Influence of Fatigue on Balance and Lower Limb Muscles Activity in Flatfoot Children

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Abstract: Fatigue could lead to excessive eversion and affect static balance. This study was aimed to find out the influence of foot posture and jumping fatiguing effect on static balance and muscle activity of lower limb muscles. Methods: 19 elementary school children aged 9 to 11 years took part in this study. Of these all children, 10 had normal foot and 9 had flatfoot which was classified by their foot posture. Foot posture was measured based on arch index of footprint by a foot scanner. Surface electromyography (EMG) activity was recorded from tibialis anterior, gastrocnemius medialis and peroneus longus muscles while participants were standing on one leg barefoot with opened eyes. Results: Normal foot had arch index 0.25±0.01 whereas flatfoot had 0.36±0.01. Statistical analysis showed that fatigue could influence static balance in flatfoot children ($p < 0.05$). Based on electromiographic data, there were no significant differences on median frequency of lower limb muscles between both groups. After fatigue, median frequency (MF) timing was significantly different ($p < 0.05$) on tibialis anterior and peroneus longus. MF timing showed earlier in flatfoot. Conclusion: Fatigue influenced static balance and tended to appear earlier on lower limb muscles in flatfoot children.

1 INTRODUCTION

Plantar arch development is observed before the age of six and then children will had characteristics features of adult feet (Hennig et al., 1994). This development affected by various factors such as internal (age, sex, genetic) and external factors (age at which closed shoe wearing begins, body composition and physical activity level) (Halabachi et al., 2013; Mortazavi et al., 2007). Most of the flatfoot are flexible, asymptomatic and physiologic. Early closed shoes wearing in children may lead to flatfoot because it could influence foot motion and ligament laxity which lead to lowering the arch height (Abolarin et al., 2011). Furthermore, excessed body weight on children also lead to the impairment of foot functional status (Krul et al., 2009).

High impact sports need an efficient foot posture for shock absorption, generating and transfering the energy. Variations of foot posture could be at high risk for overuse injuries after doing repetitive athletic tasks (Queen et al., 2007). Flatfoot is at high risk of ankle injury while participating in high impact sports because of its high intensity and frequent foot contacts with hard surface (Cain et al., 2007). Flatfoot children will get muscle fatigue and pain earlier on their lower extremity compared to normal foot children because higher muscle activity is needed to stabilize tarsal transversal and subtalar joint to reduce load on medial longitudinal arch. If muscles become fatigue, the injury risk may increase due to increased strains and bending moments because muscles cannot absorb high impact and fail to protect bones from tension (Mosca V. S., 2010).

There is still controversy about physical performances in flatfoot. Tudor et al found that static balance performances was similar between flatfoot and normal foot children (Tudor et al., 2009), but another studies found poorer physical performances in flatfoot compared to normal foot (Marginson et al., 2005; Roohi et al., 2013). Several researches have shown correlations between flatfoot and their functional limitation while running and walking mostly on adults. There has been no study to find out fatigue's effect on static balance and lower limb muscles activity in children. Therefore, we would like to know whether fatigue was the one factor that influenced physical performances in flatfoot

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children. We have hypothesized that fatigue will influence static balance and lower limb muscles activity in flatfoot compared to normal foot children.

2 METHODS

2.1 Participants

19 elementary school children aged 9 to 11 years took part in this study. Of these all children, 10 had normal foot (8 males and 2 females) and 9 had flatfoot (5 males and 4 females) with unknown pathologies were recruited to take part in this study (Table 1).

Ethics approval was obtained from the Polytechnic of Health, Ministry of Health, Research Ethics Committee (ID:LB.02.1/3.1/0260/2015). Details of the study procedure were presented, and consent was obtained from parents before children participated in the study.

2.2 Screening Protocol

Foot scanner was used to categorize foot posture. Foot posture was classified using arch index as a clinical measurement from footprint analysis with AUTOCAD 2013 software. Each foot was placed on foot scanner while participants were standing. Only one foot from was included in the data analysis where we categorized the “the flatter foot” into the flatfoot group

To qualify for the flatfoot group, participants had arch index greater than two standard deviations from the mean values obtained for the normal foot group. Figure 1 represents the arch index measurements from the footprint. Based on the arch index, we divided participants into flatfoot and normal foot group.

