Zanca *et al.*, 2013). The lack of significant alterations in scapular kinematics following muscle fatigue could be interpreted in the same direction, as a positive adaptation.

Scapular kinematics presented small alterations following the fatigue protocol, but other aspects that were not evaluated in this study may be affected by muscle fatigue and contribute to shoulder injury risk, as rotator cuff activation and sensorimotor control. The rotator cuff muscles are highly active during throwing movement (Escamilla and Andrews, 2009) and have been shown to be fatigued following repetitive throwing (Dale *et al.*, 2007). Muscle fatigue of rotator cuff can result in decreased ability to centralize the humeral head, leading to higher translations of humeral head in the glenoid cavity, increasing the risk of impingement (Chopp *et al.*, 2010). Sensorimotor system has also been shown to be altered following muscle fatigue (Myers *et al.*, 1999; Bowman *et al.*, 2006). Previous studies have found an increase in acromiohumeral distance (Luque-Suarez *et al.*, 2013) and shoulder proprioception (Lin *et al.*, 2011) using KT techniques for asymptomatic subjects. The effects of KT on humeral translations and proprioceptive deficits caused by muscle fatigue could be object of future studies.

This study presents some limitations that should be addressed. Since the EMG was not collected during the fatigue protocol, it was not possible to affirm whether the lower trapezius activity was increased during the throwing movement. Furthermore, the throwing was performed in the seated position, which may have altered the neuromuscular coordination among the scapular muscles, considering the importance of the kinetic chain during throwing (Sciascia *et al.*, 2012). However, this position was chosen in order to increase the load over the shoulder complex and focus the fatigue protocol on that region.

In conclusion, since healthy overhead athletes seems to present an adaptive mechanism to avoid scapular kinematics alterations following muscle fatigue, it may be suggested that this population does not beneficiate with a KT technique to assist scapular function. This finding should not be generalized for injured populations. Hsu et al. (Hsu *et al.*, 2009) have found a small increase in lower trapezius activity using the same KT technique in baseball players with shoulder impingement, suggesting that KT could have effects only in the presence of activation deficits. The lower fatigue intensity of serratus anterior found in the KT condition could possibly beneficiate symptomatic athletes, aiming to minimize the perpetuation of scapular alterations, as those found in swimmers with shoulder impingement following muscle fatigue (Su *et al.*, 2004). However, this is only speculative and further studies are necessary in order to investigate this hypothesis.

References

An, K. N., Korinek, S. L., Kilpela, T., & Edis, S. (1990). Kinematic and kinetic analysis of push-up exercise. *Biomed Sci Instrum, 26,* 53-57.

Anders, C., Bretschneider, S., Bernsdorf, A., Erler, K., & Schneider, W. (2004). Activation of shoulder muscles in healthy men and women under isometric conditions. *J Electromyogr Kinesiol, 14*(6), 699-707.

Borg, G. (1990). Psychophysical scaling with applications in physical work and the perception of exertion. *Scand J Work Environ Health, 16 Suppl 1*, 55-58.

Borstad, J. D., Szucs, K., & Navalgund, A. (2009). Scapula kinematic alterations following a modified push-up plus task. *Hum Mov Sci, 28*(6), 738-751.

Bowman, T. G., Hart, J. M., McGuire, B. A., Palmieri, R. M., & Ingersoll, C. D. (2006). A functional fatiguing protocol and deceleration time of the shoulder from an internal rotation perturbation. *J Athl Train, 41*(3), 275-279.

Cardinal, R. N., & Aitken, M. R. F. (2005). *ANOVA for the Behavioral Sciences Researcher*. Mahwah, NJ: Psychology Press.

Chopp, J. N., Fischer, S. L., & Dickerson, C. R. (2011). The specificity of fatiguing protocols affects scapular orientation: Implications for subacromial impingement. *Clin Biomech (Bristol, Avon), 26*(1), 40-45.

Chopp, J. N., O'Neill, J. M., Hurley, K., & Dickerson, C. R. (2010). Superior humeral head migration occurs after a protocol designed to fatigue the rotator cuff: a radiographic analysis. *J Shoulder Elbow Surg, 19*(8), 1137-1144.

Cohen, J. (1988). *Statistical Power Analysis for the Behavioral Sciences* (2nd ed.). Hillsdale, NJ: Lawrence Erlbaum Associates

Cools, A. M., Declercq, G. A., Cambier, D. C., Mahieu, N. N., & Witvrouw, E. E. (2007). Trapezius activity and intramuscular balance during isokinetic exercise in overhead athletes with impingement symptoms. *Scand J Med Sci Sports, 17*(1), 25-33.

Cools, A. M., Witvrouw, E. E., Declercq, G. A., Vanderstraeten, G. G., & Cambier, D. C. (2004). Evaluation of isokinetic force production and associated muscle activity in the scapular rotators during a protraction-retraction movement in overhead athletes with impingement symptoms. *Br J Sports Med, 38*(1), 64-68.

Crotty, N. M., & Smith, J. (2000). Alterations in scapular position with fatigue: a study in swimmers. *Clin J Sport Med, 10*(4), 251-258.

Dale, R. B., Kovaleski, J. E., Ogletree, T., Heitman, R. J., & Norrell, P. M. (2007). The effects of repetitive overhead throwing on shoulder rotator isokinetic work-fatigue. *N Am J Sports Phys Ther, 2*(2), 74-80.

De Luca, C. J. (1984). Myoelectrical manifestations of localized muscular fatigue in humans. *Crit Rev Biomed Eng, 11*(4), 251-279.

Ebaugh, D. D., McClure, P. W., & Karduna, A. R. (2006a). Effects of shoulder muscle fatigue caused by repetitive overhead activities on scapulothoracic and glenohumeral kinematics. *J Electromyogr Kinesiol, 16*(3), 224-235.

Ebaugh, D. D., McClure, P. W., & Karduna, A. R. (2006b). Scapulothoracic and glenohumeral kinematics following an external rotation fatigue protocol. *J Orthop Sports Phys Ther, 36*(8), 557-571.

Ekstrom, R. A., Soderberg, G. L., & Donatelli, R. A. (2005). Normalization procedures using maximum voluntary isometric contractions for the serratus anterior and trapezius muscles during surface EMG analysis. *J Electromyogr Kinesiol, 15*(4), 418-428.

