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Force irradiation effect of kinesiotaping on contralateral muscle activation

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ABSTRACT

We aimed to determine the force irradiation effect of kinesiotaping (KT) on contralateral muscle activity during unilateral muscle contraction. Forty healthy (26 females, 14 males) subjects were divided into two groups: KT and control groups. KT was applied on the biceps brachii at the contralateral limb (non-dominant limb) in the KT group, whereas no taping was applied to the control group. All participants performed unilateral isometric, concentric, and eccentric contractions with their dominant upper limbs (exercised limb) by means of an isokinetic dynamometer, while the contralateral limb was in the resting condition, neutral position, and motionless during the testing procedure. During the exercise, contralateral biceps brachii muscle activity was recorded by surface electromyography (EMG). To quantify the muscle activation, EMG signals were expressed as a percentage of the maximal isometric voluntary contraction, which is referred to as $\%EMG_{max}$. The KT group showed significantly higher $\%EMG_{max}$ in the biceps brachii compared to the control group at the contralateral limb during the isometric, concentric, and eccentric contractions ($p = 0.035$, $p = 0.046$, and $p = 0.002$, respectively) The median values of the contralateral muscle activity were 2.74 $\%EMG_{max}$ and 6.62 $\%EMG_{max}$ during the isometric contraction for the control and KT groups, respectively ($p = 0.035$). During the concentric contraction, the median values of the contralateral muscle activity were 1.61 $\%EMG_{max}$ and 9.39 $\%EMG_{max}$ for the control and KT groups, respectively ($p = 0.046$). The median values of the contralateral muscle activity were 4.49 $\%EMG_{max}$ and 22.89 $\%EMG_{max}$ for the eccentric contraction for the control and KT groups, respectively ($p = 0.002$). In conclusion, KT application on the contralateral limb increased the contralateral muscle activation in the biceps brachii during the unilateral isometric, concentric, and eccentric contractions.

1. Introduction

The kinesiotaping (KT) is a taping technique that is commonly used to improve muscle performance and facilitate or inhibit muscle activity in rehabilitation (Halseth, McChesney, DeBeliso, Vaughn, & Lien, 2004). Although the effects of KT are questionable, two main mechanisms are considered as the underlying rationale of the action of KT (Cai, Au, An, & Cheung, 2016). One of the

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mechanisms is the skin-lifting effect which is considered to increase the blood and lymphatic fluid circulation (Halseth et al., 2004). Another theory is that KT creates pressure and stretching effects on the skin surface that stimulate cutaneous mechanoreceptors which enhances somatosensory inputs (Kase, Wallis, Kase, & Association, 2003). The activation of modulatory mechanisms within the central nervous system through proprioceptive feedback revealed an increase in muscle excitability (Lin, Hung, & Yang, 2011).

Force irradiation is defined as an involuntary muscle activity which occurs in contralateral muscles or any other body segment during a strong unilateral muscle contraction (Adamson, MacQuaide, Helgerud, Hoff, & Kemi, 2008; Pink, 1981). There are several opinions about the underlying mechanism of the contralateral muscle activation. Some theories attribute the origin of the contralateral activation to the muscular, neural, cortical, subcortical structures and spinal cord (Devine, LeVeau, & Yack, 1981; Dragert & Zehr, 2013). Cernacek first described the involuntary muscle activity in the contralateral limb by using surface electromyography (EMG) during a unilateral contraction of exercised limb (Cernacek, 1961). The amount of the force irradiation depends on the abundance of the stimulus from the central motor pathways to the active muscles and also the afferent feedback to contralateral motor neurons (Zijdewind, Butler, Gandevia, & Taylor, 2006).

Recent studies have reported that the sensory feedback provided by the use of a mirror, which reflects the exercised limb vision instead of the resting limb, augmented the crossed effect (Carson & Ruddy, 2012; Zult et al., 2016). Additionally, electrically stimulated muscle contraction and added cutaneous afferents or inputs from muscle spindles in the active limb also produce force irradiation (Cattagni, Lepers, & Maffiuletti, 2018; Hortobágyi, Taylor, Petersen, Russell, & Gandevia, 2003; Veldman et al., 2015, 2018). Unilateral body vibration on the exercised limb, which induces short and rapid changes in muscle fiber length and stimulates reflexive muscle contractions via monosynaptic reflexes or skin and joint receptors, promotes crossed effect (Marín, Hazell, García-Gutiérrez, & Cochrane, 2014). These unilateral interventions act on the somatosensory system. The modulation of the corticospinal output by the proprioceptive feedback or inputs from the resting and exercised limb may affect the contralateral muscle activity (Post, Bakels, & Zijdewind, 2009). KT has effects on the somatosensory inputs within the taped area (Tamburella, Scivoletto, & Molinari, 2014). The skin and the muscle are elaborately innervated by the specific receptors, which are linked with the somatosensory system. KT creates pressure and stretching stimulations on the receptors of the skin and the muscle under the taped area, which is considered to enhance the afferent activity (Kase et al., 2003; Lin et al., 2011; Tamburella et al., 2014).