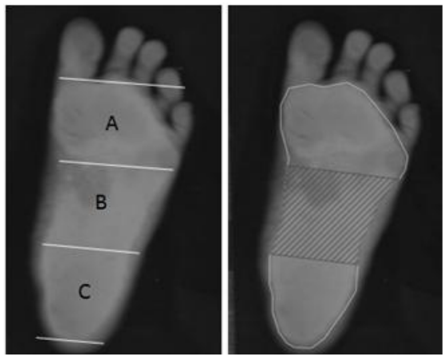

Figure 1(a) Figure 1(b)

Figure 1: Footprint of flatfoot child where the length of the foot (excluding the toes) is divided into equal thirds to give three regions: A -- forefoot; B -- midfoot; and C -- heel. Arch index is then calculated by dividing the midfoot region (B) by the entire footprint area (Arch index = B/[A+B+C] (Figure.1a). We used AUTOCAD 2013 software to calculate the arch index (Figure.1b).

2.3 Experimental Protocol

All participants completed the entire protocol in a single session. Pre fatigue data collection consisted of measurements of body mass index, body fat percentage, vertical jump test, static balance test, and electromyographic (EMG) activity while performing static balance test. Post fatigue data collection consisted of vertical jump test, static balance test, EMG activity while performing static balance test. During trials, the participants were instructed to perform static balance test and electromyographic data was collected. Each test was performed two times and separated by a 3 minutes rest period. Only the best result will be included in the statistical analysis.

2.3.1 Body Mass Index

Body height and body weight were measured using ZT 120 health scale. The weight was recorded to the nearest 0,1 kg and the height was also recorded to the nearest 0,01 m. Body mass index was calculated for each subject by dividing the weight by the square of the height. We used WHO AnthroPlus software to assess body mass index.

2.3.2 Body Fat Percentage

The measurement site was on triceps and calf at the right part of the body using skinfold calliper. Test was performed two times. The result was an average values of these two trials. Slaughter Lohman Formula was used to calculate body fat percentage.

Figure 2 (a) Figure 2 (b)

Figure 2: Measurement site of body fat percentage on triceps (Figure. 2a) and calf (Figure. 2b).

2.3.3 Vertical Jump Test

This test was performed on vertical jump meter. The task was to perform two maximal eccentric-concentric jumps with hands held at the hips along the test. A single jump started with straight legs performing a natural flexion before the take off phase. We only took the best results from two trials.

2.3.4 Static Balance Test

Participants performed single limb standing test barefoot for 30 seconds with opened eyes. The non support limb was held flexed 90^0 at the knee but not contacting the supporting limb muscles while their hands were placed on the hips. The goal of the test is to stand on static position for maximum 30 seconds. Weight shifting and/or equilibrium reactions in the feet are acceptable. These timed trials should be stopped if the supporting limb moves in a space or the non support limb touches the support limb. The result was the best performed of these two trials.

2.3.5 Electromyographic Activity

Tibialis anterior, gastrocnemius medialis and peroneus longus muscles activity were recorded using bioamplifier with the use of pediatric soft-cloth electrodes which was more comfortable for child skin. An inter-electrode distance was 10 mm.

The placement of surface electrodes followed the recommendation of SENIAM (www.seniam.org). Reference electrodes for tibialis anterior and gastrocnemius medialis were placed on malleolus medial and reference electrode for peroneus longus was placed on malleolus lateral (Figure 3).

Figure 3(a) Figure 3(b) Figure 3(c)

Figure 3: The placement of electrodes on tibialis anterior (a) gastrocnemius medialis (b) and peroneus longus (c).

2.3.6 Fatigue Protocol

Participants completed plyometric jumping fatiguing protocols (Marginson et al., 2005). Before testing, each participant followed a standardized warm-up. It consisted of five submaximal and five maximal continuous jumps. After warming up, the participants performed eight sets of 10 continuous maximal plyometric jumps.

The participants stood with feet shoulder width apart and hands on hips. They were asked to jump as high as possible and each jump was performed as fast as possible.

Each set of the 10 jumps was separated by one minute rest period, in which the participant was still walking around to reach fatigue's effect.

2.3.7 EMG Data Processing

During the static balance test, raw EMG signal was passed through a differential amplifier at a gain of 1000 with the sampling frequency of 2 kHz. A band passed filter of 512 Hz for the surface electrodes.We used three channels of 2048 samples/seconds for each muscle recording.

Encoder samples the incoming signals, digitizes, encodes, and transmits the sampled data to the TT-USB interface unit.