Escamilla, R. F., & Andrews, J. R. (2009). Shoulder muscle recruitment patterns and related biomechanics during upper extremity sports. *Sports Med, 39*(7), 569-590.

Firth, B. L., Dingley, P., Davies, E. R., Lewis, J. S., & Alexander, C. M. (2010). The effect of kinesiotape on function, pain, and motoneuronal excitability in healthy people and people with Achilles tendinopathy. *Clin J Sport Med, 20*(6), 416-421.

Fuller, J. R., Lomond, K. V., Fung, J., & Côté, J. N. (2009). Posture-movement changes following repetitive motion-induced shoulder muscle fatigue. *J Electromyogr Kinesiol, 19*(6), 1043-1052.

Haik, M. N., Alburquerque-Sendín, F., & Camargo, P. R. (2014). Reliability and minimal detectable change of 3-dimensional scapular orientation in individuals with and without shoulder impingement. *J Orthop Sports Phys Ther, 44*(5), 341-349.

Hermens, H. J., Freriks, B., Disselhorst-Klug, C., & Rau, G. (2000). Development of recommendations for SEMG sensors and sensor placement procedures. *J Electromyogr Kinesiol, 10*(5), 361-374.

Hsu, Y. H., Chen, W. Y., Lin, H. C., Wang, W. T., & Shih, Y. F. (2009). The effects of taping on scapular kinematics and muscle performance in baseball players with shoulder impingement syndrome. *J Electromyogr Kinesiol, 19*(6), 1092-1099.

Hummel, A., Läubli, T., Pozzo, M., Schenk, P., Spillmann, S., & Klipstein, A. (2005). Relationship between perceived exertion and mean power frequency of the EMG signal from the upper trapezius muscle during isometric shoulder elevation. *Eur J Appl Physiol, 95*(4), 321-326.

Johnson, G., Bogduk, N., Nowitzke, A., & House, D. (1994). Anatomy and actions of the trapezius muscle. *Clin Biomech (Bristol, Avon), 9*(1), 44-50.

Joshi, M., Thigpen, C. A., Bunn, K., Karas, S. G., & Padua, D. A. (2011). Shoulder external rotation fatigue and scapular muscle activation and kinematics in overhead athletes. *J Athl Train, 46*(4), 349-357.

Kase, K., Wallis, J., & Kase, T. (2003). *Clinical Therapeutic Applications of the Kinesio Taping Method* (2nd ed.). Tokyo, Japan: Ken Ikai.

Konishi, Y. (2013). Tactile stimulation with kinesiology tape alleviates muscle weakness attributable to attenuation of Ia afferents. *J Sci Med Sport, 16*(1), 45-48.

Lin, J. J., Hung, C. J., & Yang, P. L. (2011). The effects of scapular taping on electromyographic muscle activity and proprioception feedback in healthy shoulders. *J Orthop Res, 29*(1), 53-57.

Ludewig, P. M., & Reynolds, J. F. (2009). The association of scapular kinematics and glenohumeral joint pathologies. *J Orthop Sports Phys Ther, 39*(2), 90-104.

Luque-Suarez, A., Navarro-Ledesma, S., Petocz, P., Hancock, M. J., & Hush, J. (2013). Short term effects of kinesiotaping on acromiohumeral distance in asymptomatic subjects: a randomised controlled trial. *Man Ther, 18*(6), 573-577.

Myers, J. B., Guskiewicz, K. M., Schneider, R. A., & Prentice, W. E. (1999). Proprioception and neuromuscular control of the shoulder after muscle fatigue. *J Athl Train, 34*(4), 362-367.

Oberg, T., Sandsjö, L., & Kadefors, R. (1990). Electromyogram mean power frequency in non-fatigued trapezius muscle. *Eur J Appl Physiol Occup Physiol, 61*(5-6), 362-369.

Phadke, V., Camargo, P., & Ludewig, P. (2009). Scapular and rotator cuff muscle activity during arm elevation: A review of normal function and alterations with shoulder impingement. *Rev Bras Fisioter, 13*(1), 1-9.

Sciascia, A., Thigpen, C., Namdari, S., & Baldwin, K. (2012). Kinetic chain abnormalities in the athletic shoulder. *Sports Med Arthrosc, 20*(1), 16-21.

Seitz, A. L., & Uhl, T. L. (2012). Reliability and minimal detectable change in scapulothoracic neuromuscular activity. *J Electromyogr Kinesiol, 22*(6), 968-974.

Shaheen, A. F., Bull, A. M., & Alexander, C. M. (2014). Rigid and Elastic taping changes scapular kinematics and pain in subjects with shoulder impingement syndrome; an experimental study. *J Electromyogr Kinesiol*.

Su, K. P., Johnson, M. P., Gracely, E. J., & Karduna, A. R. (2004). Scapular rotation in swimmers with and without impingement syndrome: practice effects. *Med Sci Sports Exerc, 36*(7), 1117-1123.

Van Herzeele, M., van Cingel, R., Maenhout, A., De Mey, K., & Cools, A. (2013). Does the application of kinesiotape change scapular kinematics in healthy female handball players? *Int J Sports Med, 34*(11), 950-955.

Wilk, K. E., Obma, P., Simpson, C. D., Cain, E. L., Dugas, J. R., & Andrews, J. R. (2009). Shoulder injuries in the overhead athlete. *J Orthop Sports Phys Ther, 39*(2), 38-54.

Williams, S., Whatman, C., Hume, P. A., & Sheerin, K. (2012). Kinesio taping in treatment and prevention of sports injuries: a meta-analysis of the evidence for its effectiveness. *Sports Med, 42*(2), 153-164.

Wu, G., van der Helm, F. C., Veeger, H. E., Makhsous, M., Van Roy, P., Anglin, C., et al. (2005). ISB recommendation on definitions of joint coordinate systems of various joints for the reporting of human joint motion--Part II: shoulder, elbow, wrist and hand. *J Biomech, 38*(5), 981-992.

Zanca, G. G., Oliveira, A. B., Ansanello, W., Barros, F. C., & Mattiello, S. M. (2014). EMG of upper trapezius - Electrode sites and association with clavicular kinematics. *J Electromyogr Kinesiol, 24*(6), 868-874.

