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ORIGINAL RESEARCH PAPER

LOWER EXTREMITY MUSCLE CO-CONTRACTION AT STANCE PHASE DURING GAIT IN CHILDREN WITH AND WITHOUT DISABILITIES

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Abstract

The purpose of this study was to determine the differences of muscle co-contraction in the leading leg in 45 children (20 girls and 25 boys) with disabilities (intellectual, visual, hearing and functional) (n = 31, mean age 8.6±1.2 years) and without disabilities (n = 14, mean age 9.3 ±1.3 years). This study analysed co-contraction in knee and ankle joints during stance phase of the gait circle. BTS FREEEMG 1000 (BTS, Garbagnate Milanese MI, Italy) was used to collect EMG signals from the four muscles (m.biceps femoris, m.rectus femoris and m.tibialis anterior, medial head of m.gastrocnemius). The percentage of co-contraction (% COCON) was calculated and compared between children with and without disabilities. Pearson`s correlation did not reveal significant association between stance phase duration and agonist/antagonist co-contraction of m.gastrocnemius and m.tibialis, and m. biceps femoris and m.rectus femoris muscles in children with and without disabilities. Conclusions: This study provides evidence that lower extremity stance phase duration have no impact to muscle co-contraction during the normal walking. While this might be explained by movement restrictions associated with various disabilities, it cannot be explained by association between muscle co-contraction and stance phase duration.

Key words: *stance phase, gait, co-contraction*

Introdaction

Increased physical fitness (both cardiorespiratory fitness and muscular strength), reduced body fatness, favourable cardiovascular and metabolic disease risk profiles, enhanced bone health and reduced symptoms of depression (WHO, 2010). Previous studies of children with physical disabilities (Bloemen et al., 2015; Jaarsma 2014), intellectual disabilities (Arim et al., 2012), visual and hearing impairment (Majlesi et al., 2014; Dursuns et al., 2015) have indicated that they face multitude barriers of participation in daily social and physical activities. Bloemen et al. (2015) and Malina (2014) has explained participation in physical activity as any movements produced by skeletal muscles which results energy expenditure. Energy expenditure is main indicator of physical activities level. The World Health Organization (WHO) recommends children and youth aged 5 – 17 to accumulate at least 60min of moderate – to vigorous intensity physical activity every day.

While walking activities are recommended to increase the level of daily physical activity (WHO, 2010), walking ability depends on locomotor or gait quality. If the child's walking ability is affected by disability then he/or she might not be able to reach the recommended level of physical activity. Furthermore, it create barriers for participation in social events and decreases social engagement, for example, enjoying being with friends or playing soccer (Ross et al., 2016a; Ross et al. 2016b, Must et al., 2015; Shields et al., 2016). Many authors have studied relationship between gait related factors and subject's health aspects and its impact on gait pattern in children with cerebral palsy (Bojanic et al., 2011; Desloovere et all., 2006) and children with intellectual disabilities (Mohd-Nor et al., 2016). However, only few studies have explored this relationship in heterogeneous group of children with and without disability. For example, Majlesi et al. (2014) and Rine et al. (2004) found relevance between the quality of gait and statistic balance. Also, fall risk prediction has showed positive association with gait pattern in children with hearing impairments. Importance of balance during a gait and association with muscle co-contraction has been showed in previous studies (Rosa et al., 2014).

According Perry (1992) each gait cycle is divided into two periods, (1) stance and (2) swing phase. Stance is the term used to describe the entire period during which the foot is on the ground. Stance begins with initial contact and ends when the foot is lifted from the floor (toe-off). At 60% of gait cycle are consist of stance phase, while swing phase is 40% (Mohd-Nor et al., 2016). Increased duration of muscle co-contraction has been recognised as strategy to improve walking stability. Hallal et al. (2013) reported that excessive levels of co-contraction in older adults might lead to higher energy expenditure during ambulation, especially for persons with cognitive impairments. Also, co-contraction in the stance phase had significant associations with physical measures and co-contraction in the swing phase had significant associations with cognitive measures (Benedetti et al., 2010; Detrembleur et al., 1997). Also, Hallal et al. (2013) and Lo et al (2017) proposed to consider co-contraction in separate gait phases.

