

Effect of Kinesio taping on electromyographic activity of leg muscles during gait in children with developmental coordination disorder

A randomized controlled trial

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Abstract

Objective: This study aimed to evaluate the effectiveness of Kinesio tape (KT) on lower limb muscle activation pattern in children with developmental coordination disorder (DCD) during walking.

Design: A parallel-group randomized controlled trial.

Setting: University laboratory setting.

Participants: Twenty-five children with DCD were randomly allocated to the KT group (mean age=7.97 years) and 24 to the control group (mean age=8.04 years).

Intervention: KT group received KT application to the quadriceps and gastrocnemius muscles whereas the control group received no intervention.

Measurements: Peak muscle activation (in percentage of maximal voluntary isometric contraction [%MVIC]) in the lower limbs during gait was measured by means of surface electromyography, electrogoniometry, and foot contact switches.

Results: Gastrocnemius medialis activation during mid stance (23.46%MVIC, 95% CI=−32.53, −14.39) and late stance phases (3.25%MVIC, 95% CI=−5.67, −0.81) of gait increased after the application of KT in the KT group compared to baseline values. The KT group demonstrated 26.87%MVIC (95% CI=26.87, 7.11) higher gastrocnemius medialis muscle peak activation during mid stance phase at post-test when compared with the control group. Moreover, gastrocnemius medialis and biceps femoris muscle peak activation during loading response decreased by 8.36%MVIC (95% CI=2.71, 14.02) and 3.54%MVIC (95% CI=1.08, 6.01), respectively, in the control group overtime.

Conclusions: The application of KT on children with DCD had an increased gastrocnemius medialis muscle activation during stance phase. KT could be incorporated into gait re-education programmes to facilitate muscle contraction in these children.

Abbreviations: %MVIC = percentage of maximal voluntary isometric contraction, DCD = developmental coordination disorder, DSM-V = Diagnostic and Statistical Manual of Mental Disorder 5th Edition, EMG = electromyographic, KT = Kinesio tape, MABC-2 = Movement Assessment Battery for Children, 2nd edition, MET = metabolic equivalent, RMS = root mean square.

Keywords: developmental disabilities, electromyography, Kinesio tape, kinetics, rehabilitation, walking

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1. Introduction

Developmental coordination disorder (DCD) is a neurodevelopmental condition characterized by motor deficits and impairments that affect daily living activities.^[1] This condition constitutes around 6% of the pediatric population.^[2] Among the many motor deficits and impairments found in children with DCD, atypical gait pattern^[3] and leg neuromuscular control^[4,5] are 2 major concerns of parents and therapists as they lead to the higher incidence of trips and falls^[6] and may affect motor development.^[7] Previous studies have shown that children with DCD exhibit a weaker gait propulsion strategy primarily because of a reduction in gastrocnemius and quadricep muscle activity.^[3,4,8] A weaker gastrocnemius during stance and swing phases^[3,8] may decrease the ability to generate and sustain adequate ankle plantarflexor energy throughout the gait cycle. Having a lower quadricep muscle strength and power^[4] could influence the shock absorption ability of the leg after heel strike and during loading response phases of gait.^[9] Moreover, an inadequate control of the lower limb muscles increases the gait

variability and gait inconsistencies in children with DCD.^[10] These neuromuscular deficits and atypical gait kinetics result in a less energy efficient walking pattern which is more evident in higher demand locomotion (i.e., running).^[11] The gross motor deficits poses physical limitations in daily activities in children with DCD. Early and effective interventions for improving neuromuscular control in the lower limbs to improve gait pattern in children with DCD are deemed necessary.

Lately, Kinesio tape (KT) has gained considerable amount of popularity from its publicity through worldwide sports events. KT claims to optimize muscle function^[12] as the tactile properties of KT provide stimulation to cutaneous receptors which alter the skeletal muscle activity. It has been revealed to improve the peak gastrocnemius force immediately and 2 days after application in young healthy adults.^[13] KT also increases the vastus medialis oblique electromyographic (EMG) activity in subjects with patellofemoral pain.^[14] A previous study illustrated that KT improves the synchronization of rhythmic movements in healthy subjects.^[15] Furthermore, KT facilitates lower limb muscle strength and power during walking and possibly reduces fatigue in healthy individuals.^[16] Therefore, children with DCD may benefit from KT's potential to enhance gait performance by facilitating lower limb muscle activity and neuromuscular control.^[15,16] However, no study has proven KT's effect on gait kinetics in children with disability thus far. The aim of this study was to investigate the effect of KT on lower limb kinetics during gait in children with DCD. We hypothesized that the application of KT on lower limb muscles would positively alter muscle activation pattern during walking in these children.