Zanca, G. G., Oliveira, A. B., Saccol, M. F., Ejnisman, B., & Mattiello-Rosa, S. M. (2011). Functional torque ratios and torque curve analysis of shoulder rotations in overhead athletes with and without impingement symptoms. *J Sports Sci, 29*(15), 1603-1611.

Zanca, G. G., Saccol, M. F., Oliveira, A. B., & Mattiello, S. M. (2013). Shoulder internal and external rotations torque steadiness in overhead athletes with and without impingement symptoms. *J Sci Med Sport, 16*(5), 433-437.

ESTUDO III

KINESIO TAPING DOES NOT REDUCE FATIGUE INDUCED DEFICITS IN SHOULDER PROPRIOCEPTION

Síntese

Sabe-se que a fadiga muscular diminui a acuidade proprioceptiva, o que pode contribuir para a incidência de lesões. Tem sido sugerido que o Kinesio taping (KT) pode melhorar a propriocepção, por meio do estímulo dos mecanorreceptores cutâneos. O objetivo deste estudo foi investigar os efeitos do KT no senso de posição articular do ombro após a indução de déficits proprioceptivos causados pela fadiga muscular. Foram avaliados 24 sujeitos saudáveis, em um desenho experimental cruzado, aleatorizado, com mascaramento do sujeito. O senso de posição articular do ombro foi avaliado por meio de testes de reposicionamento ativo nos ângulos-alvo de 50°, 70° e 90° de elevação do braço no plano da escápula, em três sessões, separadas por uma semana de intervalo, em ordem aleatória: controle (sem intervenção), KT (KT aplicado sobre o músculo deltóide com tensão) e *sham* (KT aplicado sobre o músculo deltóide sem tensão). O senso de posição articular foi avaliado no início da sessão, antes da aplicação da bandagem (T0); após aplicação da bandagem ou repouso, na sessão controle (T1) e após um protocolo de fadiga no movimento de elevação do braço no plano escapular (T2). O erro de reposicionamento (ângulo reposicionado - ângulo alvo) foi considerado para a análise estatística, utilizando ANOVA de medidas repetidas de 3 vias (fatores intra-sujeitos: condição da bandagem, tempo e ângulo-alvo). Não foi encontrada interação ou efeito principal para o fator bandagem. Foi encontrada interação entre os fatores de tempo e ângulo-alvo, e a análise do efeito simples demonstrou que os erros de reposicionamento aumentaram após a fadiga nos ângulos-alvo de 70° e 90°, mas não a 50°. Os resultados deste estudo não suportam o uso do KT para diminuir os déficits proprioceptivos causados pela fadiga muscular em sujeitos saudáveis.

Abstract

Purpose: Muscle fatigue is known to decrease shoulder proprioceptive acuity, potentially contributing to injuries. It has been suggested that Kinesio taping (KT) can improve proprioception. Therefore, the aim of this study was to investigate the effects of KT on shoulder joint position sense (JPS) after muscle fatigue. **Methods**: Twenty-four healthy subjects were evaluated in a randomized, crossover, single-blind study design. Shoulder JPS was assessed during active repositioning tests at the target angles of 50°, 70° and 90° of arm elevation in scapular plane, in three sessions: control (no taping), KT (KT applied over the deltoid muscle with tension) and sham (KT applied over deltoid without tension). The JPS assessment was performed before taping (T0); after taping or rest, in the control session (T1) and after a fatigue protocol (T2). The constant error (repositioned angle - target angle) was considered for statistical analysis, using a 3-way repeated-measures ANOVA (within subject factors: taping, time and target angle). **Results**: There was no interaction or main effect involving taping. An interaction between time and angle was found and the simple effect showed that the constant error increased after fatigue at 70° and 90°, but not at 50°. **Conclusions:** The results of this study does not support the use of KT for improving proprioceptive deficits caused by muscle fatigue.

Keywords: joint position sense; deltoid muscle; muscle fatigue; skin

Introduction

The shoulder complex relies heavily on sensory-motor control for maintaining stability, due to its poor osseous and capsuloligamentous restraints (28). The sensory-motor system includes afferent, efferent, and central integration components, which all contribute to help maintaining functional joint stability. Proprioceptive signals arise from afferent neural input originating at the level of the mechanoreceptors within the muscles, tendon, fascia, joint capsule, ligaments, and skin about a joint (31). These signals are integrated in the central nervous system with other somatosensory, vestibular and visual inputs, resulting in the generation of efferent control over joint motion (28). Proprioception has generally been described as having three submodalities: joint position sense (JPS), the appreciation and interpretation of information concerning joint position and orientation; kinesthesia, the ability to identify joint movement; and the sense of force, the ability to appreciate and interpret forces applied to or generated within a joint (27).

Several studies have shown that shoulder JPS and kinesthesia are impaired by muscle fatigue (6, 21, 24, 26, 37). These deficits could predispose subjects who perform repetitive arm movement during work or sports activities to shoulder injuries. Therefore, interventions aimed at reducing these proprioceptive deficits may help prevent shoulder injury.

Skin stretch has been showed to cause illusory movement, demonstrating that cutaneous afferents plays a role in proprioception (11). Kinesio taping (KT) is a technique that consists of applying elastic adhesive tape over a target muscle, providing continual skin traction (22). This method has been widely used for musculoskeletal injury prevention and treatment, although there is still little evidence of its effectiveness (29, 38). Similar to conventional tapings, proprioception improvement due to cutaneous mechanoreceptors stimulation is one of the effects attributed to KT (22). Previous studies have found increased accuracy in grip force sense (8) and shoulder JPS (25) after the application of KT in healthy subjects.

Given the potential of KT to directly affect proprioception, it could serve as a possible modality for mitigating the negative consequences of fatigue at the shoulder. Consequently, the purpose of this study was to investigate the effects of KT applied on the deltoid muscle in shoulder JPS after muscle fatigue. It was hypothesized that the application of KT would partially compensate the proprioceptive deficits caused by muscle fatigue.