The purpose of this study is to determine the differences of muscle co-contraction of the leading leg in children with and without disabilities during a stance phase.

Materials and Methods

Subjects

Participants were 45 children (20 girls and 25 boys) with and without various disabilities recruited from special and general education programs. They were divided in two subgroups, (1) children without disability, and (2) children with disability. The first group included 14 children without disability (6 girls and 8 boys). The mean age was 8.6 ±1.2 years, the mean height was 139.10 ± 12.6 cm, the mean weight was 30.2 ± 78.3kg. Second group included 31 children with mild to moderate intellectual, visual, hearing and functional (14 girls and 17 boys) with mean age of 9.3±1.3 years; mean height 138.00±10.2; mean weight 30.4±7.2. Inclusion criteria were following, (1) 7 to 12 years old; (2) ability to perform 10 m walk without walking devices; and (3) ability to understand instructions and to follow the test procedure. Exclusion criteria were severing musculoskeletal disorders, neurological pathology and orthopaedic surgery during last three month.

Data were recorded in the Kinesiology Laboratory at the Latvian Academy of Sports Education after approval was obtained from the Research Ethics Committee. Participant's parents signed informed consent forms. The research was undertaken in compliance with ethical principles oh Helsinki Declaration.

Procedure of Data Collection

Data were obtained from EMG signal analysis of the four muscles in the dominant leg muscles (m.biceps femoris (BF), m.rectus femoris (RF) and m.tibialis anterior (TA), medial head of m.gastrocnemius (MG)) during stance phase. BTS FREEEMG 1000 (BTS, Garbagnate Milanese MI, Italy) was used to collect data. To define the dominant/ leading leg each participant was asked to answer following question: "Which leg you would use to kick a ball?". Surface EMG probes were attached to m.tibialis anterior, medial head of m.gastrocnemius, m.rectus femoris, and lateral hamstring m.biceps femoris as it was reported in previous studies (Hallal et al., 2013; Lo et al., 2017; Bojanic et al., 2011). To detect signals, adhesive Ag/AgCl electrodes (Covidien, UK) with an effective diameter of 10mm and an inter-electrode distance of 20mm (center to center) were used.

According standards for surface electromyography called "Surface EMG for non-invasive assessment of muscles (SENIAM)" recommendations, before electrode placement, the skin was cleaned with alcohol and shaved (if needed), electrodes were placed to the belly of selected muscles (Bojanic et al., 2011; Rainoldi et al., 2004). After positioning of electrodes, children were instructed to walk barefoot at their natural pace over the straight track with force plates, which were synchronized with EMG and used to identify phases of gait. Before the beginning of the gait trials, all participants were familiarized with test procedure and practiced walking for 3 min at their preferred gait speed (Dingwell & Marin, 2006). After the familiarization, five different trials were recorded. Trials were not retained when the participant made excessive movements of the head, arms or trunk unrelated to walking. Despite careful measurement, some trials had to be omitted due to irregularities in the kinematics of heal strike (Mahdi et al., 2014). Gait stance phase was identified based on data from the force plate (BTS P-6000, 60 x 40cm, BTS, Garbagnate Milanese MI, and Italy). These data were collected unilaterally as subjects walked over the two force plates at regular walking speed, from heel strike to toe-off. Trial was considered valid when a full heel strike pattern was captured by the pressure plate per walk (Agostini et al., 2014; Shanthikumar et al., 2009).

Signal processing

Signal from the force plate was used to extract the individual stance phases of the gait cycle; data were sampled at 1.080Hz and filtered with a 2^{nd} order bidirectional. Butterworth filter using a low-pass frequency of 50Hz was used to corrected phase. Data were collected unilaterally as each participant walked over the force plate at his/her self-selected walking speed, from heel strike to toe-off. To overcome artifact-connected problems EMG signals were processed with BTS SMART – Analyzer (BTS Bioengineering, Padua) using a Butterworth bandpass fourth order filter of 20–400Hz, full-wave rectification, and then a Butterworth low pass, fourth order filter with a cut-off frequency of 6 Hz to calculate linear envelopes. A similar method was reported in previous studies (Hallal et al., 2006; Hermens et al., 2000).