2. Methods

2.1. Study design

This was a parallel-group randomized controlled trial. Due to the nature of KT application, both the participants and assessors were not blinded to group assignment. To avoid ascertainment bias after data collection, identities of study groups were censored to the person in charge of data analyses. This study was registered at the ClinicalTrials.gov (NCT02945124) and approved by the Human Research Ethics Committee of the University of Hong Kong. Details of the study were thoroughly explained to the participants and parents before obtaining written, informed consent from them. All procedures were conducted in accordance with the Declaration of Helsinki (2013) which was administered by 2 physiotherapists at the Physical Activity Laboratory at the University of Hong Kong.

2.2. Participants

Participants were recruited from local primary schools and the community through invitation letters, posters, social media, and personal invitations. To determine children with DCD, a 2-step method was used:

- (i) children aged 6 to 9 years with fine and gross motor difficulties were chosen to participate in this study;
- (ii) determination of DCD was assessed against the Diagnostic and Statistical Manual of Mental Disorder 5th Edition (DSM-V)^[2] using the Movement Assessment Battery for Children, 2nd edition (MABC-2)^[17] for screening.

Criterion A of DSM-V was fulfilled with a score ≤ 15 th percentile on the MABC-2 Test indicating that motor skills were below that of the expected age. Teachers and/or parents provided

information regarding the interference of daily activities due to motor difficulties and the onset of symptoms (criteria B & C). Lastly, parents completed questions to rule out that motor deficits were not neurologically or intellectually related (criterion D). The DCD questionnaire (DCDQ)^[18] was used to provide additional information.

Exclusion criteria consisted of:

- (i) history of serious lower limb injuries including fractures;
- (ii) receiving rehabilitative or any related treatments in the recent 2 months;
- (iii) excessively disruptive behavior;
- (iv) inability to follow instructions;
- (v) tape allergy;
- (vi) previous KT experience; or
- (vii) 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

The children were screened by 2 physiotherapists before baseline assessments. Participants were randomly allocated to either a KT group or a control group by an independent person (Fig. 1). To ensure an equal number of participants in each group, block randomization (with blocks of 4) was used. Allocation concealment was ensured by using sealed opaque envelopes.

2.4. Intervention

After the baseline assessments, children in the KT group received KT intervention—with the participant in sitting, KT (Kinesio Tex Gold[®], Kinesio Holding Corporation, Albuquerque, NM) was applied to bilateral rectus femoris and gastrocnemius muscles by an experienced physiotherapist. All KT applications were intended to facilitate muscle activation using methods specifically designed for the pediatric population.^[12] It took about 20 minutes to complete the following procedures of KT application for each child.

First, a Y-shaped KT was applied to the rectus femoris muscle in a seated position with the knee supported in 60 degrees flexion. Application details were as follows:

- (i) proximal end of the tape, that was tension free, was placed 5 cm below the anterior superior iliac spine;
- (ii) middle portion of the tape was stretched and applied with 50% tension along the belly of quadriceps muscle until it reached the base of the patella;
- (iii) at the tape junction, medial and lateral tails were applied with 50% tension at the borders of the patella; and
- (iv) distal ends of the tape were placed below the patella region at the level of tibial tuberosity with no tension (Fig. 2).

Then, 2 I-shaped KTs were applied to the gastrocnemius muscle (medial and lateral heads) with slight knee flexion and ankle in full dorsiflexion. Application details included:

- (i) proximal end of the tape, with no tension, was placed at the posteromedial aspect of knee just below the knee joint line;
- (ii) middle part of the tape was stretched and applied with 50% tension along the medial gastrocnemius muscle; and
- (iii) distal end of the tape, which was free of tension, was taped at the base of calcaneus. The above procedures were repeated for taping the lateral gastrocnemius muscle (Fig. 3).

