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Authors: Timothy T.T. Yam, Peggy P.L. Or, Ada W.W. Ma, Shirley S.M. Fong, Man Sang Wong

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Effect of Kinesio Taping on Y-balance test performance and the associated leg muscle activation patterns in children with developmental coordination disorder: a randomized controlled trial

Timothy T.T. Yam^a, Peggy P.L. Or^b, Ada W.W. Ma^b, Shirley S.M. Fong^{a,*}, Man Sang Wong^c

^aSchool of Public Health, LKS Faculty of Medicine, The University of Hong Kong, Hong Kong

^bDepartment of Health and Physical Education, Faculty of Liberal Arts and Social Sciences, The Education University of Hong Kong

^cDepartment of Biomedical Engineering, Faculty of Engineering, The Hong Kong Polytechnic University, Hong Kong

***Corresponding author at:** School of Public Health, The University of Hong Kong, Pokfulam, Hong Kong. E-mail address: smfong@hku.hk (S.S.M. Fong).

Highlights:

- KT improved YBT performance in children with DCD
- KT showed *positive* effects on neuromuscular balance control
- KT may be incorporated into balance rehabilitation as an adjunct

Abstract

Background: Children with developmental coordination disorder (DCD) have leg muscular deficits which negatively affects their dynamic postural stability. Kinesio tape (KT) could

enhance muscle activation, postural control and functional activities in healthy individuals. Therefore, we hypothesized that the usage of KT may address the postural instability problem of children with DCD.

Research question: To investigate the immediate effect of KT on dynamic postural stability and the associated lower limb muscle activity in children with DCD.

Methods: Forty-nine children with DCD were recruited where twenty-five children were randomly assigned to the KT group (mean age = 8.18 ± 1.16 years) and twenty-four to the control group (mean age = 8.06 ± 0.93 years). KT group received KT application to the rectus femoris and gastrocnemius muscles whereas the control group received no intervention. Measurements were taken before and after the application of KT. Dynamic balance performance was measured using a lower quartile Y-balance test (YBT-LQ). Leg muscle peak activation and time-to-peak muscle activation of the dominant lower limb during YBT-LQ were measured by surface electromyography.

Results: YBT-LQ composite score increased by 6.3% in the KT group at posttest (95% CI: -7.308, -2.480). In addition, a higher rectus femoris peak activation was illustrated for YBT-LQ anterior (32.5%; 95% CI: -48.619, -16.395) and posteromedial (24.6%; 95% CI: -42.631, -6.591) reach directions from pretest values in the KT group. Moreover, KT group exhibited a 38% (95% CI: 0.015, 2.983) longer gastrocnemius medialis time-to-peak duration for YBT-LQ posteromedial reach direction when compared to the control group.

Significance: KT revealed an immediate beneficial effect on YBT-LQ performance. Application of KT also increased rectus femoris peak activation and lengthened the muscle time-to-peak duration for specific reach directions. Incorporating KT as an adjunct with dynamic balance training programme could be beneficial for children with DCD.

Keywords: *developmental coordination disorder*; postural stability; electromyography;
kinesiology tape; dynamic balance

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1. Introduction

Developmental coordination disorder (DCD) is a common neuromotor condition, affecting around 6% of school-age children [1]. Children with DCD demonstrate poor motor control with decreased lower limb muscle power and electromyography (EMG) activity during many daily activities [2,3]. In particular, they exhibit longer hamstring and gastrocnemius muscle activation onset latencies during unexpected perturbations in standing *which accounts to around 20% of balance performance* [4]. *Furthermore, children with DCD have a less competent dynamic balance control measured by the Lower Quarter Y-balance Test (YBT-LQ) which is an equipment to assess dynamic balance performance* [5]. *The motor and balance deficits negatively influence normal daily activities and may persist to adulthood* [6] *which is of great concern for parents, clinicians and teachers.*

Dynamic postural stability involves controlling the body's center of mass within the base of support by generating appropriate feedback and feedforward responses [7]. Feedforward control (*i.e., anticipatory postural adjustment*) is fundamental and generally developed in children as early as age of 6 to reliably control postures and navigate accurately throughout movements [8]. However, children with DCD likely have an underdeveloped and heterogenous feedforward response for dynamic postural adjustments. The dissimilar postural muscle response is the primary cause of atypical feedforward control in children with DCD [5]. Therefore, exploring interventions to improve feedforward postural control and dynamic postural stability is essential.

Kinesio tape (KT) is commonly used in rehabilitation which claims to normalize muscle *tension* [9]. It is because KT stimulates the cutaneous receptors which changes the muscle spindle sensitivity [10] and EMG activity [11]. Previous studies have reported that patients with impaired postural stability, such as those with chronic ankle instability and

patellofemoral pain syndrome, also benefited from KT by improving their neuromuscular control and *feedback/ feedforward* balance performance *measured by the Sensory Organization Test and Kinesthetic Ability Trainer* [12,13]. Therefore, we postulated that KT may also induce positive changes on muscle activity efficiencies and dynamic balance performance in children with DCD. Accordingly, the aim of this study was to investigate the immediate effect of KT on lower limb muscle activity during dynamic balance performance in these children.

2. Methods

2.1. Study design

This randomized controlled study used a parallel-group design. Ethical clearance was obtained from the Human Research Ethics Committee of the University of Hong Kong with the trial registered under the ClinicalTrials.gov (NCT02945124) and was conducted in accordance with the Declaration of Helsinki (2013). Written, informed consents were obtained from participants and parents before the study was administered by two physiotherapists which took place at the Physical Activity Laboratory at the University of Hong Kong.