Methods

Subjects

Twenty-four healthy subjects (12 males and 12 females), with a mean age of 21.5 years (± 2.7), mean height of 158 cm (± 10) and mean body mass of 70.5 kg (± 13.1) participated in this study. Prior to participation, all subjects signed an informed consent form approved by the Institutional Review Board of the University of Oregon. Subjects were included if they were healthy, between the ages of 18 and 50 years and had no history of shoulder injuries that required rehabilitation or surgery. Exclusion criteria were current participation in overhead sports training, history of shoulder dislocation and ligamentous laxity. This study was registered prospectively with ClinicalTrials.gov (NCT02104570).

Power calculations were performed using G*Power (version 3.1.9.2) (13). Data were from a previous study using the same JPS protocol on 79 healthy subjects (14). Given an overall standard deviation of 3.2 degrees and a correlation among repeated measures of 0.5, 24 subjects would result in a power of 0.8 to detect an effect size as small as 0.27 (or approximately 0.9 degrees in this case).

Experimental Design

A crossover, randomized, sham-controlled, single-blind (subject) design was used in this investigation. The dominant shoulder of the participants was evaluated in three sessions: control (no intervention), KT application and sham application, in a randomized order. Subjects performed the three sessions on the same day of the week and time of the day. Additionally, there was a one-week interval between sessions in order to avoid accumulation of taping effects (19) or muscle fatigue (26). Participants were instructed not to perform upper-body exercises for the 24 hours prior to each session. The experimental protocol was the same for all sessions, except for the taping application (Figure 1).

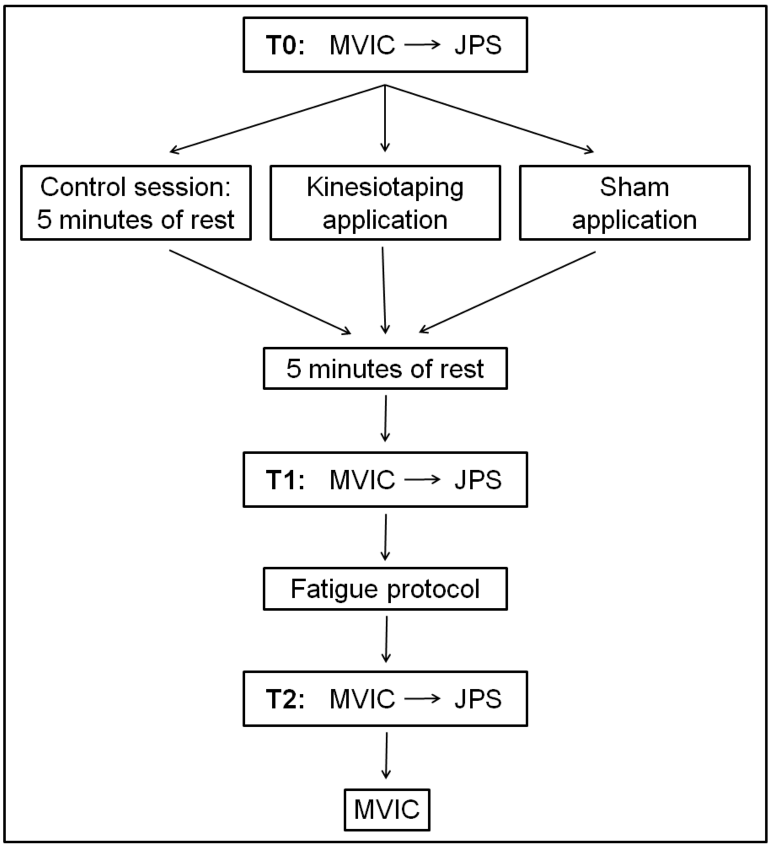

Figure 1 Schematic representation of the procedures during the experiments. MVIC: Maximal voluntary isometric contractions; JPS: Joint position sense

Procedures

For all sessions, participants were seated on an ergonomically designed kneeling chair (Better Posture Kneeling Chairs, Jobri, Konawa, OK). Initially, a maximal isometric voluntary contraction (MVIC) of shoulder abduction was performed, with the arm at 90º of shoulder elevation in the scapular plane. These contractions were performed in order to determine the weight to be used during the fatigue protocol and the criteria considered as muscle fatigue. Subjects performed three MVIC trials, 5 seconds each, with 1 minute of rest between them. Data were collected at 12 Hz with a hand held dynamometer (MicroFET 2, Hoggan Health Industries, Draper, UT) attached to a rigid support. The mean force generated between the second and third seconds was calculated and then averaged over the 3 MVIC trials.

Following MVIC testing, shoulder JPS was assessed with an active joint repositioning task, using an app developed for Apple's 4th generation iPod Touch (14). This app uses the internal sensors of the device (accelerometers and gyroscopes) to record the orientation of a segment with respect to gravity, and enables an evaluation protocol similar to that performed using an electromagnetic tracking device (34, 35). Instead of visual cues, the app provides auditory commands to the subject thought Bluetooth noise canceling headphones, while subjects keep their eyes closed.

The iPod was attached to the distal arm of the subjects, between the deltoid insertion and lateral epicondyle, to minimize artifacts from muscle contraction. The initial position of each trial was with the arm vertical at the side of the body. Subjects were instructed to elevate the arm in the scapular plane (Figure 2). There were two audible cues to help guide the subjects to the correct target angle. A low frequency tone was presented when the elevation angle was below the target angle and a high frequency tone when the angle was above the target angle. Subjects were instructed to stop arm movement when the tones were silenced, which occurred when the arm was within 2º of the target angle. They held this position for 3 seconds and subsequently returned the arm to the initial position. After 2 seconds, they were instructed to reproduce the target position, with no audio or verbal feedback of shoulder position. Three target angles of elevation (50º, 70º and 90º) were presented, two times each, in a randomized order. Two familiarization trials were performed before starting the tests. The differences between the angle reached in the trial with auditory feedback (in a range ±2° of the target angle) and the repositioned angles were calculated and the mean (constant error) was used for analysis.