The unilateral isometric, concentric, and eccentric contractions produce contralateral muscle activity, although there is no consensus on whether one induces more contralateral muscle activity than another. A study showed that the contralateral EMG amplitude was higher during isometric contractions than that during isotonic contractions (Abreu, Lopes, Sousa, Pereira, & Castro, 2015; Shinohara, Keenan, & Enoka, 2003). However, Uematsu et al. revealed that H-reflex in the contralateral limb was similar during the three contraction types (Uematsu et al., 2010).

The unilateral exercise training is extensively used to prevent muscle weakness in injured extremity, increase mobility and strength in the early rehabilitation of sports and orthopedic injuries and in the treatment programs of the neurological diseases such as stroke (Papandreou, Billis, Papathanasiou, Spyropoulos, & Papaioannou, 2013; Urbin, Harris-Love, Carter, & Lang, 2015). Therefore, enhancing the effect of force irradiation on the contralateral muscle activity may enable important clinical outcomes. In this respect, we aimed to determine the effects of KT on the contralateral muscle activity during unilateral contractions.

2. Methods

2.1. Study design

The research was advertised to the student groups at the Bezmialem Vakif University. Forty healthy and sedentary subjects (26 females, 14 males), who are university students without a history of any neurological or acute musculoskeletal injury, participated in the study. All volunteers were right hand dominant. The subjects were randomly divided into two groups as KT (14 females, 6 males) and control (12 females, 8 males) groups by an electronic random sequence generator (www.random.org). The subjects were asked to abstain from caffeine, alcohol, exercise, or any form of central nervous system stimulant or depressant for at least 6 h prior to testing. Written informed consent was obtained from all subjects. The experimental procedure was approved by the Bezmialem Vakif University Human Research Ethics Committee and the experiments were performed in accordance with the Declaration of Helsinki. The study was registered to ClinicalTrial.Gov website with the registration number of NCT03470714.

2.2. Maximal isometric voluntary contraction measurements

In the study, the dominant and non-dominant limbs were defined as exercising and contralateral limbs, respectively. Before the testing sessions, each participant performed a maximal isometric voluntary contraction (MIVC) of elbow flexion with their contralateral limbs in order to record EMG signals from the contralateral biceps brachii to be used for the contralateral EMG signal normalization. The contralateral elbow was at 90° flexion and the forearm was in the supine position during three repetitions of the MIVC. In addition, maximum contralateral elbow joint torques were recorded to determine whether there is a difference between the maximum torques at the contralateral limbs of the groups, which may lead to dissimilarity in terms of the muscle strength between the groups.

2.3. Taping procedure

The kinesiotapes (Kinesio Tex Gold, Kinesio USA, Albuquerque, NM) were applied to the contralateral biceps brachii of the KT

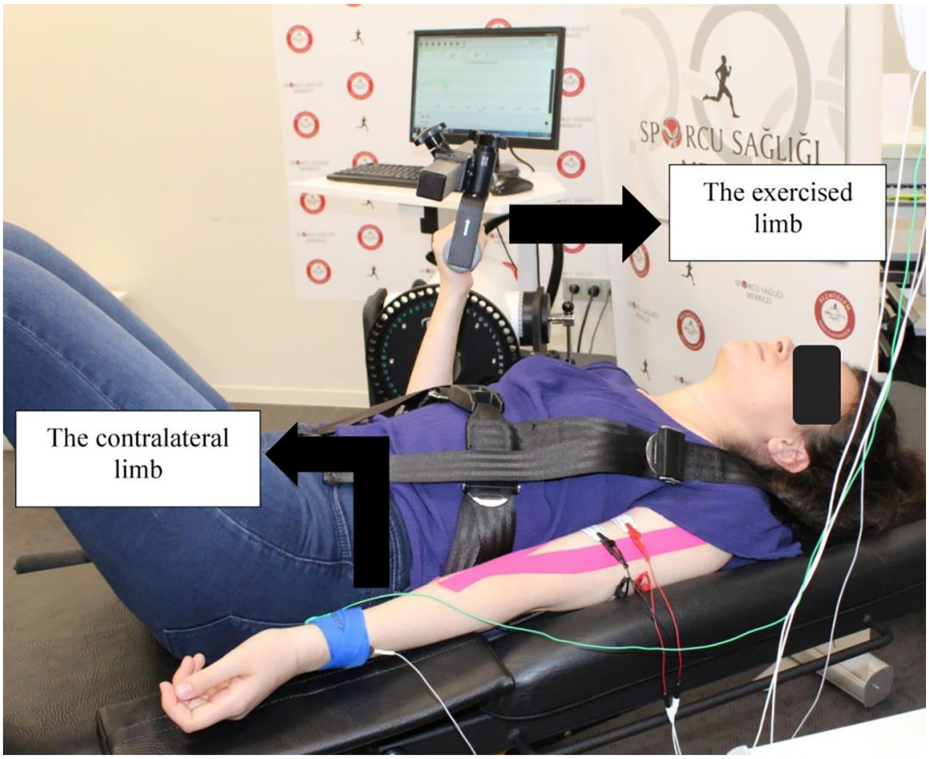

Fig. 1. Experimental design of the study.