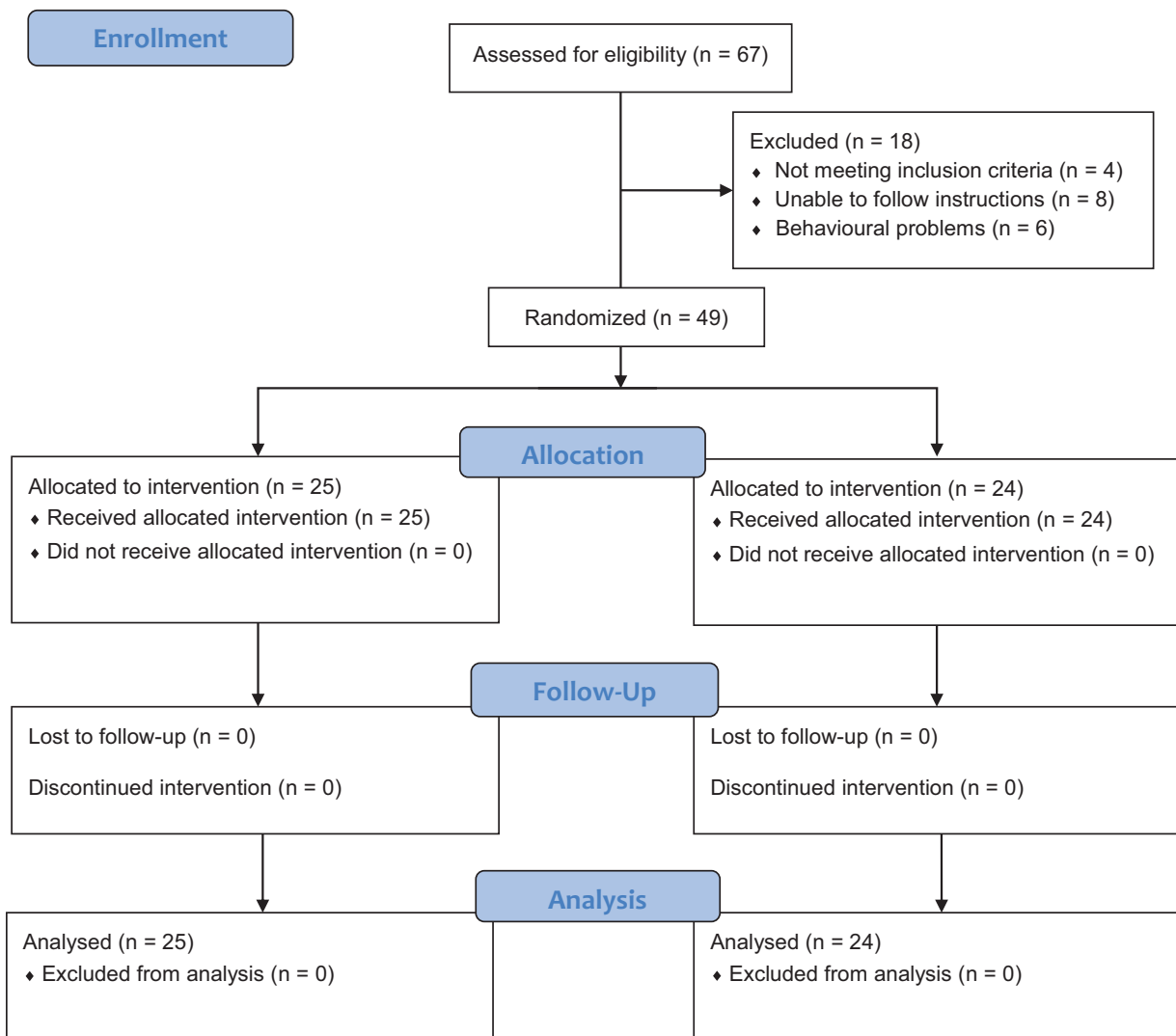


Figure 1. A CONSORT flow diagram.

To ensure that the tension of the tape was consistent with all participants in the KT group, the following equation was used to determine the length of the KT^[19]:

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

where *x* is the measured length between the origin and insertion sites. The anchor length was set at 4 cm (2 cm each for proximal and distal sites). The control group received no KT intervention and rested in a seated position for 20 minutes.