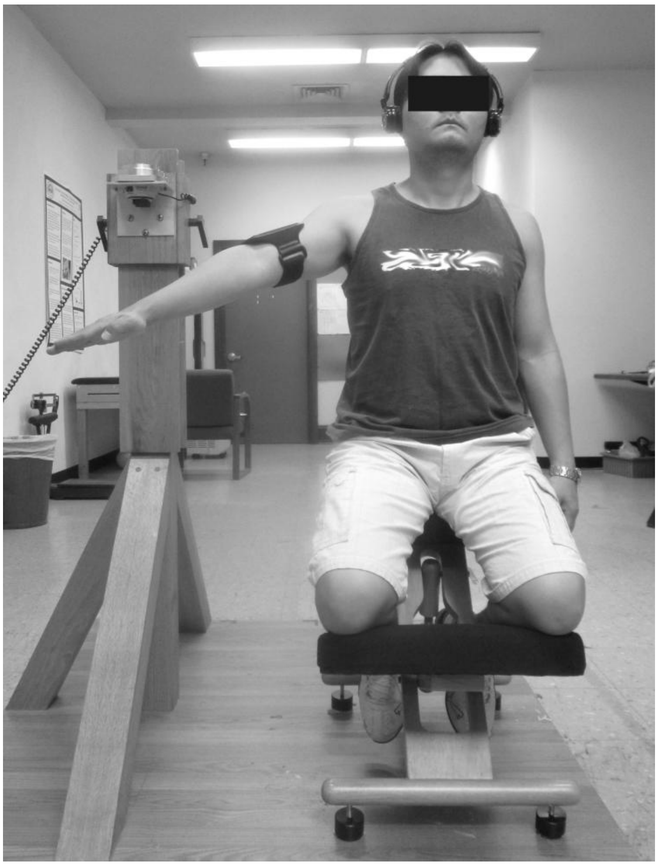

Figure 2 Subjects positioning during the joint position sense assessment.

Following baseline evaluations (T0), taping was applied (KT or sham) or subjects rested for 10 minutes (control session) (Figure 1). In both taping sessions, two strips of the Kinesio Tex Gold Standard (Kinesio USA, LLC, Albuquerque, NM), 5 cm width, were applied over the deltoid muscle, from origin to insertion (Figure 3). In the KT session, the base of each strip was applied with no tension, over the acromioclavicular joint, with the arm at trunk side. Then, the shoulder was placed in abduction, external rotation and horizontal abduction, and the tape was applied along the anterior deltoid to the deltoid tuberosity. For the posterior strip application, the shoulder was moved into horizontal adduction with internal rotation while maintaining around 90º abduction. Both strips were applied using approximately 50% of the available tension, as recommended by Kase et al (22) for muscle facilitation. For the sham condition, the tape was applied using the same configuration, but the arm remained at the side during all the application procedure and no tension was applied. The subjects were blinded to the intervention they were receiving. They were informed that there were two different techniques, but were not given any further details about the taping procedure. After taping (or rest in the control session), MVIC and JPS were reassessed (T1).

Figure 3 Taping application over the deltoid muscle.

During the fatigue protocol, a weight was attached to the subject's wrist. The weight was set at 20% of the baseline MVIC of the first evaluation session and maintained the same in the second and third sessions. The fatigue protocol consisted of repetitive shoulder elevation in the scapular plane, up to 90º of shoulder elevation. The movement frequency was controlled using a metronome and consisted of 1 second for the concentric phase and 1 second for the eccentric phase. When the subject could not perform the movement at the correct frequency or through the complete range of motion, the MVIC was reassessed. If the force had fallen less than 50% of MVIC at T1, the exercise continued. When the drop in force was greater than 50% of MVIC at T1, they stopped the exercise and the JPS was immediately reassessed (T2).

Statistical Analysis

Statistical analysis was performed using SPSS version 22 (IBM, Chicago, IL). Mauchly’s test of sphericity was performed for all measures and Greenhouse–Geisser correction was used if the assumption was violated. In order to compare the fatigue protocol between session, the number of repetitions before reaching the fatigue criteria, the MVIC immediately after the fatigue protocol (T2) and at the end of the session (after JPS reassessment) were compared between sessions using one-way repeated-measures analyses of variance (ANOVAs). For the JPS assessment data (constant error), a three-way repeated-measures ANOVA was conducted, with the following within-subject factors: taping condition (control, KT and sham), time (T0, T1 and T2) and target angle (50º, 70º and 90º). Significance level was set as 5%. When a significant interaction was found, the simple effects were calculated using the Sidak correction for multiple comparisons (5).

Results

All subjects completed the fatigue protocol with no complications. There were no significant differences between the sessions regarding the number of repetitions during fatigue protocol, the MVIC at T2 and the MVIC after JPS reassessment (Table 1).

Table 1 Number of repetitions performed during the fatigue protocol and maximal voluntary isometric contraction (MVIC; expressed as a percentage of MVIC before fatigue protocol) at each evaluation session.

	Control session	Kinesio taping session	Sham session	*P* value
Number of repetitions during fatigue protocol	95 ± 6	98 ± 6	93 ± 6	0.61
MVIC after fatigue protocol	41.6 ± 1.2	44.6 ± 0.9	42.2 ± 1.1	0.13
MVIC after JPS reassessment	66.9 ± 2.4	65.5 ± 2.4	66.3 ± 2.6	0.88

Regarding JPS data, there was no significant three-way interaction (p=0.18). A two-way interaction between time and angle was found (p=0.005) (Figure 4). This effect was further investigated using a simple effect analysis, which showed a significant increase in constant error at T2 compared to T0 and T1 at the target angles of 70º and 90º (p<0.001), but not of 50º (p>0.05). Lower errors were found at the target angles of 70º and 90º compared to 50º at T0 and T1 (p<0.05), but not at T2 (p>0.05). There was no main effect of taping condition (p=0.41).