group 24 h before the testing. The tapes were attached from the muscle origin to insertion with paper-off tension (without stretch) by taking the Kenzo Kase procedure into account. “X” taping method was applied since the origin and insertion of the biceps brachii change depending on the movement (Kase, Martin, & Yasukawa, 2006). The length of the applied kinesiotape was determined from the supraglenoid tubercle and coracoid process to the proximal third of supinated forearm with the elbow positioned in 30°–45° flexion. The medial and lateral tails of the proximal ends of the kinesiotape were applied from the coracoid process to the antecubital crease and from the supraglenoid tubercle to the antecubital crease, respectively. The middle portion of the kinesiotape was applied onto the antecubital area with the elbow in 30°-45° flexion. The lateral and medial tails of the distal ends of the kinesiotape were applied on the proximal third of the forearm, respectively.

2.4. Testing procedure

After a warm-up, subjects performed elbow flexion at an angular velocity of 60°/s for the concentric contraction and elbow extension at an angular velocity of 30°/s for the eccentric contraction within the range of motion of 5°–105°, and isometric contraction at an angle of 90° of elbow flexion with a maximal effort of their exercised limb (Fig. 1). All muscle contractions were practiced by using the Cybex isokinetic dynamometer (Humac Norm, Cybex CSMI, Stoughton, MA, USA.). The contralateral limb was in resting condition and motionless during the testing procedure. It was positioned near the body (resting on a horizontal board) with the forearm was supinated and the wrist was at the neutral position. EMG signals of the biceps brachii muscle from the contralateral limb were recorded during the contractions of the exercised limb. Probable differences between the torque levels of the groups may prevent an objective comparison of the muscle activities between the groups (Abreu et al., 2015). Therefore, the elbow joint torques at the exercised limbs during unilateral contractions were also recorded to be able to compare the torque levels of the groups. The subjects were given a one-minute resting period between the trials to prevent muscle fatigue.

2.5. EMG data recording

Before surface EMG electrodes are placed on the skin, the cell debris was removed and the skin was cleaned with 70% of ethyl alcohol. Skin surface that the electrode is placed was shaved and a special conducting gel was applied. Ag/AgCl disk electrodes with 10 mm diameter were placed on the middle of the biceps brachii muscle belly in the contralateral limb, parallel to the direction of muscle fibers, and they were fixed to the skin with adhesive tape. A bipolar configuration with 20 mm of inter-electrode distances was adopted. The reference electrode was placed on the wrist. EMG signals were recorded by using Nihon Kohden EMG device (model 9400, Japan) with a sampling frequency of 2000 Hz. EMG recording procedure was carried out according to the recommendations of the SENIAM Project (Hermens et al., 1999).