Gait Analysis

First, the stance phase duration was measured. The length of stance was defined as the time during the gait cycle when the foot is in contact with the ground (Lo et al., 2017). The mean stance phase duration of the leading leg was calculated from all five recorded trials for each participant.

According to SENIAM (1997) and Standards for reporting EMG data (ISEK) (Merletti, & Torino,1999) and recommendations of Konrad (2005) and Perry (1992), EMG data normalization was applied. The linear EMG envelopes of each muscle were time normalized to the mean duration of that particular stance phase obtained in all five strides. The whole stance phase was represented in percentages from 0 to 100%. The next step was to normalize the EMG amplitude, which is crucial for comparisons between muscles, subjects and groups. The amplitudes of the linear envelopes from all five strides of each muscle were averaged, and the peak value of the mean pattern was normalized to the same procedure was perform to create mean pattern for each group.

The percent co-contraction between the agonist/antagonist muscles RF/BF and TA/GM were calculated using the following equation:

$$\%COCON = 2 * \frac{common\ area\ A\ \&\ B}{area\ A + erea\ B} * 100$$

Where % COCON is the percentage of co-contraction between the agonist/antagonist muscles; area A is the area below the processed EMG curve of muscle A; area B is the area below the processed EMG curve of muscle B, common area A & B is the area under the curves shared by both muscle A and muscle B during an average stance phase (Fig. 1) (Candotti et al., 2009; Hallal et al., 2013; Lo et al., 2017).

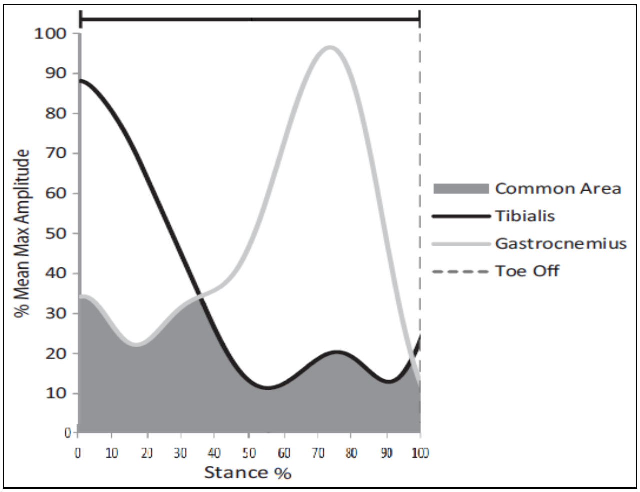

Figure 1. Percentage of co-contraction between TA/GM (Lo et al. 2017)

Statistical Analysis

SPSS 22.0 was used for statistical analyses of obtained data. Descriptive statistics were used to analyse the group mean data of characteristics. The Shapiro–Wilcoxon test was used to determine if the data were normally distributed. Then, a Student t-Test was performed in order to evaluate differences in co-contraction indices and stance phase duration values between both groups. Significance was set at p= .05. Pearson correlation was performed in order to determine the relationship between stance phase duration and co-contraction values in both groups.

Results

The percentage of co-contraction and stance phase duration data were analysed across 42 out of the 45 recruited participants. Missing co-contraction and stance phase duration data was due to missing or corrupted EMG files and/or missing footswitch data (n =3).

Student t-Tests revealed no significant differences in co-contraction indices for stance phase duration tested (Table 1). Mean values for m. gastrocnemius and m. tibialis anterior (TA/GM) co-contraction indices were for 4.2% COCON higher in children without disabilities than children with disabilities (p> .05). But mean m. biceps femoris and m.rectus femoris (BF/RF) co-contraction indices were for 6.6 %COCON higher in children with disability (p> .05). Stance duration for children without disabilities was for .05s shorter than in children with disabilities (p> .05).