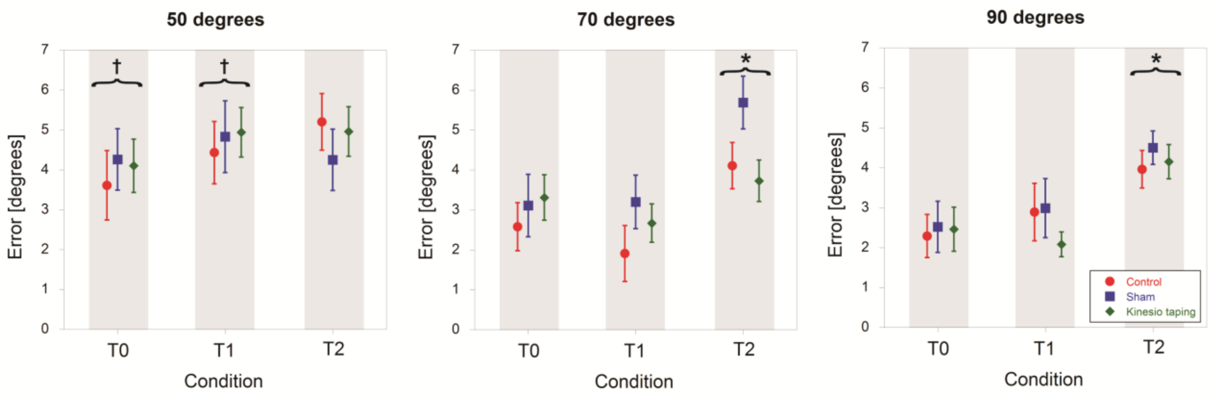

Figure 4 Mean constant errors and standard error at each target angle in the baseline (T0), immediately after taping application or rest (T1) and after fatigue (T2).

*Significant difference ($P<0.05$) compared to T0 and T1, †Significant difference ($P<0.05$) compared to 70° and 90°.

Discussion

Kinesio taping has been widely and increasingly used in clinical and sports practice, although its effects are still not clear (29, 38). Few studies have evaluated the effects of KT on proprioception (7-9, 17, 25). An improvement in the grip force sense was found with KT applied over the wrist flexor muscles of healthy subjects compared to no taping and sham conditions (8). The authors attributed this effect to the tension applied to the taping, which would have stimulated skin and underlying superficial fascia. However, the sham application was a small piece of KT applied across the belly of wrist flexors, providing different skin stimulation and making it difficult to attribute the alterations found to the tension applied to the tape. In the present study, the sham was applied using the same taping configuration, removing only the principal characteristic of the KT method, i.e., the tension. This ensured the same skin contact stimulation, and then any possible difference found between the taping conditions could be attributed to the tension applied. Furthermore, using the same material for the sham application avoids any movement restriction potentially caused by rigid tape, as previously reported (19).

Other studies investigated the effects of KT on proprioception, but have not compared to a sham or placebo technique. Lin et al (25) found a decrease in shoulder repositioning errors in healthy subjects when using KT applied with full tension, aiming to maintain scapular retraction and depression. Since the subjects were tested before and after the taping application in a single session, a learning effect cannot be discarded. Halseth et al (17), also using a pretest-posttest design, found no effect of a KT technique for lateral ankle sprain on ankle JPS of healthy subjects, similar to our findings. Our results are also in accordance with another study (4) that have not found improvements in shoulder JPS with a rigid taping technique for shoulder stabilization in healthy football players. It is possible that an intact sensory-motor system, as is the case of subjects with no shoulder injuries, would not beneficiate from any extra stimulus potentially provided by taping.

The hypothesis of this study was that KT would compensate for proprioceptive deficits caused by muscle fatigue. To our knowledge, only one study have previously tested this hypothesis, finding smaller errors of knee repositioning after KT application compared to immediately after fatigue, without taping (18). However, that study did not have a placebo group and the KT was applied after the fatigue protocol, which may have allowed fatigue recovery. It is also possible that skin stimulation improves the afferent input for a limited time and, after a period, the receptors accommodate to the additional stimulus. In the present study, taping was applied before the fatigue protocol and removed only at the end of the session. This method is more similar to the real application of KT, since athletes, for example, use it during game or training, not after. Our results demonstrate that when KT is used during the exercise practice, it does not compensate for fatigue induced decreases in shoulder JPS in healthy subjects.

A previous study found that KT applied from origin to insertion of the triceps surae increases gastrocnemius activation and maximal strength, but this effect was significantly higher with the ankle at 20° of dorsiflexion, when the tape was under greatest tension (12). This finding suggests that KT effects may be related to the degree of cutaneous stimulation of the taping. In our study, the taping was applied over the deltoid muscle and JPS was assessed during shoulder abduction movements, in the direction of taping and skin shortening. Future studies could investigate the effects of KT applied in a region that is elongated during the testing movements in order to better understand these mechanisms. It is also important to point that although skin afferents play a role in JPS, their contribution is likely to be less important than the input from muscle spindles in proximal joints like the shoulder (11).

Data from the present study also showed that KT had no effect on muscle fatigue, with subjects performing the same number of repetitions until fatigue criteria and having the same rate of recovery in all the sessions. Álvarez-Álvarez et al (3) found an improvement in the resistance to fatigue of trunk extensor musculature when using KT during the Biering-Sorensen test, an isometric task. During isometric contractions, one of the main causes of task failure is the occlusion of blood flow and, consequently, decrease in oxygen supply and increase in metabolite accumulation (20). Therefore, the effect on fatigue resistance may have been related to one of the attributed effects of KT – an improvement in peripheral blood and lymphatic flow, due to the lifting effect on the skin (1, 33). However, during dynamic contractions, blood flow is not a limiting factor (20), which may help to explain why KT had no effect on fatigue development in the present study. This is consistent with a previous study that evaluated the effects of KT on plantarflexor muscle endurance during dynamic contractions (12).

The present study found a significant increase in the repositioning errors after muscle fatigue at the higher target angles of elevation. The general decrease in proprioceptive acuity after fatigue is in accordance with previous studies that have evaluated internal and external rotations of the shoulder, using repositioning and threshold movement detection tests (6, 21, 24, 37). In the baseline tests, the subjects presented a pattern of smaller errors at higher target angles, which is in accordance with previous studies that have evaluated JPS during arm elevation in healthy subjects (23, 34). After muscle fatigue, the relationship between target angle and repositioning error was altered, with no significant effects of fatigue on JPS at 50º, but an increase in errors at 70º and 90º. The pattern of smaller errors at greater elevation found by previous studies was initially attributed to the muscle activation level, since at higher angles the moment arm of the limb increases, increasing the torque applied to the shoulder due to gravity (34). However, more recent studies showed that external load causes only a small improvement in JPS (35) and body orientation does not change this pattern (10), suggesting that the angular position has a greater role in the repositioning acuity than the generated torque.