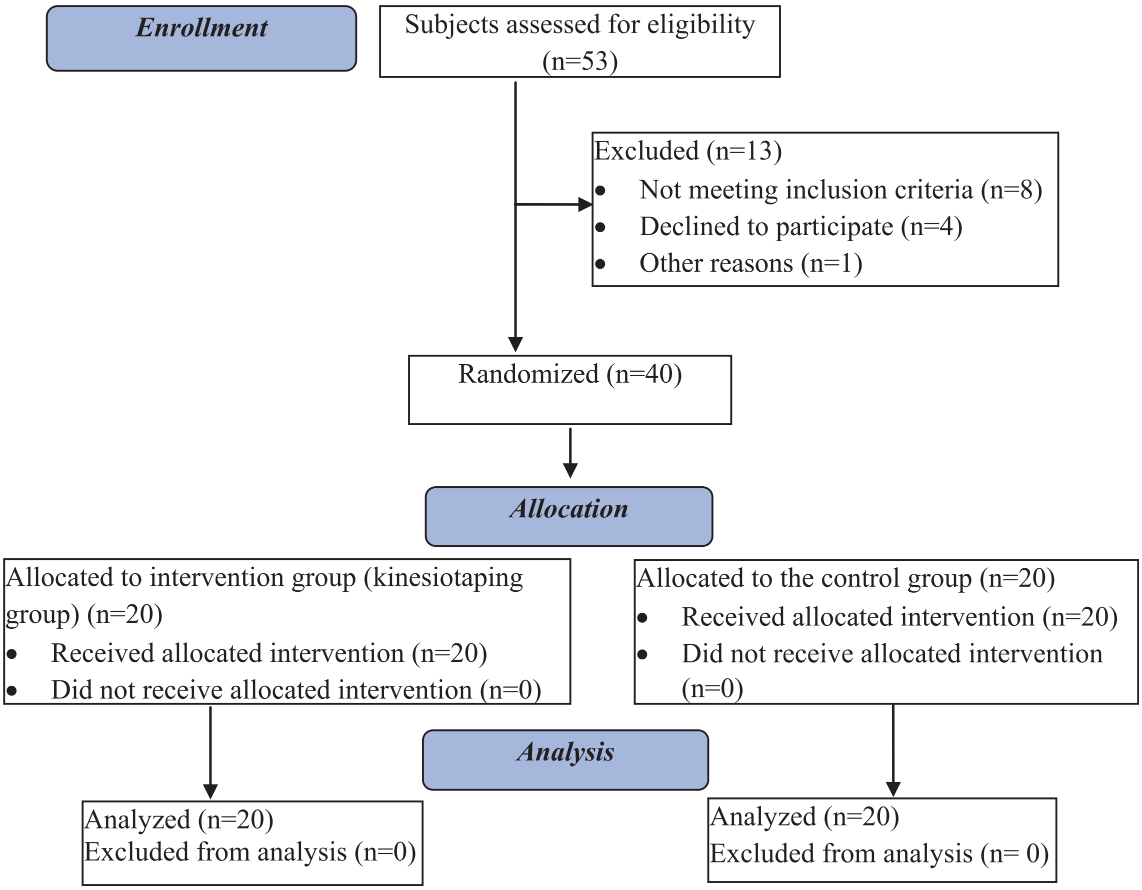

Fig. 2. Flow chart of the study design.

2.6. EMG signal processing

The central 3 s-, 2 s-, and 2 s-long segments of EMG signals were extracted from each trial of the isometric, concentric, and eccentric contractions for the analysis, respectively. First, raw EMG signals were filtered (6th order Butterworth bandpass filter with 50–450 Hz pass-band) and full-wave rectified. Then, the signals were segmented via sliding windows of 200 ms duration. The time interval between the successive windows was chosen as 25 ms (Chen, Zhang, & Zhu, 2013). Root mean square (RMS) value was calculated for each segmented window and the average of the RMS values was calculated for the entire signal. Average RMS values obtained from each subject were normalized to the corresponding maximum EMG value recorded during the MIVC tests. By doing so, muscle activations of the contralateral biceps brachii were expressed as a percentage of the MIVC, which is referred to as $\%EMG_{max}$ (Hazaki, Ichihashi, & Morinaga, 1996).

2.7. Sample size and statistical analysis

A pilot study including data from 10 individuals (five from each group) was conducted to determine the sample size for the present study. The effect size was calculated as 0.97 for the difference of $\%EMG_{max}$ during eccentric contraction between the KT and control groups using GPower program (Faul, Erdfelder, Lang, & Buchner, 2007). Considering this effect size, a priori power analysis yielded a minimum sample size of 36 (18 in each group) to achieve a power equal to 0.80 with a probability of Type I error equal to 0.05. Fig. 2 shows a flow chart for the subjects who were eligible for the study.

The statistical procedure was carried out by using SPSS software (Version 16.0; SPSS; Chicago, IL, USA). Normality of all variables was tested using the Kolmogorov-Smirnov test. The dependent variables ($\%EMG_{max}$ during isometric, concentric, and eccentric contractions and torque values) were not normally distributed therefore they were compared between the two groups using the Mann-Whitney *U* test. The effect size was calculated according to Cohen's definition (d_{Cohen}). We considered that an effect size less than 0.2 was negligible, between 0.2 and 0.5 was small, between 0.5 and 0.8 was moderate, and equal to or greater than 0.8 was large. Differences in the $\%EMG_{max}$ among three contraction types were assessed by the Kruskal–Wallis test for each group (KT and control groups). A *p*-value of less than 0.05 was considered statistically significant with 95% confidence interval.

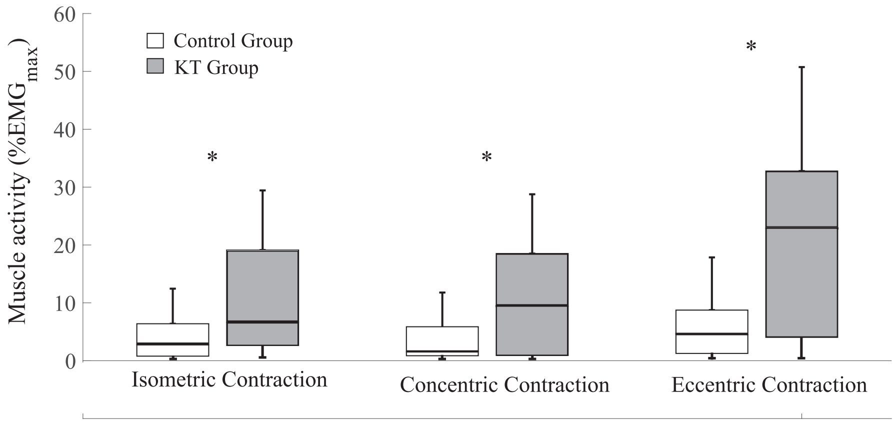

Fig. 3. Comparison of the contralateral muscle activations between the control and kinesiotaping (KT) groups for each type of contraction (%EMG$_{max}$: percentage of maximum isometric voluntary contraction). *differences between groups (KT vs control) with $p < 0.05$.