2.2. Participants

Participants aged 6 to 9 years were recruited from local primary schools and community through invitation letters, advertisements and personal invitations. The two-step method [5] was used to determine children with DCD by using Movement Assessment Battery for Children, 2nd edition [14] and information provided by parents/teachers.

Exclusion criteria consisted of (i) history of serious lower limb injuries (i.e. fractures) which may limit participant's ability to perform large lower limb range of motion movements; (ii) receiving rehabilitative or any related treatments in the recent 2 months; (iii) excessively disruptive behaviour; (iv) inability to follow instructions; (v) tape allergy; (vi) open/chronic wound at the lower limbs; (vii) previous KT experience; or (viii) any disorder (e.g., cardiopulmonary diseases and musculoskeletal problems) that may interfere with children's locomotor or exercise ability.

2.3. Screening, randomization and allocation concealment

An independent individual randomly allocated the eligible participants to either KT or control group (Fig. 1). Block randomization (blocks of four) was used to ensure each group had equal number of participants. Allocation concealment was ensured with sealed opaque envelopes used.

2.4. Taping intervention

The KT group received KT application to the bilateral rectus femoris and gastrocnemius muscles in accordance to the KT application guidelines for paediatric population [9] whereas the control group received no intervention. KT (Kinesio Tex Gold[®], Kinesio Holding Corporation, Albuquerque, NM, USA) was applied *on top of any electrodes* to the participants in a seated position by an experienced physiotherapist. KT application took around 20 minutes for each participant in the KT group whereas control group participants rest in a seated position for that duration.

To maintain the consistency of the KT tension applied to the muscles, the leg length was considered when calculating the KT length with the following equation [5]:

$$\text{Actual length of tape to cut (cm)} = \left[\left(\frac{x - 4}{1.5} \right) + 4 \right] \times 1.10$$

where x is the measured length between the origin and insertion sites. The anchor length was set at 4cm (2cm each for proximal and distal sites).

For the rectus femoris muscle, a Y-shaped KT was applied in a seated position with knee supported in 60° flexion. Proximal and distal end (tension free) were located 5cm below the anterior superior iliac spine and below the patella region at the level of tibial tuberosity, respectively. A 50% tension was present at the middle portion and the medial and lateral tails arising from the tape junction (Fig. 2) [9].

For the gastrocnemius muscle, two I-shaped KT was applied in the seated position with knee in slight flexion and ankle in full dorsiflexion. Proximal and distal end (tension free) were located at the posterolateral aspect of knee just below the knee joint line and at the base of calcaneus, respectively. A 50% tension was present at the middle portion along the medial and lateral heads of gastrocnemius muscle (Fig. 3) [9].

2.5. Test procedures

2.5.1. Demographics

The parents first provided participant information regarding demographics, medical history and details on exercise habits (metabolic equivalent hours/week, exercise intensity, duration and frequency). Physical activity level was expressed in metabolic equivalent value of activity according to the Compendium of Energy Expenditures for Youth [15].

Furthermore, body weight and height were measured by an electronic scale and height stadiometer, respectively.

2.5.2. Maximal voluntary isometric contraction of leg muscles

To compare muscle activation patterns across participants, the maximal voluntary isometric contractions (MVIC) was first measured for rectus femoris, biceps femoris, tibialis anterior and gastrocnemius medialis of the right leg. MVIC testing methods were based on a standardized manual [16] where each muscle was measured twice, with a 1-minute recovery period in between, in a seated position [17]. Raw EMG data *was bandpass filtered (20 to 460Hz) and sampled at a rate of 1000Hz (amplified by a gain factor of 1000)*, and *then* root mean squared (RMS) where the highest EMG_{rms} values were extracted from the two trials and averaged for subsequent data normalization.

2.5.3. YBT-LQ and lower limb EMG activity measurements

All participants performed the YBT-LQ by using the Y-Balance Test Kit™ (Move2Perform, Evansville, IN, USA). Surface EMG electrodes (EMG sensor SX230-1000, Biometrics, Newport, UK) were placed on prepped skin. The circular-shaped Ag/AgCl bipolar surface EMGs with an interelectrode distance of 2cm were applied to the test limb's rectus femoris, biceps femoris, tibialis anterior and gastrocnemius medialis muscles [18]. Foot pressure sensors (FS4 contact switch assembly, Biometrics, Newport, UK) were placed at the base of calcaneus and the base of the first metatarsal of the test limb to register the start of each YBT-LQ trial. The test limb (i.e. weight-bearing limb) was determined as the dominant limb which unilateral recording method was adopted in a previous study [19]. During each YBT-LQ trial, raw EMG data was collected simultaneously. The collected EMG

raw data were recorded set at a bandwidth of 20 to 460 Hz and amplified at a rate of 1000 Hz, with an input impedance at $>10^{15} \Omega$ and common mode rejection ratio $>96\text{dB}$. The ipsilateral tibial tuberosity was chosen as the reference electrode (R506, Biometrics, Newport, UK) location. All equipment was secured with adhesive tape to the skin and wires were bundled and connected to a DataLOG device at the waist level. Data was subsequently processed through the Biometrics EMG analysis software for DataLOG version 8.51 (Newport, UK).