The mechanisms that cause proprioceptive deficits after muscle fatigue have been extensively investigated. It was initially suggested that proprioception impairment could be caused by damage to muscle receptors (32), however experiments with animals showed no significant alterations in muscle spindle and tendon organs response after eccentric exercise (15, 16). These studies contrast with another that found changes in perceived movement with tendon vibration two days after eccentric exercise, suggesting a decrease in dynamic sensitivity of spindle primary endings (30). Other study suggests a central mechanism alteration, considering that the direction of repositioning errors are the same independent of the fatigued muscle group (agonist or antagonist), but dependent of the joint, with the elbow being perceived as more extended and the knee more flexed (2). Furthermore, Tsai et al (36) found JPS deficits after 24 hours of eccentric exercise, when the acute fatigue effects and metabolites were gone, but there was still a decrease in muscle strength. The authors suggested that proprioceptive disturbance could be caused by central mechanisms, perhaps an alteration of body map triggered by the fall in force. It is important to note that the majority of these studies have assessed JPS using a bilateral matching task, in which one limb was positioned in the target angle and the other should match the position. Different results could be found assessing an ipsilateral matching task, in which the afferent information at presentation of the target position is similar to that during the repositioning. Further studies are necessary for a better understanding of the mechanisms involving fatigue and proprioception, which might help planning possible interventions to decrease these deficits and, potentially, prevent injuries.

There are limitations of the present study that need to be addressed. Although the participants were trained to perform the movements in the scapular plane, before the JPS evaluation, the plane of elevation was not controlled, only visually inspected by the examiner. However, since it was demonstrated that shoulder JPS is not significantly affected by the plane of movement (34), it is unlikely that this would influence our results. Due to the small number of trials at each target angle during the repositioning task, the variable error was not calculated. The number of repetitions was determined in order to avoid fatigue recovery before the end of the reassessment.

The main hypothesis of this study, that KT could partially compensate for the proprioceptive deficits induced by muscle fatigue, was not supported. Although subjects presented an increase in the repositioning errors after fatigue, the change was the same in all the sessions, independent of the intervention. Therefore, this study does not support the use of KT for compensating or preventing proprioceptive deficits caused by muscle fatigue.

References

1. Aguilar-Ferrándiz ME, Castro-Sánchez AM, Matarán-Peñarrocha GA, Guisado-Barrilao R, García-Ríos MC, Moreno-Lorenzo C. A randomized controlled trial of a mixed Kinesio taping-compression technique on venous symptoms, pain, peripheral venous flow, clinical severity and overall health status in postmenopausal women with chronic venous insufficiency. *Clin Rehabil*. 2014;28(1):69-81.

2. Allen TJ, Leung M, Proske U. The effect of fatigue from exercise on human limb position sense. *J Physiol*. 2010;588(Pt 8):1369-77.

3. Alvarez-Álvarez S, José FG, Rodríguez-Fernández AL, Güeita-Rodríguez J, Waller BJ. Effects of Kinesio® Tape in low back muscle fatigue: Randomized, controlled, doubled-blinded clinical trial on healthy subjects. *J Back Musculoskelet Rehabil*. 2014;27(2):203-12.

4. Bradley T, Baldwick C, Fischer D, Murrell GA. Effect of taping on the shoulders of Australian football players. *Br J Sports Med*. 2009;43(10):735-8.

5. Cardinal RN, Aitken MRF. *ANOVA for the Behavioral Sciences Researcher*. Mahwah (NJ): Psychology Press; 2005. 464 p.

6. Carpenter JE, Blasier RB, Pellizzon GG. The effects of muscle fatigue on shoulder joint position sense. *Am J Sports Med*. 1998;26(2):262-5.

7. Chang HY, Cheng SC, Lin CC, Chou KY, Gan SM, Wang CH. The effectiveness of kinesio taping for athletes with medial elbow epicondylar tendinopathy. *Int J Sports Med*. 2013;34(11):1003-6.

8. Chang HY, Chou KY, Lin JJ, Lin CF, Wang CH. Immediate effect of forearm Kinesio taping on maximal grip strength and force sense in healthy collegiate athletes. *Phys Ther Sport*. 2010;11(4):122-7.

9. Chang HY, Wang CH, Chou KY, Cheng SC. Could forearm Kinesio Taping improve strength, force sense, and pain in baseball pitchers with medial epicondylitis? *Clin J Sport Med*. 2012;22(4):327-33.

10. Chapman J, Suprak DN, Karduna AR. Unconstrained shoulder joint position sense does not change with body orientation. *J Orthop Res*. 2009;27(7):885-90.

11. Collins DF, Refshauge KM, Todd G, Gandevia SC. Cutaneous receptors contribute to kinesthesia at the index finger, elbow, and knee. *J Neurophysiol*. 2005;94(3):1699-706.

12. Csapo R, Herceg M, Alegre LM, Crevenna R, Pieber K. Do kinaesthetic tapes affect plantarflexor muscle performance? *J Sports Sci*. 2012;30(14):1513-9.

13. Faul F, Erdfelder E, Lang A, Buchner A. G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods*. 2007;39:175-91.

14. Gillespie E, Hyler J, Lin Y-L, Karduna A. Want To Test Proprioception? There's an APP for That. Abstract presented at the 37th Annual Meeting of the American Society of Biomechanics, Omaha, NE, September 4-7, 2013.

15. Gregory JE, Brockett CL, Morgan DL, Whitehead NP, Proske U. Effect of eccentric muscle contractions on Golgi tendon organ responses to passive and active tension in the cat. *J Physiol*. 2002;538(Pt 1):209-18.

16. Gregory JE, Morgan DL, Proske U. Responses of muscle spindles following a series of eccentric contractions. *Exp Brain Res*. 2004;157(2):234-40.

17. Halseth T, McChesney JW, Debeliso M, Vaughn R, Lien J. The effects of kinesio™ taping on proprioception at the ankle. *J Sports Sci Med*. 2004;3(1):1-7.

18. Han JT, Lee JH. Effects of kinesiology taping on repositioning error of the knee joint after quadriceps muscle fatigue. *J Phys Ther Sci*. 2014;26(6):921-3.