3. Results

The KT group showed significantly higher %EMG$_{max}$ in the biceps brachii compared to the control group at the contralateral limb during the isometric, concentric, and eccentric contractions ($p = 0.035$, $p = 0.046$, and $p = 0.002$, respectively) (Fig. 3). The median values of the contralateral muscle activity were 2.74 %EMG$_{max}$ and 6.62 %EMG$_{max}$ during the isometric contraction for the control and KT groups, respectively ($p = 0.035$, $d_{Cohen} = 0.708$). During the concentric contraction, the median values of the contralateral muscle activity were 1.61 %EMG$_{max}$ and 9.39 %EMG$_{max}$ for the control and KT groups, respectively ($p = 0.046$, $d_{Cohen} = 0.667$). For the eccentric contraction, the median values of the contralateral muscle activity were 4.49 %EMG$_{max}$ and 22.89 %EMG$_{max}$ for the control and KT groups, respectively ($p = 0.002$, $d_{Cohen} = 1.066$) (Fig. 3).

In the KT group, the contralateral muscle activity during eccentric contraction was higher than those produced during the isometric and concentric contractions ($p = 0.044$), but post hoc test did not reveal a significant difference among them (Fig. 4). In the control group, all contraction types of exercised limb created a similar effect on the contralateral muscle activity ($p = 0.372$) (Fig. 4).

Isometric, concentric, and eccentric maximum torques of the exercised limb were not different between the groups (Fig. 5). The median values of the isometric, concentric, and eccentric maximum torques of the exercised limb were 37.0 Nm and 30.5 Nm ($p = 0.414$), 24.2 Nm and 23.8 Nm ($p = 0.904$), and 36.3 Nm and 36.8 Nm ($p = 0.968$) for the control and KT groups, respectively (Fig. 5). The median values of the maximum contralateral elbow joint torques were 33.0 Nm and 31.5 Nm for the control and KT groups, respectively ($p = 0.715$) (Fig. 6).

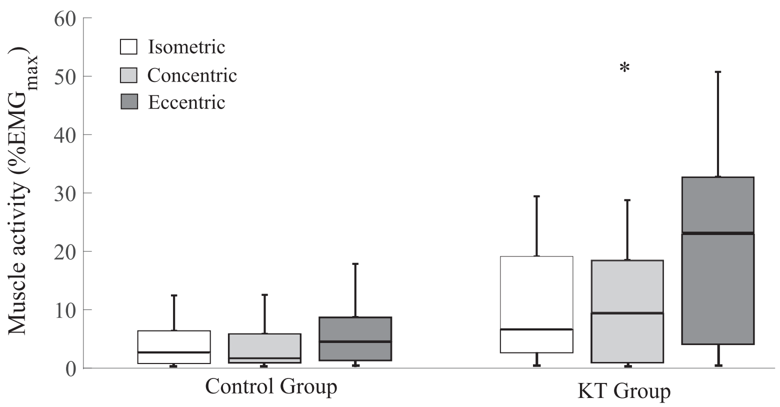

Fig. 4. Intragroup comparisons of the contralateral muscle activations recorded during the isometric, concentric, and eccentric contractions for the control and kinesiotaping (KT) groups (%EMG$_{max}$: percentage of maximum isometric voluntary contraction). *differences in KT group with $p < 0.05$.

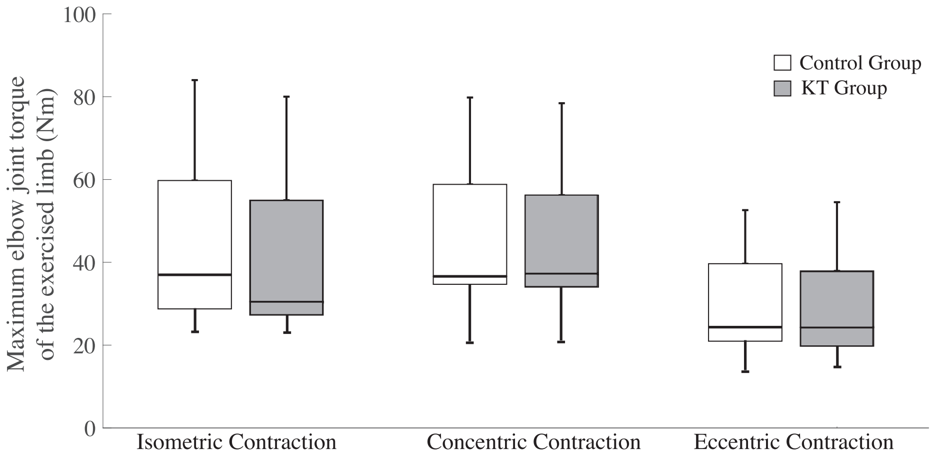

Fig. 5. Maximum elbow joint torques obtained from the exercised limbs during executing the isometric, concentric, and eccentric contractions (KT: kinesiotaping).