A fiber optic cable was used for transmission to the TT-USB, providing maximum freedom of movement and electrical isolation. Myoscan sensor connected each electrode set to EMG encoder**.**

The raw EMG signal of the selected lower limb muscles between pre fatigue and post fatigue were analysed every 2 seconds to get power spectrum profile. Median frequency was used as a parameter for muscle fatigue which divided power spectrum into two equal parts. Median frequency timing was also analysed for each muscle.

2.3.8 Statistical Analysis

Shapiro wilk test was used for data distribution. The statistical analysis was chosen based on compatibility with the measure scale. We used a parametric test or non parametric test which was based on data distribution.

To show differences between pre fatigue and post fatigue *t*-dependent tests were used, where independent samples *t*-tests were used to show differences between flatfoot and normal foot with *p* value less than 0.05 considered significant.

3 RESULTS

Table 1: Participants Anthropometric and Foot Posture Characteristics.

General Anthopometric	Flatfoot N=9	Normal Foot N=10	*p* value
Gender Ratio (Male/Female)	5/4	8/2	
Age (Mean±SD) Years	9.89 ± 0.60	10.10 ± 0.88	0.538
Height (Mean±SD) Cm	134.06 ± 6.32	140.50 ± 9.7	0.108
Weight (Mean±SD) Kg	33.11 ± 7.25	34.00 ± 8.46	0.810
BMI (Mean±SD) Kg/m^2	18.26 ± 2.94	17.26 ± 4.48	0.579
Body Fat Percentage (Mean±SD) %	28.38 ± 6.52	27.85± 6.12	0.855
Foot Posture Characteristics			
Arch Index (Mean±SD)	0.36 ± 0.01	0.25 ± 0.01	0.000*

*Significantly different *p* value < 0.001

There were no significant differences for anthropometric characteristics between flatfoot and normal foot groups. Body composition (body mass index and body fat percentage) between flatfoot and normal foot was almost equal. However, foot posture was shown significantly different ($p < 0.05$) in both groups (Table 1).

Table 2: Physical Fitness Profile between Flatfoot and Normal Foot.

Physical fitness	Pre fatigue		*p* value	Post fatigue		*p* value
	Flatfoot	Normal foot		Flatfoot	Normal foot	
Static balance (mean±SD) seconds	27.44 ± 4.61	29.80 ± 0.63	0.188	21.67 ± 8.66	29.10 ± 2.23	0.020*
Vertical Jump (mean ± SD) cm	34.00 ± 6.8	29.00 ± 5.68	0.873	33.60 ± 3.59	29.60 ± 3.02	0.774

*Significantly different *p* value < 0.05

Based on physical fitness profile, there were significant differences on static balance performances between both groups at post fatigue condition (p< 0.05) (Table 2).

Table 3: Median Frequency (MF) of Selected Lower Limb Muscles between Flatfoot and Normal Foot.

Lower limb muscles	Pre fatigue		*p* value	Post fatigue		*p* value
	Flatfoot	Normal foot		Flatfoot	Normal foot	
MF tibialis anterior (Hz)	78.71 ± 23.31	90.77 ± 37.38	0.902	88.86± 45.50	99.86 ± 50.64	0.806
MF gastrocnemius medialis (Hz)	90.12 ± 35.88	90.90 ± 23.09	0.327	91.35 ± 37.83	85.18 ± 30.16	0.870
MF peroneus longus (Hz)	120.52 ± 38.60	98.57 ± 44.28	0.221	104.62 ± 39.83	110.73 ± 78.98	0.806

*Significantly different *p* value < 0.05

Decreased median frequency of lower limb muscles (tibialis anterior, gastrocnemius medialis and peroneus longus muscles) showed no differences between both groups (Table 3).

Table 4: Median Frequency (MF) Timing of Selected Lower Limb Muscles between Flatfoot and Normal Foot.