Table 1

Mean data of muscle co-contraction and stance duration. Values are meaning (standard deviation)

Variable	*Children without disabilities (n=12)*	*Children with disabilities (n=30)*	*Significance*
TA/GM (% COCON)	52.3± 14.3	48.1± 18.7	p> .05
BF/RF (% COCON)	42.6± 7.1	49.2± 15.6	p> .05
Stance duration(s)	.65± .1	.7± .1	p> .05

Pearson`s correlation did not reveal any significant associations between stance phase duration and agonist/antagonist co-contraction of m.gastrocnemius and m.tibialis, and m. biceps femoris and m.rectus femoris muscles (Table 3)

Table 2

Pearson`s correlation coefficients (r) for muscle pairs and stance phase duration

Children without disabilities (n=12)			*Children with disabilities (n=30)*		
Pair (%COCON : seconds)	*r*	*p*	*Pair (%COCON : seconds)*	*r*	*p*
TA/GM : stance duration	.05	p> .05	*TA/GM : stance duration*	.08	p > .05
BF/RF : stance duration	.27	p > .05	*BF/RF : stance duration*	.004	p > .05

Discussion

Stance phase duration and percent of muscle co-contraction for both groups was in line with findings of other authors Hallal et al., (2010) and Lo et al., (2017). Previous studies by Benedetti et al., (2010) and Detrembleur et al., (1997) have showed association between gait speed and behaviour of ankle joint agonist/ antagonist muscles. Increased gait speed leads to stance phase duration decrease which might affect muscle co-contraction as result of ground reaction force becoming greater. This study found that stance phase duration was longer among children with disabilities .7± .1 than in children without disabilities .65± .1, and co-contraction of m.gastrocnemius and m.tibialis anterior (TA/GM) was lower in children with disabilities (48.1± 8.7). On the contrary, mean m. biceps femoris and m.rectus femoris (BF/RF) co-contraction index during the stance phase in children with disabilities was higher than in children without disabilities, however the duration of stance phase was longer. Furthermore, Hallal et al., (2010), and Lo et al., (2017) has confirmed, that disturbed balance conditions have impact to co-contraction levels, respectively co-contraction level is higher, they also found that persons with low balance confidence had higher lower limb co-contraction compared to others. These findings coincide with Abbud et al., (2009) who concluded balance confidence association with lower limb co-contraction level directly at stance phase. It may explain one of barriers why children with disabilities face the difficulties to reach a recommended physical activities level, but there is still need for more specific studies aimed to verify association between stance phase duration and muscle co-contraction. No one of the mentioned studies does not provide data of positive association between stance duration and muscle co-contraction in children with or without disabilities during a normal walking. However, Lo et al (2017) found positive association between co-contraction level and phase duration during the stride phase in dual task walking exercise ($R2=0.157$, $p=0.034$), also Detrembleur et al (1997) found that changes in phase duration affects muscle involvement level in movement stabilization during the treadmill walking. Children with disabilities groups result might be impacted by variability between different disabilities. Especially functional disabilities subgroup had high variability in co-contraction value, they could only be analysed separately if amount of participants would be increased. Current study purpose was not to show differences between specific disabilities, but to compare variables between children with and without disabilities.

Study limitations include measuring only relative muscle activity and testing association with stance phase duration of children with and without disabilities, in future studies other variables, like gait speed and dynamic balance measurements, should be take into account. For more informative comparison of specific age or disabilities group co-contraction level, future studies should develop normative co-contraction levels for children, similar, as it has been done for normative EMG activation patterns by Agostini et al., 2009.

Conclusion

This study provides evidence that lower extremity stance phase duration have no impact to muscle co-contraction during the normal walking. Evidence provide information that muscle co-contraction may have important functional role, which may explain some of the mobility impairment associated various disabilities but it cannot be explained by muscle co-contraction and stance phase duration association as it is explained at Results and Discussion chapters.

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Declaration of Interest

The authors report no conflict of interest. The authors alone are responsible for the content and writing of this article.

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