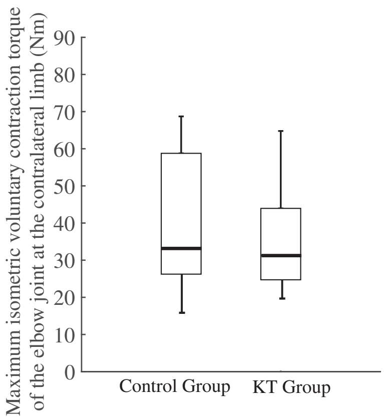

Fig. 6. The contralateral elbow joint torques of the control and kinesiotaping (KT) groups recorded during the maximum isometric voluntary contraction.

4. Discussion

In this study, we aimed to determine the force irradiation effect of the KT on the contralateral muscle activation. We observed that the contralateral muscle activations in the biceps brachii obtained from the KT group were higher than those obtained from the control group, which indicates that the KT induced force irradiation on the contralateral muscle activation. All subjects separately performed isometric, concentric, and eccentric contractions to produce the force irradiation in the contralateral limb. The comparison of contraction types showed that an eccentric contraction created higher contralateral muscle activation than isometric and concentric contractions in the KT group; however, post hoc analysis failed to show a significant difference. Intragroup comparison of the contralateral muscle activations obtained in the control group indicated that contralateral muscle activities were not affected by the type of muscle contraction.

In the present study, KT was applied on the basis of its augmentation effect on the somatosensory inputs in the taped area (Tamburella et al., 2014). It is known that the modulation of the corticospinal output by proprioceptive feedback from resting limb or visual input may affect contralateral activity (Post et al., 2009). Previous studies which focused on the visual feedback and altered sensory input of active limb found greater crossed effects (Hortobágyi et al., 2003; Maudrich et al., 2017; Zult et al., 2016; Zult, Goodall, Thomas, Hortobagyi, & Howatson, 2015). To our best knowledge, there is no study investigating the effects of external (additional) inputs on the contralateral limb to augment the crossed effect. Only Giovannelli et al. (2009) revealed that the real or imagined movement of the contralateral limb during unilateral exercise increases the interhemispheric motor inhibition of the opposite primary motor cortex (Giovannelli et al., 2009). Transcranial stimulation of opposite primary motor cortex during unilateral exercise also promotes the interhemispheric motor inhibition which is a critical factor for crossed effect (Hübers, Orekhov, & Ziemann, 2008). In our study, the contralateral limb was in the resting condition and it was positioned in the same direction with the target movement to prevent asymmetrical orientation. Post et al. related the contralateral muscle activity to the position of contralateral limb and movement direction (Post et al., 2009). When we take our results into consideration we assumed that the occurrence of a change in the somatosensory inputs triggered by the KT was due to the somatosensory re-afferent feedback modulated the motor output of the resting muscle.

KT causes mechanical changes in the muscle and other deep and superficial connective tissues (Pamuk & Yucesoy, 2015). Sensory receptors, which are under the skin and other soft tissues, provide information to the central nervous system. KT increases afferent inputs under the taped area via applying pressure and stretching stimulation to these receptors (Kase et al., 2003; Lin et al., 2011; Tamburella et al., 2014). The information gathered from the mechanoreceptors promotes the blood flow within the cortical, subcortical, and cerebellar regions via the dorsal column. Furthermore, the studies revealed that the effect of somatosensory inputs does not limit the sensorimotor cortex yet, it produces widespread cortical projections (Veldman et al., 2018; Wardman, Gandevia, & Colebatch, 2014). Consequently, the effects of muscle and cutaneous afferent stimulus that are produced by the KT may create a summation effect on the motor activity of the resting limb, which we observed in our study.

Dynamic and static muscle contractions both induce contralateral muscle activation (Panzer, Schinowski, & Kohle, 2011). A study about cross-education suggested that the unilateral eccentric training increased the contralateral muscle strength more than the unilateral concentric training (Hortobagyi, Lambert, & Hill, 1997). On the other hand, the contralateral EMG amplitude was found greater during isometric contractions than those during isotonic contractions (Shinohara et al., 2003). However, Uematsu et al. presented that there were differences between the contraction types on H-reflex, which showed excitability changes at the spinal level, but they could not reveal significant differences among the sequence of isometric, concentric, and eccentric contractions (Uematsu et al., 2010). Our study revealed that eccentric contraction produced higher contralateral muscle activity than the isometric and concentric contractions in the KT group, but the difference was not statistically significant. On the other hand, in the control group, contralateral muscle activity was not affected by the type of contraction. It is considered that the contralateral muscle activity is related to the supracortical level and the KT effect is related to subcortical level (Alexander, Stynes, Thomas, Lewis, & Harrison, 2003), this may explain why we observed difference in the effects of the contraction types on the contralateral muscle activity in the KT group, but not in the control group.