19. Hsu YH, Chen WY, Lin HC, Wang WT, Shih YF. The effects of taping on scapular kinematics and muscle performance in baseball players with shoulder impingement syndrome. *J Electromyogr Kinesiol*. 2009;19(6):1092-9.

20. Hunter SK. Sex differences and mechanisms of task-specific muscle fatigue. *Exerc Sport Sci Rev*. 2009;37(3):113-22.

21. Iida N, Kaneko F, Aoki N, Shibata E. The effect of fatigued internal rotator and external rotator muscles of the shoulder on the shoulder position sense. *J Electromyogr Kinesiol*. 2014;24(1):72-7.

22. Kase K, Wallis J, Kase T. *Clinical Therapeutic Applications of the Kinesio Taping Method* 2nd ed. Tokyo, Japan: Ken Ikai; 2003. 249 p.

23. King J, Harding E, Karduna A. The shoulder and elbow joints and right and left sides demonstrate similar joint position sense. *J Mot Behav*. 2013;45(6):479-86.

24. Lee HM, Liau JJ, Cheng CK, Tan CM, Shih JT. Evaluation of shoulder proprioception following muscle fatigue. *Clin Biomech (Bristol, Avon)*. 2003;18(9):843-7.

25. Lin JJ, Hung CJ, Yang PL. The effects of scapular taping on electromyographic muscle activity and proprioception feedback in healthy shoulders. *J Orthop Res*. 2011;29(1):53-7.

26. Myers JB, Guskiewicz KM, Schneider RA, Prentice WE. Proprioception and neuromuscular control of the shoulder after muscle fatigue. *J Athl Train*. 1999;34(4):362-7.

27. Myers JB, Lephart SM. The role of the sensorimotor system in the athletic shoulder. *J Athl Train*. 2000;35(3):351-63.

28. Myers JB, Wassinger CA, Lephart SM. Sensorimotor contribution to shoulder stability: effect of injury and rehabilitation. *Man Ther*. 2006;11(3):197-201.

29. Parreira PoC, Costa LaC, Hespanhol Junior LC, Lopes AD, Costa LO. Current evidence does not support the use of Kinesio Taping in clinical practice: a systematic review. *J Physiother*. 2014;60(1):31-9.

30. Regueme SC, Barthèlemy J, Gauthier GM, Nicol C. Changes in illusory ankle movements induced by tendon vibrations during the delayed recovery phase of stretch-shortening cycle fatigue: an indirect study of muscle spindle sensitivity modifications. *Brain Res*. 2007;1185:129-35.

31. Riemann BL, Lephart SM. The Sensorimotor System, Part II: The Role of Proprioception in Motor Control and Functional Joint Stability. *J Athl Train*. 2002;37(1):80-4.

32. Saxton JM, Clarkson PM, James R et al. Neuromuscular dysfunction following eccentric exercise. *Med Sci Sports Exerc*. 1995;27(8):1185-93.

33. Shim JY, Lee HR, Lee DC. The use of elastic adhesive tape to promote lymphatic flow in the rabbit hind leg. *Yonsei Med J*. 2003;44(6):1045-52.

34. Suprak DN, Osternig LR, van Donkelaar P, Karduna AR. Shoulder joint position sense improves with elevation angle in a novel, unconstrained task. *J Orthop Res*. 2006;24(3):559-68.

35. Suprak DN, Osternig LR, van Donkelaar P, Karduna AR. Shoulder joint position sense improves with external load. *J Mot Behav*. 2007;39(6):517-25.

36. Tsay A, Allen TJ, Leung M, Proske U. The fall in force after exercise disturbs position sense at the human forearm. *Exp Brain Res*. 2012;222(4):415-25.

37. Voight ML, Hardin JA, Blackburn TA, Tippett S, Canner GC. The effects of muscle fatigue on and the relationship of arm dominance to shoulder proprioception. *J Orthop Sports Phys Ther*. 1996;23(6):348-52.

38. Williams S, Whatman C, Hume PA, Sheerin K. Kinesio taping in treatment and prevention of sports injuries: a meta-analysis of the evidence for its effectiveness. *Sports Med*. 2012;42(2):153-64.

CONSIDERAÇÕES FINAIS

Os estudos apresentados nesta tese abordaram o posicionamento de eletrodos para avaliação EMG do trapézio superior e sua relação com a cinemática clavicular e os efeitos do Kinesio taping (KT) na cinemática escapular e propriocepção do ombro após um protocolo de fadiga muscular. Baseado nos estudos apresentados nesta tese, podemos concluir que:

- O posicionamento de eletrodo tradicionalmente utilizado para capturar o sinal EMG do trapézio superior, ou seja, sobre as fibras inseridas no acrômio, é representativo e pode ser relacionado aos movimentos de elevação e retração da clavícula em indivíduos saudáveis. Entretanto, as diferenças de ativação encontradas durante as contrações isométricas máximas são compatíveis com o conceito de subdivisão funcional do trapézio superior. Portanto, sugere-se que a avaliação das fibras claviculares deveria ser considerada em condições patológicas. Para este fim, o posicionamento de eletrodo 20% lateral ao ponto médio entre C3 e o ponto mais lateral da clavícula foi indicado, pois provavelmente inclui o sinal de todos os fascículos que se inserem na clavícula.
- O uso do KT para facilitação do trapézio inferior pode diminuir a intensidade da fadiga do serrátil anterior de atletas arremessadores saudáveis, quando comparado a uma técnica aplicada sem tensão. No entanto, estes atletas parecem apresentar um mecanismo de adaptação, por meio de um aumento de ativação do trapézio inferior, que previne alterações na cinemática escapular, mesmo após um protocolo de fadiga intenso. Sendo assim, podemos considerar que estes atletas não se beneficiam do uso do KT com o intuito de prevenir alterações na cinemática escapular devido à fadiga.
- Embora o aumento do *feedback* proprioceptivo seja atribuído a diversas técnicas de bandagem, esta tese também demonstrou que o KT não é eficiente para melhorar o

senso de posição articular do ombro de sujeitos saudáveis, mesmo na presença de déficits proprioceptivos induzidos pela fadiga muscular.