Prior to the six practice trials and official trials of YBT-LQ, a physiotherapist demonstrated each direction with verbal instructions referenced from the Move2Perform website to each participant. *Participants were instructed to push the reach indicator as far as possible at their own pace with the non-weight-bearing limb while keeping their balance.* Three official trials were performed for each direction after the practice trials in the following order: (i) anterior (AT); (ii) posteromedial (PM); and (iii) posterolateral (PL). The maximum reach distance of each successful trial was recorded to the nearest one decimal place and averaged subsequently. The trial was discarded and repeated if the participant (i) kicked/stepped on the reach indicator; (ii) touched the floor at any instance during the trial; or (iii) lost balance.

2.6. Outcome measures

2.6.1. Primary outcome measures

2.6.1.1. YBT-LQ normalized scores

The normalized scores of each reach direction was scaled to the participant's leg length. A total of three successive trials were averaged for the normalized mean reach distance. The composite score was calculated with the following equation:

$$\text{Composite score} = \left[\frac{(AT + PM + PL)}{(\text{Leg length} \times 3)} \right] \times 100$$

2.6.2. Secondary outcome measures

2.6.2.1. Lower limb muscle peak activation

The peak EMG_{rms} value for each YBT-LQ trial and reach direction from three successful trials was extracted from a 100-millisecond window to be averaged. To compare values across participants, averaged values were normalized to the MVIC RMS values of the muscle to be expressed in percentage of MVIC (%MVIC) [20].

2.6.2.2. Time-to-peak EMG_{rms} value of lower limb muscles

The non-weight-bearing limb's starting position was placed with sole contacting the ground. The pressure sensors were located at the base of calcaneus and base of first metatarsal of the non-weight-bearing limb to register the start of the trial when the entire sole left the ground after the verbal cue. The time-to-peak EMG duration (ms) was determined from the onset of foot pressure sensor signal to the peak EMG_{rms} of each muscle.

2.7. Statistical analyses

The sample size calculation was performed by the G*Power version 3.1.0 software (Franz Faul, Universität Kiel, Germany). A previous study investigated the acute effect of KT on lower limb strength and balance measures with medium effect sizes ranging from 0.75-0.94 [21]. Therefore, an effect size of 0.85 was chosen for this study with the statistical power set at 80% and an alpha level at 5% (two-tailed). Assuming no one dropped out (as

participants visited our laboratory once only), a minimum of twenty-three participants were required for each group.

The Statistical Package for Social Science 23.0 (IBM, Armonk, NY) was used for statistical analysis. The normality criterion was checked by using the Shapiro-Wilk test and histogram. Baseline demographic and outcome variable differences between the two groups were determined by using the independent t-test (continuous data) and chi-square (categorical data) accordingly. The overall effect of KT on YBT-LQ performance and EMG outcomes were examined by using two-way repeated measure analysis of covariance. MVIC and EMG patterns may be a potential covariate(s) with significant variability across subjects [3]. The within- and between-subject factors were set as time and group, respectively. Intention-to-treat approach was used to minimize dropout effects, if any. Post-hoc independent t test and paired t test were performed to the outcomes with significant group, time or time-by-group interaction effects. The overall alpha level was set at 5% (two-tailed).

3. Results

3.1. Participants

From March to October 2016, sixty-seven children with DCD were recruited where they were screened by two physiotherapists for eligibility. Forty-nine qualified participants were randomly assigned to the KT group (n=25) and control group (n=24) (Fig. 1). All children were able to complete all testing trials successfully accordingly with no dropout. Table 1 illustrates the baseline demographic characteristics of the participants. No significant between-group differences were found between the two groups ($p > 0.05$). The muscle peak EMG_{rms} (%MVIC) for rectus femoris during PL direction at baseline was treated as a covariate due to a significant difference between the two groups ($p = 0.037$).

3.2. Primary outcome measures

3.2.1 YBT-LQ normalized scores

After KT application, the composite score revealed a significant group \times time effect ($p=0.030$). The YBT-LQ composite score increased by 4.90 points compared to the baseline value in the KT group ($p<0.001$). However, the between-group difference at posttest was not significant ($p>0.05$). Individual reach direction did not reveal within- or between-group differences in either groups (Table 2).

3.3. Secondary outcome measures

3.3.1. EMG_{rms} peak muscle activation

During the AT and PM directions, rectus femoris peak muscle activation illustrated a significant group \times time effect ($p=0.039$ and $p=0.005$, respectively). The KT group exhibited a higher activation than the control group for posttest-values ($p=0.023$ and $p=0.042$, respectively). When comparing posttest to pretest values, both KT and control groups revealed an increase in rectus femoris activation for AT ($p<0.001$ and $p=0.011$, respectively) and PM ($p=0.010$ and $p=0.029$, respectively) directions. Biceps femoris, tibialis anterior and gastrocnemius medialis peak muscle activation for AT and PM directions did not reveal any significant group, time or group-by-time interaction effect. No significant group, time, or group-by-time interaction effects were illustrated in all muscles for the PL reach direction (Table 3).

3.3.2. EMG time-to-peak

For PM direction, there was a significant group \times time effect for the gastrocnemius medialis time-to-peak duration ($p=0.008$). The post-hoc test revealed a significant between-group difference ($p=0.048$) where KT group had a 1.50ms longer duration than the control group for posttest values. Findings showed a 1.32ms decrease in gastrocnemius medialis time-to-peak duration from pretest values in the control group ($p=0.043$) but not in the KT group. No significant group, time and group-by-time interaction effects were noted in the remaining secondary outcome variables (Table 3).