Lower limb muscles	Pre fatigue		*p* value	Post fatigue		*p* value
	Flatfoot	Normal foot		Flatfoot	Normal foot	
MF timing of tibialis anterior (seconds)	16.44 ± 10.52	10.8 ± 8.12	0.234	6.89 ± 5.57	14.0 ± 9.04	0.054*
MF timing of gastrocnemius medialis (seconds)	10.44 ± 8.11	17.2 ± 6.47	0.060	9.33 ± 7.07	14.2 ± 8.66	0.201
MF timing of peroneus longus (seconds)	14.44 ± 10.76	13.2 ± 9.24	0.790	5.78 ± 4.17	12.4 ± 7.7	0.033*

*Significantly different *p* value < 0.05

Median frequency timing of tibialis anterior, gastrocnemius medialis and peroneus longus were appeared earlier (at 6,9,5 seconds) in flatfoot compared to normal foot children (at 14,14,12 seconds) at post fatigue. It showed significant differences on median frequency timing of tibialis anterior and peroneus longus ($p<0.05$) in flatfoot compared to normal foot, but there were no significant differences for gastrocnemius medialis (Table 4).

4 DISCUSSION

Anthropometric characteristics were almost equal in both groups. Flatfoot children were shorter than normal foot children. We found that body mass index and also body fat percentage had no differences in both groups. These findings is in contrast to another studies (Chang et al., 2010; Cetin et al., 2011). In this study, there was no body size effect on physical performances in both groups.

Prevalence of flatfoot is higher in males than in females (Abolarin et al., 2011; Chang et al., 2010; Ezema et al., 2014; Mickle et al., 2011; Wozniacka et al., 2013), and it is also similar to findings of our study.

Arch index of the participants was determined with inclusion value for clinical measurements (Murley et al., 2009). Arch index is most repeatable and have a high correlation with arch height value (Queen et al., 2007).

The arch index value of children was higher than young adults in a previous study conducted by Murley et.al (Murley et al., 2009). In this study, we chose the “flatter foot” for flatfoot group to get the best comparison with normal foot.

This study would like to find out the influence of foot posture and fatigue on static balance and EMG activity of selected lower limb muscles. At pre fatigue condition, our findings were similar to Tudor et.al (Tudor et al., 2009) which showed no differences on physical performances such as static balance and vertical jump between flatfoot and normal foot children. In the other hand, several researches (Roohi et al., 2013; Marginson et al., 2005) showed poorer performances in flatfoot children.

Our findings gave an explaination about the controversial findings in static balance performances between flatfoot and normal foot in previous studies. We investigated the effect of fatigue on physical performances in both groups. The results revealed that fatigue was one factor which influenced static balance in flatfoot children. Lack of stability in flatfoot was in agreement with Tsai et.al (Tsai et al., 2005) where flatfoot had greater displacement in anterior posterior direction as a mechanism to their poorer postural stability.

The fatigue protocol using plyometric jumping fatiguing protocols (Marginson et al., 2005) could of reach fatigue’s effect in both groups. It was shown on significantly decreased vertical jump performances between pre fatigue and post fatigue.

Muscle fatigue are measured through EMG signal. Decreased median frequency and greater percentage of maximum amplitude are the parameter of fatigue condition on muscles. During static balance trials, decreased median frequency of lower limb muscles showed no differences between pre fatigue and post fatigue in both groups. These findings are in contrast to Murley et.al (Murley et al., 2009) which showed a greater percentage of maximum amplitude for tibialis anterior in flatfoot compared to normal foot. This might be caused to the fact that mean aged of these children were 10 years which were less competent at the task of balancing on one limb (Mickle et al., 2011), so both groups can’t maintain their balance well.

However, median frequency timing of the selected lower limb muscles were showed earlier in flatfoot children. It gave the facts that flatfoot children experienced fatigue earlier compared to normal foot children. It seemed significant for median frequency timing of tibialis anterior and peroneus longus because they worked harder to stabilize the subtalar joint. These findings is similar with Neptune et al (Neptune et al., 1999) where tibialis anterior and peroneus longus had to work harder to limit excessive subtalar joint rotation in order to prevent ankle injuries. Everted and dorsiflexed foot will stretch the invertor muscles (tibialis anterior) and plantarfleksor groups (peroneus longus) during weight bearing position.

This study may have implications when choosing an appropriate sport type for flatfoot children in order to prevent earlier fatigue in flatfoot children that might lead to injury because of the impairment of static balance. These findings are in agreement with the importance of strengthening exercise on inversion muscles (tibialis anterior) and peroneus longus in flatfoot children.

5 CONCLUSION

Fatigue influenced static balance and tended to appear earlier on lower limb muscles in flatfoot children. It should take into consideration when flatfoot children get involved in high impact sports. Further research might needed to investigate the influence of foot posture and fatigue on static balance in children over 11 years to get better comparison because balance slowly improves until 10 years of age.

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