2.5. Test procedures

2.5.1. Demographics. Demographic information, medical history, and exercise habits were obtained from parents before the physical assessments. Body weight and height were measured by an electronic scale and height stadiometer, respectively. Body mass index was then calculated by dividing body weight by the square of height. Physical activity level (in metabolic equivalent [MET] hours/week) was also estimated on the basis of exercise

intensity, duration, frequency and the MET value of the activity in the Compendium of Energy Expenditures for Youth.^[20]

2.5.2. Maximal voluntary isometric contraction of leg muscles. Before the actual gait analysis, maximal voluntary isometric contractions (MVIC) of the 4 major lower limb muscles (rectus femoris, biceps femoris, tibialis anterior, and gastrocnemius medialis) of the right leg were assessed using standardized manual muscle testing methods^[21] and surface electromyography (EMG). MVIC was measured, with the subject in a seated position, twice for each muscle^[22] with a 1-minute recovery period between measurements. EMG data was subsequently filtered, and root mean squared (RMS). The highest EMG_{rms} values from the 2 trials of each leg muscle were averaged and used for later data normalization.

2.5.3. Primary and secondary outcome measurements. All participants, regardless of group assignment, underwent the following kinetic gait assessment on a motorized treadmill before (baseline assessment) and after the intervention period (post-test) (OA Flow Diagram). Skin of the EMG electrode placement sites



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



Figure 3. Kinesio tape application on the gastrocnemius muscle.

was first prepped with alcohol swabs and shaved where necessary to reduce skin impedance. Circular Ag/AgCl bipolar surface EMG electrodes (interelectrode distance of 1 cm) (EMG sensor SX230-1000, Biometrics, Newport, UK) were then applied to the right leg muscles (rectus femoris, biceps femoris, tibialis anterior, and gastrocnemius medialis) according to the locations specified by Barbero, Merletti, & Rainoldi.^[23] The right limb was chosen based on the assumption of bipedal gait symmetry. Raw EMG data was sampled at a rate of 1000 Hz which was amplified ($\times 1000$) with a bandwidth of 20 to 460 Hz (input impedance at $>10^{15} \Omega$ and a common mode rejection ratio >96 dB).^[24] A reference electrode (R506, Biometrics, Newport, UK) was placed at the ipsilateral tibial tuberosity. A pair of foot pressure sensors (FS4 contact switch assembly, Biometrics, Newport, UK) was

applied on the right heel and first metatarsal to register heel strike and toe-off phases of gait. To monitor knee flexion and extension during gait, an electrogoniometer (twin-axis goniometer SG150B, Biometrics, Newport, UK) was placed at the lateral knee joint. Knee flexion and extension were used to determine the remaining stance and swing phases due to its considerable contribution to stance^[25] and swing^[26] phases. Signals from the EMG electrodes, electrogoniometer, and foot contact switches were recorded by a DataLOG device (Biometrics, Newport, UK) for later offline analysis. The DataLOG uses a high-pass filter (20 Hz) to remove movement artefact and DC offsets due to membrane potential, and a low-pass filter (450 Hz) to remove noise contamination of the EMG signals.^[27] It was securely attached to the participant's waist during data collection.

After attaching all the devices, participants wore socks during the gait assessment on a motorized treadmill (KLS-008 2B2, X2Fit treadmill, PT. Maharupa Gatra, Indonesia) for about 15 minutes (10 minutes of familiarization, followed by 2-minute actual testing and recording of data, and 3-minute cool down).^[8] Treadmill speed was scaled to the leg length (L) of the participant with a Froude number (Fr) of 0.15 in the following equation^[3]:

$$Fr = \frac{v^2}{g \cdot L}$$

where v is velocity (m/s) and g is the acceleration of gravity (m/s^2).

Offline signal processing and data analysis were performed using a Biometrics software (DataLOG PC Software version 8.51). Peak EMG_{rms} value of each leg muscle during different phases of gait was first identified. The peak EMG_{rms} value of each leg muscle was then normalized against the RMS value of the MVIC of that particular muscle. Therefore, all EMG outcomes were expressed as a percentage of maximal voluntary isometric contraction (%MVIC). The primary outcome measures were rectus femoris and gastrocnemius medialis muscle peak EMG_{rms} during gait as KT was applied on these muscles. Secondary outcome measures included biceps femoris and tibialis anterior muscle peak EMG_{rms} during gait.

2.6. Statistical analyses

Sample size was calculated by using the G*Power version 3.1.0 software (Franz Faul, Universität Kiel, Germany). A previous study that investigated the effects of KT on lower limb EMG patterns during walking in healthy individuals had effect sizes ranging from 0.75 to 0.94.^[28] Therefore, an effect size of 0.85 was used in this study. Statistical power was set at 80% and a 2-tailed alpha level at 5%. 23 participants for each group were required to detect a within-between group interaction effect in the leg muscle activation outcomes.