Studies showed that contraction intensities influence the amount of contralateral muscle activity (Abreu et al., 2015). In our study, the maximum torques of both limbs were found to be similar between the KT and control groups, indicating that the differences in the magnitudes of the contralateral muscle activity cannot be attributed to the differences in the magnitudes of the joint torques of the groups.

In our study, one group was formed as a control group whose members performed the unilateral movement without KT. Further studies may investigate the probable effects of the placebo taping and KT on the contralateral muscle activation, especially in patients with neurologic and orthopedic impairments.

5. Conclusion

Our study showed that the KT promotes contralateral muscle activity in the biceps brachii. Eccentric contraction produced more contralateral muscle activity than isometric and concentric contractions in the KT group. We suggest that the KT on the resting limb may promote the force irradiation.

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None.

Declaration of Competing Interest

None.

References

Abreu, R., Lopes, A. A., Sousa, A. S., Pereira, S., & Castro, M. P. (2015). Force irradiation effects during upper limb diagonal exercises on contralateral muscle activation. *Journal of Electromyography and Kinesiology: Official Journal of the International Society of Electrophysiological Kinesiology, 25*, 292–297.

Adamson, M., MacQuaide, N., Helgerud, J., Hoff, J., & Kemi, O. J. (2008). Unilateral arm strength training improves contralateral peak force and rate of force development. *European Journal of Applied Physiology, 103*, 553–559.

Alexander, C., Stynes, S., Thomas, A., Lewis, J., & Harrison, P. (2003). Does tape facilitate or inhibit the lower fibres of trapezius? *Manual Therapy, 8*, 37–41.

Cai, C., Au, I. P., An, W., & Cheung, R. T. (2016). Facilitatory and inhibitory effects of Kinesio tape: Fact or fad? *Journal of Science and Medicine in Sport, 19*, 109–112.

Carson, R. G., & Ruddy, K. L. (2012). Vision modulates corticospinal suppression in a functionally specific manner during movement of the opposite limb. *Journal of Neuroscience, 32*, 646–652.

Cattagni, T., Lepers, R., & Maffiuletti, N. A. (2018). Effects of neuromuscular electrical stimulation on contralateral quadriceps function. *Journal of Electromyography and Kinesiology: Official Journal of the International Society of Electrophysiological Kinesiology, 38*, 111–118.

Cernacek, J. (1961). Contralateral motor irradiation–cerebral dominance. Its changes in hemiparesis. *Archives of Neurology, 4*, 165–172.

Chen, X., Zhang, D., & Zhu, X. (2013). Application of a self-enhancing classification method to electromyography pattern recognition for multifunctional prosthesis control. *Journal of Neuroengineering and Rehabilitation, 10*, 44.

Devine, K. L., LeVeau, B. F., & Yack, H. J. (1981). Electromyographic activity recorded from an unexercised muscle during maximal isometric exercise of the contralateral agonists and antagonists. *Physical Therapy, 61*, 898–903.

Dragert, K., & Zehr, E. P. (2013). High-intensity unilateral dorsiflexor resistance training results in bilateral neuromuscular plasticity after stroke. *Experimental Brain Research, 225*, 93–104.

Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G* Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods, 39*, 175–191.

Giovannelli, F., Borgheresi, A., Balestrieri, F., Zaccara, G., Viggiano, M. P., Cincotta, M., & Ziemann, U. (2009). Modulation of interhemispheric inhibition by volitional