4. Discussion

Our results demonstrated that KT improved YBT-LQ performance and *muscle activity (peak and time-to-peak)* of children with DCD. The results are in line with previous studies that revealed KT applied on quadriceps and gastrocnemius muscles could increase and preserve reach distances during the star excursion balance test (SEBT) in healthy individuals [22,23]. It is because the application of KT provides tactile stimulation to the cutaneous receptors, more specifically the Ia afferent fibres [24]. This increases the gamma motor neuron activities which alters muscle activation patterns [10,25]. The improvement in composite score confirms the immediate beneficial effects of KT on dynamic balance control in children with DCD. However, the posttest values for KT group were not significantly different from the control group suggesting that other factors may contribute to this.

The magnitude of balance improvement may be influenced by the duration of KT application where effects were detected as early as immediately after application to 24-72 hours post KT removal [11,21-23]. Nakajima et al. [22] found that KT improved SEBT performance 24-hours post application but not immediately. The varied effects of KT during different time periods could be attributable to the alteration of muscle tone due to a reflex

effect on the nervous system [11]. We elucidate a longer KT duration may enhance the cutaneous stimulation for more prominent and YBT-LQ reach-direction-specific effects.

The application of KT increased rectus femoris peak muscle activation and the posttest outcome values were significantly greater than that of the control group. During YBT-LQ, the knee is flexed at 60° to 80° with the quadriceps contracting eccentrically to control the single-leg squat movement [20]. AT direction, in particular, has a relatively higher peak quadriceps muscle activation followed by PM and PL, respectively [20]. Interestingly, the higher the required quadriceps activity for the reach direction, the greater the amplitude of quadriceps increments were shown in our results. We postulated that the muscle deficits in children with DCD [2] may predispose the effects of KT influencing on muscle activity.

This is the first study to measure EMG changes with KT application during YBT-LQ. It would be insightful to compare studies assessed by different types of balance valuations. Our results agree with the significant increase in quadriceps muscle activity assessed with single-leg hop test and kinesthetic ability trainer after the application of KT [12,26]. Furthermore, daily activities often incorporate various aspects of balance components. For instance, stair descent and YBT-LQ AT reach direction both involve lowering one's centre of mass in a single-leg stance position [27]. Chen et al. [28] reported that application of KT to the quadriceps increased the vastus medialis obliquus/vastus lateralis ratio during stair descent in patients with patellar femoral pain syndrome. Our study provides *insights* on the potential benefits of KT to not only dynamic balance tasks but specifically to YBT-LQ in children with DCD.

The KT group exhibited longer gastrocnemius medialis time-to-peak duration during PM direction when compared to the control group for posttest values. This reassures the previously reported KT's potential to *influence* muscle activity duration during gait in healthy

individuals [21]. We elucidate the change of muscle activity duration in children with DCD be due to modulation of the skin stretch receptors to compensate for the less developed feedforward system [5,21]. A distinctive feature of YBT-LQ from stair descent is to control ankle plantarflexion at around 20° and having to apply pressure to the reach indicator [20]. Thus, an increase in gastrocnemius time-to-peak duration could be beneficial to YBT-LQ for subtle compensatory postural reactions.

The control group's gastrocnemius medialis time-to-peak duration decreased by 35% from pretest values which is comparable to the recently reported 27-37% shorter duration in children with DCD [5]. Although the time-to-peak duration for the KT group increased by 55% from pretest values, it did not reach a significant level. It is uncertain as to why other muscles did not reveal significant difference. Future research is warranted to investigate the influence of KT on muscle time-to-peak activation.

A limitation was that this study did not investigate the prolonged effect of KT and follow-up effect post KT removal. Determining the optimal KT application duration to enhance dynamic postural control will be essential to optimize balance rehabilitation for children with DCD. Secondly, placebo/sham tape group was not included in this study. Thus, one cannot determine the extent of the KT effect attributable to psychological components. The KT group may have had expectations about the benefits of KT, which may have introduced some biases in the outcomes [29]. *Moreover, it is uncertain if applying KT over EMG electrodes alters its effectiveness which requires further investigation.* Lastly, dynamic postural control can be measured in several forms of which YBT-LQ is one of them. Results should not be overgeneralized to other dynamic postural tasks.

5. Conclusions

The immediate effect of KT to improve YBT-LQ performance was non-specific to reach direction. This was accompanied with a significantly higher amplitude of rectus femoris muscle activity and a longer gastrocnemius medialis time-to-peak muscle activity. Therefore, children with DCD could benefit from using KT as an adjunct when performing dynamic postural control exercises.

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Conflict of interest

The authors declare that they have no conflicts of interest.

Conflict of interest

None declared.

References

- [1] American Psychiatric Association (Ed.), Diagnostic and Statistical Manual of Mental Disorders: DSM-5, 5th ed., American Psychiatric Association, Washington D.C., 2013.
- [2] A.J. Raynor, Strength, power, and coactivation in children with developmental coordination disorder, *Dev. Med. Child Neurol.* 43 (2001) 676–684.
- [3] R.H. Geuze, Postural control in children with developmental coordination disorder, *Neural Plast.* 12 (2005) 183–196.
- [4] S.S.M. Fong, S.S.M. Ng, X. Guo, Y. Wang, R.C.K. Chung, W.Y. Ki, D.J. Macfarlane, Deficits in lower limb muscle reflex contraction latency and peak force are associated with impairments in postural control and gross motor skills of children with developmental coordination disorder: a cross-sectional study, *Med.* 94 (2015) e1785.
- [5] T.T.T. Yam, S.S.M. Fong, Y-balance test performance and leg muscle activations of children with developmental coordination disorder, *J. Motor Behav.* (2018) 1–9, <https://doi.org/10.1080/00222895.2018.1485011>
- [6] M. Cousins, M.M. Smyth, Developmental coordination impairments in adulthood, *Hum Mov Sci*, 22 (2003) 433–459.
- [7] S.L. Westcott, L.P. Lowes, P.K. Richardson, Evaluation of postural stability in children: current theories and assessment tools, *Phys. Ther.* 77 (1997) 629–645.
- [8] R. Grasso, C. Assaiante, P. Prevost, A. Berthoz, Development of anticipatory orienting strategies during locomotor tasks in children, *Neurosci. Biobehav. Rev.* 22 (1998) 533–539.
- [9] K. Kase, P. Martin, A. Yasukawa, *Kinesio Taping® in Pediatrics: Fundamentals and Whole Body Taping*, Albuquerque, 2006.