Statistical analyses were performed using the Statistical Package for Social Science (SPSS) 23.0 software (IBM, Armonk, NY). The Shapiro-Wilk test was used to ensure that normality criterion was met for continuous data. Independent t test (continuous data) and chi-square test (categorical data) were used to compare demographic characteristics and outcome variables at baseline between the 2 groups. Any significant baseline between-group differences were treated as covariates in subsequent analyses. Two-way repeated measure analysis of covariance (ANCOVA) was used to examine the overall effect of KT on muscle activation outcomes. The within-subject factor was time whereas between-subject factor was group. An intention-to-treat

approach was adopted to minimize the effects of dropouts. Post hoc independent *t* test and pairwise *t* test were then used, as appropriate, to reveal the between- and within-group effects, respectively. The alpha level was set at 5% (2-tailed).

3. Results

3.1. Participants

Between March and October 2016, 67 children with DCD were recruited for this study and were screened by 2 physiotherapists. Forty-nine of them were eligible to participate in the study and were randomly assigned to either a KT group ($n=25$) or a control group ($n=24$) (Fig. 1). The participation rate in the KT intervention was 100% and no one dropped out. None of the participants used medication before the assessments and intervention.

Baseline demographic characteristics revealed no significant between-group differences ($P>.05$) (Table 1). However, when comparing the baseline peak muscle activation values, rectus femoris peak EMG_{rms} for heel strike ($P=.022$) and late swing ($P=.034$) phases were different between the 2 groups (Table 2). Thus, the baseline values of these 2 outcomes were treated as covariates in the subsequent analyses.

3.2. Primary outcome measures

Our results revealed that gastrocnemius medialis muscle peak activation during mid stance phase of gait increased significantly by 23.46% MVIC (95% CI = -32.53, -14.39; $P<.001$) after the application of KT. The KT group did demonstrate higher gastrocnemius medialis muscle peak EMG_{rms} value than the control group at post-test (between-group difference = 26.87% MVIC; 95% CI = 26.87, 7.11; $P<.001$). Furthermore, gastrocnemius medialis muscle peak activation during late stance phase

of gait also improved by 3.25% MVIC (95% CI = -5.67, -0.81; $P=.011$) at post-test when compared to the baseline value though the group effect was not significant ($P=.685$) (Table 2).

During loading response, there was a decrease in muscle peak activation of the gastrocnemius medialis (8.36% MVIC; 95% CI = 2.71, 14.02; $P=.006$) from baseline to post-test in the control group. However, such decline in peak muscle activity was not observed in the KT group ($P>.05$). No significant group, time and group-by-time interaction effects were noted in all other primary outcome variables (Table 2).

3.3. Secondary outcome measures

Our results also revealed that during loading response, there was a decrease in muscle peak activation of the biceps femoris (3.54% MVIC; 95% CI = 1.08, 6.01; $P=.007$) from baseline to post-test in exclusively the control group. No significant group, time, and group-by-time interaction effects were noted in all other secondary outcome variables (Table 2).

3.4. Adverse events

No adverse events were reported during the assessments and intervention. No child felt discomfort or had adverse reactions after the application of KT.

4. Discussion

To the best of our knowledge, this was the first study to explore the immediate effects of KT on gait muscle activation pattern in children with DCD. Our results generally supported our hypothesis which revealed a positive KT effect on gastrocnemius medialis muscle activation while suboptimal biceps femoris and gastrocnemius medialis activation patterns were illustrated during gait without the application of KT. Specific gait phases

Table 1

Baseline characteristics of children participants with DCD.