motor activity: An ipsilateral silent period study. *The Journal of Physiology, 587*, 5393–5410.
Halseth, T., McChesney, J. W., DeBeliso, M., Vaughn, R., & Lien, J. (2004). The effects of kinesio™ taping on proprioception at the ankle. *Journal of Sports Science & Medicine, 3*, 1.
Hazaki, K., Ichihashi, N., & Morinaga, T. (1996). Electromyographic analysis of thigh muscles in pnf patterns of the lower extremity: Muscle activities in the lengthened range. *Journal of Physical Therapy, 8*, 29–32.
Hermens, H. J., Freriks, B., Merletti, R., Stegeman, D., Blok, J., Rau, G., ... Hägg, G. (1999). European recommendations for surface electromyography. *Roessingh Research and Development, 8*, 13–54.
Hortobagyi, T., Lambert, N. J., & Hill, J. P. (1997). Greater cross education following training with muscle lengthening than shortening. *Medicine and Science in Sports and Exercise, 29*, 107–112.
Hortobágyi, T., Taylor, J. L., Petersen, N. T., Russell, G., & Gandevia, S. C. (2003). Changes in segmental and motor cortical output with contralateral muscle contractions and altered sensory inputs in humans. *Journal of Neurophysiology, 90*, 2451–2459.
Hübers, A., Orekhov, Y., & Ziemann, U. (2008). Interhemispheric motor inhibition: Its role in controlling electromyographic mirror activity. *European Journal of Neuroscience, 28*, 364–371.
Kase, K., Martin, P., & Yasukawa, A. (2006). Kinesio Taping in Pediatrics: Fundamentals and Whole Body Taping. *Kinesio*.
Kase, K., Wallis, J., Kase, T., & Association, K. T. (2003). *Clinical therapeutic applications of the Kinesio taping methods.* Kinesio Taping Assoc.
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. *Journal of Orthopaedic Research, 29*, 53–57.
Marín, P., Hazell, T., García-Gutiérrez, M., & Cochrane, D. (2014). Acute unilateral leg vibration exercise improves contralateral neuromuscular performance. *Journal of Musculoskeletal and Neuronal Interactions, 14*, 58–67.
Maudrich, T., Kenville, R., Lepsien, J., Villringer, A., Ragert, P., & Steele, C. J. (2017). Mirror electromyographic activity in the upper and lower extremity: A comparison between endurance athletes and non-athletes. *Frontiers in Human Neuroscience, 11*, 485.
Pamuk, U., & Yucesoy, C. A. (2015). MRI analyses show that kinesio taping affects much more than just the targeted superficial tissues and causes heterogeneous deformations within the whole limb. *Journal of Biomechanics, 48*, 4262–4270.
Panzer, S., Schinowski, D., & Kohle, D. (2011). Cross-Education and contralateral irradiation. *Journal of Human Kinetics, 27*, 66–79.
Papandreou, M., Billis, E., Papathanasiou, G., Spyropoulos, P., & Papaioannou, N. (2013). Cross-exercise on quadriceps deficit after ACL reconstruction. *The Journal of Knee Surgery, 26*, 51–58.
Pink, M. (1981). Contralateral effects of upper extremity proprioceptive neuromuscular facilitation patterns. *Physical Therapy, 61*, 1158–1162.
Post, M., Bakels, R., & Zijdewind, I. (2009). Inadvertent contralateral activity during a sustained unilateral contraction reflects the direction of target movement. *Journal of Neuroscience, 29*, 6353–6357.
Shinohara, M., Keenan, K. G., & Enoka, R. M. (2003). Contralateral activity in a homologous hand muscle during voluntary contractions is greater in old adults. *Journal of Applied Physiology, 94*, 966–974.
Tamburella, F., Scivoletto, G., & Molinari, M. (2014). Somatosensory inputs by application of KinesioTaping: Effects on spasticity, balance, and gait in chronic spinal cord injury. *Frontiers in Human Neuroscience, 8*, 367.
Uematsu, A., Obata, H., Endoh, T., Kitamura, T., Hortobágyi, T., Nakazawa, K., & Suzuki, S. (2010). Asymmetrical modulation of corticospinal excitability in the contracting and resting contralateral wrist flexors during unilateral shortening, lengthening and isometric contractions. *Experimental Brain Research, 206*, 59–69.
Urbin, M. A., Harris-Love, M. L., Carter, A. R., & Lang, C. E. (2015). High-intensity, unilateral resistance training of a non-paretic muscle group increases active range of motion in a severely paretic upper extremity muscle group after stroke. *Frontiers in Neurology, 6*, 119.
Veldman, M. P., Maurits, N. M., Zijdewind, I., Maffiuletti, N. A., van Middelkoop, S., Mizelle, J. C., & Hortobagyi, T. (2018). Somatosensory electrical stimulation improves skill acquisition, consolidation, and transfer by increasing sensorimotor activity and connectivity. *Journal of Neurophysiology, 120*, 281–290.
Veldman, M., Zijdewind, I., Solnik, S., Maffiuletti, N. A., Berghuis, K., Javet, M., ... Hortobágyi, T. (2015). Direct and crossed effects of somatosensory electrical stimulation on motor learning and neuronal plasticity in humans. *European Journal of Applied Physiology, 115*, 2505–2519.
Wardman, D. L., Gandevia, S. C., & Colebatch, J. G. (2014). Cerebral, subcortical, and cerebellar activation evoked by selective stimulation of muscle and cutaneous afferents: An fMRI study. *Physiological Reports,* 2.
Zijdewind, I., Butler, J. E., Gandevia, S. C., & Taylor, J. L. (2006). The origin of activity in the biceps brachii muscle during voluntary contractions of the contralateral elbow flexor muscles. *Experimental Brain Research, 175*, 526–535.
Zult, T., Goodall, S., Thomas, K., Hortobagyi, T., & Howatson, G. (2015). Mirror illusion reduces motor cortical inhibition in the ipsilateral primary motor cortex during forceful unilateral muscle contractions. *Journal of Neurophysiology, 113*, 2262–2270.
Zult, T., Goodall, S., Thomas, K., Solnik, S., Hortobagyi, T., & Howatson, G. (2016). Mirror Training Augments the Cross-education of Strength and Affects Inhibitory Paths. *Medicine and Science in Sports and Exercise,* 1001–1013.