- [10] Y. Konishi, Tactile stimulation with Kinesiology tape alleviates muscle weakness attributable to attenuation of Ia afferents, *J. Sci. Med. Sport.* 16 (2013) 45–48.
- [11] A. Slupik, M. Dwornik, D. Bialoszewski, E. Zych, Effect of Kinesio Taping on bioelectrical activity of vastus medialis muscle. Preliminary report, *Ortop. Traumatol. Rehabil.* 9 (2007) 644–651.
- [12] A. Aytar, N. Ozunlu, O. Surenkok, G. Baltacı, P. Oztop, M. Karatas, Initial effects of kinesio® taping in patients with patellofemoral pain syndrome: A randomized, double-blind study, *Isokinet. Exerc. Sci.* 19 (2011) 135–142.
- [13] C. de-la-Torre-Domingo, I.M. Alguacil-Diego, F. Molina-Rueda, A. López-Román, J. Fernández-Carnero, Effect of kinesiology tape on measurements of balance in subjects with chronic ankle instability: A randomized controlled trial, *Arch. Phys. Med. Rehab.* 96 (2015) 2169–2175.
- [14] S.E. Henderson, D.A. Sugden, A.L. Barnett, *Movement Assessment Battery for Children*, 2nd ed., Harcourt Assessment, London, 2007.
- [15] K. Ridley, B.E. Ainsworth, T.S. Olds, Development of a compendium of energy expenditures for youth, *Int. J. Behav. Nutr. Phy.* 5 (2008) 45.
- [16] H.M. Clarkson, *Musculoskeletal assessment: Joint range of motion and manual muscle strength*, 2nd ed., Lippincott Williams & Wilkins, Philadelphia, 2000.
- [17] V.C. Dionisio, G.L. Almeida, M. Duarte, R.P. Hirata, Kinematic, kinetic and EMG patterns during downward squatting, *J. Electromyogr. Kines.* 18 (2008) 134–143.
- [18] M. Barbero, R. Merletti, A. Rainoldi, *Atlas of Muscle Innervation Zones – Understanding Surface Electromyography and Its Applications*, Springer Milan, Milano, 2012.

- [19] M.H. Kang, D.K. Lee, K.H. Park, J.S. Oh, Association of ankle kinematics and performance on the Y-balance test with inclinometer measurements on the weight-bearing-lunge test, *J. Sport Rehabil.* 24 (2015) 62–67.
- [20] J.E. Earl, J. Hertel, Lower-extremity muscle activation during the star excursion balance tests, *J. Sport Rehabil.* 10 (2001) 93–104.
- [21] J. Martínez-Gramage, M.A. Merino-Ramirez, J.J. Amer-Cuenca, J.F. Lisón, Effect of Kinesio Taping on gastrocnemius activity and ankle range of movement during gait in healthy adults: A randomized controlled trial, *Phys. Ther. Sport* 18 (2016) 56–61.
- [22] M.A. Nakajima, C. Baldrige, The effect of kinesio[®] tape on vertical jump and dynamic postural control, *Int. J. Sports Phys. Ther.* 8 (2013) 393–406.
- [23] N. Zulfikri, M. Justine, Effects of kinesio[®] taping on dynamic balance following fatigue: A randomized controlled trial, *Phys. Ther. Res.* 20 (2017) 16–22.
- [24] R. Bravi, E.J. Cohen, E. Quarta, A. Martinelli, D. Minciocchi, Effect of direction and tension of kinesio taping application on sensorimotor coordination, *Int. J. Sports Med.* 37 (2016) 909–914.
- [25] A. Prochazka, P. Ellaway, Sensory systems in the control of movements, *Compr. Physiol.* 2 (2012) 2615–2627.
- [26] I.K. Ahn, Y.L. Kim, Y.H. Bae, S.M. Lee, Immediate effects of kinesiology taping on quadriceps on motor performance after muscle fatigued induction, *Evid-Based. Compl. Alt.* (2015) 1–7.
- [27] S.J. Kinzey, C.W. Armstrong, The reliability of the star-excursion test in assessing dynamic balance, *J. Orthop. Sports Phys. Ther.* 27 (1998) 356–360.

[28] P.L. Chen, W.H. Hong, C.H. Lin, W.C. Chen, Biomechanics effects of kinesiio taping for persons with patellofemoral pain syndrome during stair climbing. In 4th Kuala Lumpur International Conference on Biomedical Engineering 2008, Berlin, 2008, pp. 395–397.

[29] M.T. Crocetti, D.D. Amin, R. Scherer, Assessment of risk of bias among pediatric randomized controlled trials, *Pediatr.* 126 (2010) 298–305.