	KT group (n=25)	Control group (n=24)	P value
Age, yr	7.97 ± 1.15	8.04 ± 0.98	.826
Sex			.321
Male (n, %)	17 (68.0)	21 (87.5)	
Female (n, %)	8 (32.0)	4 (12.5)	
Height, cm	123.92 ± 9.36	128.86 ± 8.78	.077
Body weight, kg	23.95 ± 5.11	27.57 ± 7.74	.058
Leg length, cm	63.56 ± 7.23	65.04 ± 7.18	.477
Body mass index, kg/m ²	15.50 ± 2.25	16.40 ± 3.06	.246
MABC-2, percentile	7.70 ± 5.62	9.23 ± 6.18	.369
DCD questionnaire 2007 total score	46.64 ± 13.47	42.50 ± 10.85	.243
Physical activity level (metabolic equivalent hours/week)	12.28 ± 10.77	7.38 ± 5.37	.051
Treadmill speed, km/h	1.28 ± 0.25	1.20 ± 0.36	.332
Comorbid conditions (n, %)			1.000
Attention deficit hyperactivity disorder	1 (4.0)	1 (4.2)	
Autism spectrum disorder	3 (12.0)	3 (12.5)	
EMG MVIC values (μV)			
Quadriceps	1.41 ± 0.41	1.24 ± 0.50	.215
Hamstring	1.41 ± 0.45	1.36 ± 0.58	.746
Tibialis anterior	1.83 ± 0.59	1.70 ± 0.56	.444
Gastrocnemius	0.92 ± 0.55	0.80 ± 0.43	.422

Means ± standard deviations are presented (unless otherwise specified).

KT = Kinesio taping, DCD = developmental coordination disorder, MABC-2 = Movement Assessment Battery for Children 2nd edition, DCDQ = developmental coordination disorder questionnaire, MET = metabolic equivalent, EMG = electromyography, MVIC = maximal voluntary isometric contraction.

Table 2**Comparison of outcome measurements between the KT and control groups.**

Muscle peak EMG _{rms} (%MVIC) during different phases of gait	KT group (n=25)		Control group (n=24)		P value		Group x time effect
	Pre-test	Post-test	Pre-test	Post-test	Group effect	Time effect	
Heel strike							
Rectus femoris	8.36 ± 4.60	6.92 ± 3.36	13.99 ± 11.03	10.72 ± 8.76	.949	.163	.949
Biceps femoris	15.67 ± 8.20	15.27 ± 9.57	17.07 ± 10.20	13.92 ± 8.68	.944	.880	.268
Tibialis anterior	10.75 ± 7.46	12.46 ± 8.70	13.13 ± 9.26	12.94 ± 8.49	.735	.731	.443
Gastrocnemius medialis	13.66 ± 9.13	12.11 ± 12.55	20.15 ± 16.52	13.52 ± 9.77	.450	.806	.409
Loading response							
Rectus femoris	7.66 ± 3.16	5.76 ± 2.12	10.88 ± 7.59	9.05 ± 7.02	.558	.108	.961
Biceps femoris	17.64 ± 9.74	18.28 ± 11.83	17.53 ± 12.74	13.99 ± 13.83 [‡]	.747	.209	.016*
Tibialis anterior	8.18 ± 8.54	7.65 ± 8.59	8.75 ± 8.03	8.58 ± 5.44	.887	.358	.544
Gastrocnemius medialis	17.37 ± 12.25	17.48 ± 13.80	25.74 ± 22.45	17.38 ± 16.77 [‡]	.376	.229	.032*
Mid stance							
Rectus femoris	2.56 ± 2.23	2.27 ± 1.72	3.63 ± 3.85	2.81 ± 2.97	.934	.698	.779
Biceps femoris	7.41 ± 5.49	10.48 ± 10.70	9.55 ± 7.03	8.20 ± 6.66	.990	.438	.159
Tibialis anterior	6.48 ± 5.38	6.40 ± 5.02	9.29 ± 11.12	7.01 ± 7.40	.738	.365	.235
Gastrocnemius medialis	35.37 ± 19.20	58.83 ± 25.1 ^{‡,†}	31.29 ± 25.73	31.96 ± 24.59	.054	.069	.002*
Late stance							
Rectus femoris	2.72 ± 1.68	1.78 ± 1.14	5.00 ± 5.55	3.84 ± 7.34	.348	.051	.689
Biceps femoris	4.38 ± 3.85	4.38 ± 3.01	5.27 ± 5.12	4.12 ± 3.52	.637	.532	.881
Tibialis anterior	13.21 ± 10.32	11.24 ± 8.18	15.26 ± 10.27	16.22 ± 15.76	.702	.690	.325
Gastrocnemius medialis	6.90 ± 5.77	10.15 ± 8.84 [‡]	8.09 ± 6.65	6.69 ± 7.47	.685	.453	.004*
Toe-off							
Rectus femoris	4.05 ± 2.61	2.70 ± 1.75	5.88 ± 5.77	4.61 ± 6.90	.634	.007	.772
Biceps femoris	5.61 ± 5.67	3.99 ± 3.48	6.38 ± 8.22	5.11 ± 6.95	.960	.510	.327
Tibialis anterior	17.68 ± 13.96	18.01 ± 13.91	17.33 ± 10.11	17.62 ± 9.53	.567	.271	.874
Gastrocnemius medialis	6.01 ± 7.52	5.25 ± 4.44	5.44 ± 3.40	6.24 ± 6.92	.792	.262	.167
Early swing							
Rectus femoris	3.72 ± 2.67	2.09 ± 1.15	5.36 ± 5.79	4.75 ± 7.91	.454	.136	.460
Biceps femoris	4.88 ± 3.57	4.61 ± 3.95	4.43 ± 3.44	3.98 ± 3.18	.311	.869	.971
Tibialis anterior	18.99 ± 13.79	20.76 ± 14.02	20.30 ± 9.71	21.33 ± 14.22	.759	.690	.473
Gastrocnemius medialis	5.08 ± 4.51	5.37 ± 4.86	5.42 ± 4.38	4.82 ± 3.20	.575	.533	.684
Mid swing							
Rectus femoris	3.87 ± 2.31	2.93 ± 1.36	6.33 ± 5.79	4.74 ± 4.56	.431	.586	.728
Biceps femoris	11.64 ± 7.90	9.10 ± 5.63	11.90 ± 9.82	10.70 ± 8.80	.911	.454	.371
Tibialis anterior	9.09 ± 7.31	8.88 ± 6.83	10.82 ± 8.31	11.33 ± 9.28	.586	.185	.741
Gastrocnemius medialis	8.82 ± 10.53	7.37 ± 7.45	6.33 ± 5.55	6.91 ± 6.03	.488	.432	.362
Late swing							
Rectus femoris	7.10 ± 4.15	5.72 ± 3.51	11.59 ± 8.94	8.52 ± 7.64	.444	.961	.444
Biceps femoris	14.95 ± 7.24	16.40 ± 10.94	16.45 ± 10.87	14.94 ± 9.73	.896	.422	.297
Tibialis anterior	10.94 ± 7.11	11.03 ± 7.06	11.64 ± 10.21	11.01 ± 6.08	.908	.331	.508
Gastrocnemius medialis	13.67 ± 10.61	14.33 ± 12.23	14.81 ± 12.28	12.74 ± 11.36	.797	.597	.591

DCD = developmental coordination disorder, EMG_{rms} = electromyographic root mean squared value, KT = Kinesio taping, MVIC = maximal voluntary isometric contraction.

Group-by-time interaction effect:

* Denotes a significant group-by-time interaction effect ($P < .05$).

Between-group effect:

† Denotes a significant difference at $P < .05$ when compared with the control group.

Within-group effect:

‡ Denotes a significant difference at $P < .05$ when compared with the pre-test value.

showed dissimilar lower limb muscle activation patterns between the KT and control groups and before and after KT application which will be further discussed in the subsequent paragraphs.

4.1. Leg muscle activation pattern during mid stance and late stance phases

During mid and late stance phases of gait, gastrocnemius medialis muscle peak activation increased by 47.1% and 66.3% from pre-test values, respectively, in the KT group. Furthermore, the KT group had a 26.87%MVIC higher gastrocnemius medialis activity than the control group at mid-stance phase. Our results

agree with previous studies that KT enhanced kinetic gait performance.^[16,29] Indeed, previous studies have shown that KT enhanced gastrocnemius activity in healthy individuals.^[30,31] Lumbroso et al revealed a 46 Newton and 137 Newton increase in gastrocnemius peak force immediately and 2 days after KT application, respectively.^[30] KT also enhanced the EMG activity of gastrocnemius medialis when performing a vertical jump task.^[31] Although the EMG activity for vertical jump was different from walking, the importance of gastrocnemius muscle power during stance phase cannot be overlooked. During the late stance phase, gastrocnemius muscle generates the highest power in a gait cycle to accelerate limb to swing phase.^[9] Thus, it is

comprehensible that gastrocnemius, which is emphasized in stance phase, reveal larger increases in EMG activities after KT application. Our findings unveiled that KT positively altered gastrocnemius medialis activity during stance phase.