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Figure captions

Fig. 1. CONSORT flowchart

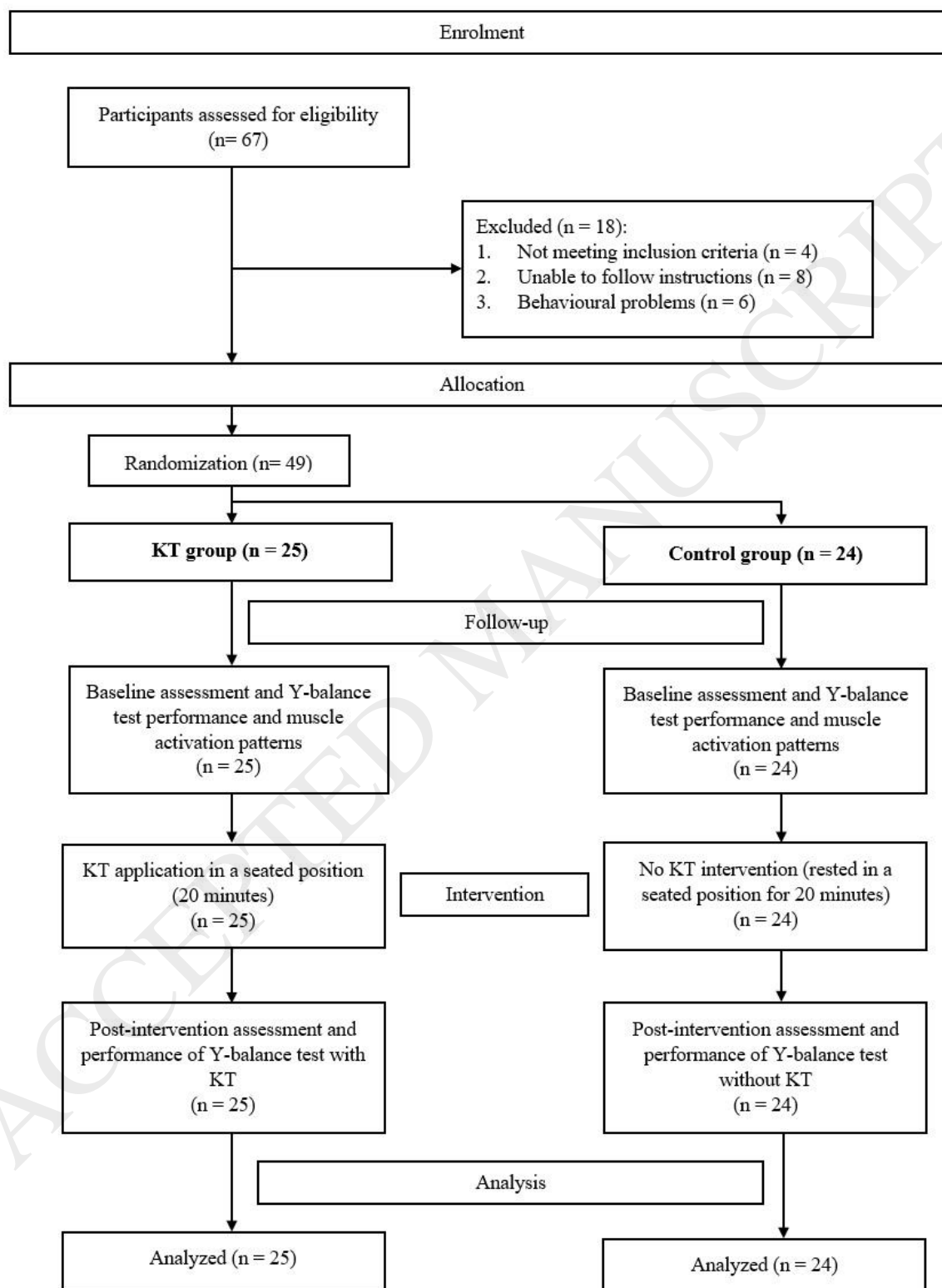


Fig. 2. Kinesio tape application on the rectus femoris muscle



Fig. 3. Kinesio tape application on the gastrocnemius muscle



Tables

Table 1: Baseline characteristics of participants with DCD

| | KT group (n = 25) | Control group (n = 24) | p value |
|--|----------------------|---------------------------|---------|
| Age (years) | 8.18 ± 1.16 | 8.06 ± 0.93 | 0.696 |
| Sex | | | 0.520 |
| Male (n, %) | 17 | 19 | |
| Female (n, %) | 8 | 5 | |
| Height (cm) | 125.40 ± 10.47 | 128.33 ± 8.70 | 0.292 |
| Body weight (kg) | 24.93 ± 6.18 | 27.75 ± 7.87 | 0.169 |
| Body mass index (kg/m ²) | 15.69 ± 2.36 | 16.59 ± 3.28 | 0.272 |
| Leg length (cm) | 64.74 ± 6.84 | 65.19 ± 6.77 | 0.819 |
| MABC-2 (percentile) | 7.26 ± 5.74 | 9.23 ± 6.19 | 0.254 |
| Manual dexterity (percentile) | 12.46 ± 15.53 | 14.52 ± 17.02 | 0.660 |
| Aiming & catching (percentile) | 11.24 ± 15.09 | 8.52 ± 11.61 | 0.484 |
| Balance (percentile) | 26.18 ± 22.70 | 33.60 ± 28.51 | 0.318 |
| Physical activity level (metabolic equivalent hours/week) | 10.71 ± 10.26 | 8.05 ± 5.23 | 0.261 |
| Comorbid conditions (n, %) | | | 0.143 |
| Attention deficit hyperactivity disorder | 0 (0%) | 2 (8.3%) | |
| Autism spectrum disorder | 4 (16%) | 1 (4.2%) | |
| Dominant lower limb | | | |
| Right (n, %) | 24 (96.0) | 24 (100.0) | |
| Left (n, %) | 1 (4.0) | 0 (0.0) | |
| EMG MVIC values (μV) | | | |
| Quadriceps | 3.00 ± 0.86 | 2.75 ± 0.95 | 0.341 |
| Hamstring | 3.09 ± 1.00 | 3.11 ± 1.01 | 0.929 |
| Tibialis anterior | 3.91 ± 1.36 | 3.75 ± 1.23 | 0.680 |