We elucidated such favorable gait kinetic changes to be attributable to the stimulation of cutaneous receptors by KT. With the application of KT, skin deforms which stretches both muscles and fascia.^[32] It has been proposed that KT stimulates cutaneous receptors, specifically the Ia sensory fibers.^[15] The primary afferent fiber responds to muscle length changes contributing to proprioception and movement.^[33] Additionally, the Ia pathway contributes to adaptive changes of ankle plantarflexion activity during walking.^[34] A previous study has revealed that tactile stimulation from KT inhibited the decline of both muscle strength and EMG activity in the rectus femoris muscle through the Ia pathways.^[35] This increases the gamma motor neuron activity which heightens the muscle spindle sensitivity.^[35] Through the fusimotor system, alpha motor neuron is enhanced which alters the muscle activity.^[36,37] All these physiological mechanisms may explain our findings that gastrocnemius medialis muscle peak activation was higher during mid and late stance phases after the application of KT in the KT group.

An interesting finding in this study was that despite we applied KT on the rectus femoris directly; muscle activity during mid to late stance phase was not altered. This actually agrees with de Jesus et al where KT did not improve quadriceps strength and lower limb function in healthy individuals.^[14] It is plausible that children with DCD who have a weaker knee muscle strength and power adopt a gait pattern with an increased knee flexion before stance phase.^[3,4] The lack of full utilization of quadriceps at stance phase may hinder KT to reach its full potential. Moreover, we found that KT had no effects on biceps femoris and tibialis anterior during mid and late stance phases. This finding was expected since both are not primary muscles for stance phase and we did not apply KT on these two muscles directly. Further studies may explore the direct and indirect effects of KT on gait kinetics in children with DCD.

4.2. Leg muscle activation pattern during loading response phase

KT revealed no positive effects on leg muscle activity during loading response phase. The result was not surprising because, at loading response, the two key muscles rectus femoris and tibialis anterior contract eccentrically to control knee flexion and descent foot slowly to the ground, respectively.^[38] It has been reported that KT was effective in enhancing concentric but not eccentric muscle work.^[31,39] It is because the concentric and eccentric contraction mechanisms are inherently different with unique motor units recruitment order.^[39,40]

Our results also showed a decrease in biceps femoris and gastrocnemius medialis muscle activity in the control group overtime. The exact physiological mechanism was not known. Perhaps it was related to muscle fatigue,^[41] increased gait complexity^[10] and neuromuscular deficits^[4] in children with DCD. Further study is required to explore the kinetic changes associated with prolonged walking in this group of children.

4.3. Leg muscle activation pattern during heel strike, toe-off, early swing, mid swing, and late swing phases

Our results revealed that KT was not effective in enhancing rectus femoris, biceps femoris, tibialis anterior and gastrocnemius

medialis muscle activation during heel strike, toe-off, early swing, mid swing, and late swing phases of gait in children with DCD. Although rectus femoris and biceps femoris are the primary muscles for heel strike and late swing phases respectively,^[9] our findings did not exhibit any positive effects with KT. Since the spinal feedback and peripheral control are impaired in children with DCD,^[42] sensory input from KT may be integrated differently. Whether children with DCD have a dissimilar response or not after KT application is still uncertain. Further research is warranted to explore how sensory input from KT interacts with primary muscles for specific gait phases in children with DCD.

4.4. Limitations and clinical implications

This study had some limitations. First, it did not include a placebo/sham tape group where one could not distinguish if results were due to physiological or psychological sources. Second, findings of this study applied to children with DCD which limited the generalizability of results to adults and children with other disabilities. Third, EMG was the primary outcome for this study thus including both kinetic and kinematic measures in the future may provide a more comprehensive outlook of gait in children with DCD. Finally, only the immediate effects of KT on gait performance were investigated. Further research is warranted to investigate the prolonged effects of KT on locomotion in children with DCD. Nevertheless, our results suggest that KT is a promising tool to include as an adjunct into gait rehabilitation programmes for children with DCD to facilitate leg muscle activation, in particular, the weak gastrocnemius^[8] during stance phase of gait.

5. Conclusions

Applying KT to facilitate rectus femoris and gastrocnemius unveiled an immediate effect on increasing gastrocnemius medialis peak activation from mid to late stance phase. However, other gait phases did not provide definite pointers on its influence from KT. In conclusion, KT has favorable effects on gait performance in children with DCD and could be used as an adjunct in gait re-education programmes.

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