| | | | |
|---------------|-----------------|-----------------|-------|
| Gastrocnemius | 2.09 ± 1.19 | 1.82 ± 0.93 | 0.381 |
|---------------|-----------------|-----------------|-------|

Means \pm standard deviations are presented (unless otherwise specified)

KT: Kinesio Taping; DCD: developmental coordination disorder; MABC-2: Movement Assessment Battery for Children 2nd edition; EMG: electromyography; MVIC: maximal voluntary isometric contraction

Table 2: Comparison of Y-balance test normalized scores between the KT and control groups

| Y-balance test normalized scores | KT group (n = 25) | | | Control group (n = 24) | | | Between-group mean difference at posttest (KT - Control) (95% CI) |
|----------------------------------|-------------------|----------------------------|--|------------------------|---------------|--|---|
| | Pretest | Posttest | Within-group mean difference (pre - post) (95% CI) | Pretest | Posttest | Within-group mean difference (pre - post) (95% CI) | |
| Anterior | 39.70 ± 6.65 | 40.92 ± 8.07 | -1.22 (-3.265, 0.825) | 40.21 ± 7.47 | 39.32 ± 8.34 | 0.89 (-1.767, 3.538) | -0.92 (-3.12, 1.28) |
| Posteromedial | 57.20 ± 12.20 | 60.68 ± 13.21 | -3.48 (-7.699, -2.301) | 60.04 ± 11.56 | 60.08 ± 13.55 | -0.04 (-6.148, -0.143) | 0.04 (-6.25, 6.17) |
| Posterolateral | 55.83 ± 12.59 | 60.83 ± 14.38 | -5.00 (-5.861, -1.099) | 55.42 ± 13.42 | 58.56 ± 15.27 | -3.14 (-4.054, 3.971) | 3.14 (-7.09, 0.81) |
| Composite Score ^d | 77.79 ± 16.25 | 82.69 ± 18.41 ^c | -4.90 (-7.308, -2.480) | 79.62 ± 12.15 | 79.83 ± 14.08 | -0.21 (-3.846, 3.427) | 0.21 (-6.58, 6.16) |

KT: Kinesio Taping; DCD: developmental coordination disorder; MVIC: maximal voluntary isometric contraction; EMG_{rms}: electromyographic root mean squared value

Group-by-time interaction effect:

^aDenotes a significant group-by-time interaction effect ($p < 0.05$).

Between-group effect:

^bDenotes a significant difference at $p < 0.05$ when compared with the control group.

Within-group effect:

^cDenotes a significant difference at $p < 0.05$ when compared with the pre-test value.

Remarks:

^dComposite score = [(anterior + posterolateral + posteromedial) / (leg length × 3)] × 100

Table 3: Comparison of EMG outcome measures between the KT and control groups

| Muscle peak EMG _{rms} (%MVIC) for Y- balance test | KT group (n = 25) | | | Control group (n = 24) | | | Between mean at p (KT (95% |
|---|-------------------|---------------------------------|---|------------------------|-------------------------------|---|--|
| | Pretest | Posttest | Within-group mean difference (pre - post) (95% CI) | Pretest | Posttest | Within-group mean difference (pre - post) (95% CI) | |
| Anterior | | | | | | | |
| Rectus femoris | 23.46 ± 13.68 | 55.96 ± 36.84 ^{b,c} | -32.50 (-48.619, -16.395) | 23.18 ± 13.43 | 36.08 ± 19.33 ^c | -12.90 (-22.544, -3.251) | 1 (2.868 |
| Biceps femoris | 34.44 ± 15.86 | 72.22 ± 33.91 | -37.78 (-51.569, -23.998) | 29.29 ± 15.22 | 55.47 ± 26.99 | -26.18 (-38.836, -13.537) | 1 (-0.912 |
| Tibialis anterior | 44.18 ± 24.33 | 76.58 ± 35.39 | -32.40 (-49.629, -15.173) | 49.06 ± 30.33 | 84.22 ± 35.67 | -35.16 (-53.676, -16.657) | - (-28.06 |
| Gastrocnemius medialis | 66.46 ± 42.14 | 181.51 ± 137.85 | -115.05 (-174.337, - 55.767) | 74.51 ± 45.38 | 187.11 ± 143.36 | -112.60 (-172.446, - 52.753) | - (-86.40 |
| Posteromedial | | | | | | | |
| Rectus femoris | 46.56 ± 25.15 | 71.17 ± 41.10 ^{b,c} | -24.61 (-42.631, -6.591) | 61.20 ± 22.39 | 48.55 ± 34.20 ^c | 12.65 (1.445, 23.846) | 2 (0.838 |
| Biceps femoris | 60.50 ± 25.21 | 54.57 ± 29.84 | 5.93 (-11.037, 22.899) | 56.11 ± 22.59 | 48.67 ± 33.63 | 7.44 (-4.859, 19.739) | 5 (-12.35 |
| Tibialis anterior | 95.55 ± 59.93 | 96.94 ± 34.09 | -1.39 (-28.133, 25.353) | 121.66 ± 57.67 | 94.73 ± 41.70 | 26.93 (2.646, 51.211) | 2 (-19.64 |
| Gastrocnemius medialis | 130.29 ± 86.70 | 156.59 ± 114.64 | -26.30 (-85.479, 32.867) | 145.86 ± 105.26 | 155.80 ± 125.47 | -9.94 (-85.126, 65.251) | 0 (-72.10 |
| Posterolateral | | | | | | | |
| Rectus femoris | 62.82 ± 33.00 | 68.03 ± 40.16 | -5.21 (-21.696, 11.279) | 55.17 ± 19.98 | 54.43 ± 24.80 | 0.74 (-11.747, 13.220) | 1 (-5.683 |
| Biceps femoris | 59.59 ± 24.27 | 53.75 ± 29.31 | 5.84 (-6.888, 18.550) | 66.40 ± 40.23 | 55.91 ± 34.85 | 10.49 (-9.261, 30.242) | - (-20.63 |
| Tibialis anterior | 102.76 ± 42.90 | 102.88 ± 45.36 | -0.12 (-23.421, 23.169) | 124.95 ± 58.64 | 100.00 ± 38.60 | 24.95 (-3.849, 53.746) | 2 (-21.37 |
| Gastrocnemius medialis | 130.76 ± 74.89 | 163.65 ± 114.08 | -32.89 (-87.044, 21.268) | 156.40 ± 96.02 | 151.66 ± 85.27 | 4.74 (-38.287, 47.764) | 1 (-46.08 |
| Time-to-peak EMG (ms) for Y- balance test | | | | | | | |
| Anterior | | | | | | | |
| Rectus femoris | 3.28 ± 1.61 | 4.22 ± 3.10 | -0.94 (0.648, -2.285) | 3.65 ± 2.71 | 4.53 ± 4.32 | -0.88 (-2.784, 1.021) | - (-2.46 |
| Biceps femoris | 2.91 ± 1.86 | 3.39 ± 3.25 | -0.48 (-2.114, 1.151) | 2.47 ± 2.11 | 3.70 ± 3.15 | -1.23 (-2.955, 0.498) | - (-2.14 |
| Tibialis anterior | 2.90 ± 2.14 | 3.49 ± 3.82 | -0.59 (-2.069, 0.895) | 2.73 ± 1.87 | 3.39 ± 4.08 | -0.66 (-2.808, 1.685) | 0 (-2.17 |
| Gastrocnemius medialis | 3.11 ± 1.91 | 4.31 ± 2.95 | -1.20 (-2.346, -0.059) | 3.28 ± 2.56 | 3.84 ± 2.79 | -0.56 (-1.712, 0.581) | 0 (-1.18 |
| Posteromedial | | | | | | | |

| | | | | | | | |
|---------------------------|----------------|-----------------------------|--------------------------|----------------|-----------------------------|--------------------------|--------------|
| Rectus femoris | 3.40 ± 2.26 | 3.32 ± 2.89 | 0.09 (-0.727, 0.902) | 3.99 ± 2.88 | 3.45 ± 3.68 | 0.54 (-0.719, 1.795) | - (-2.03) |
| Biceps femoris | 3.70 ± 2.58 | 4.42 ± 3.69 | -0.72 (-2.217, 0.786) | 3.90 ± 2.25 | 4.00 ± 3.99 | -0.10 (-1.826, 1.632) | 0 (-1.78) |
| Tibialis anterior | 2.91 ± 2.46 | 4.01 ± 3.60 | -1.10 (-2.392, 0.196) | 3.43 ± 2.98 | 3.24 ± 3.48 | 0.19 (-1.153, 1.527) | 0 (-1.26) |
| Gastrocnemius medialis | 2.54 ± 1.51 | 3.94 ± 3.21 ^b | -1.40 (-2.837, 0.045) | 3.76 ± 2.69 | 2.44 ± 1.70 ^c | 1.32 (0.042, 2.588) | 1 (0.01) |
| Posterolateral | | | | | | | |
| Rectus femoris | 3.60 ± 2.57 | 3.80 ± 3.25 | -0.20 (-1.572, 1.173) | 3.53 ± 2.95 | 3.88 ± 4.63 | -0.35 (-2.317, 1.605) | - (-2.37) |
| Biceps femoris | 4.18 ± 2.72 | 3.63 ± 2.70 | 0.55 (-0.362, 1.466) | 4.13 ± 2.73 | 4.19 ± 4.48 | -0.06 (-1.789, 1.671) | - (-2.67) |
| Tibialis anterior | 3.22 ± 2.58 | 3.28 ± 3.20 | -0.06 (-1.131, 1.000) | 2.51 ± 2.21 | 3.41 ± 4.69 | -0.90 (-2.998, 1.206) | - (-2.42) |
| Gastrocnemius medialis | 2.98 ± 2.60 | 3.34 ± 2.12 | -0.36 (-1.401, 0.678) | 3.24 ± 2.12 | 3.92 ± 4.75 | -0.68 (-2.360, 0.998) | - (-2.68) |

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