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Gait ground reaction force characteristics in children with and without forward head posture

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Abstract

Background: Forward head posture is one of the most prevalent abnormal postures in patients with neck disorders. The aim of this study was to evaluate the effects of forward head posture on gait ground reaction force characteristics in children.

Methods: Twelve children with forward head posture (age: 11.8±1.3 years) and sixteen healthy control children (age: 11.7±1.4 years) volunteered to participate in this study. Each participant was asked to walk 10 m in six trials with self-selected speed. The ground reaction force was measured by two Kistler Force Platforms at a frequency of 1000 Hz. MANOVA test ((version 16, SPSS Inc, Chicago, Il)) was used for between group comparisons.

Results: In the non-dominant limb, the medio-lateral ground reaction force during push off phase in the forward head group was greater than that in the healthy group by 22.1% (P=0.049). In the dominant limb, time to peak for vertical ground reaction force during heel contact (by 13.7%; P=0.015) and push off (by 14.2%; P=0.004), mediolateral ground reaction force during heel contact (by 46.0%; P=0.006) and push off (by 15.1%; P=0.039) in the forward head group were significantly lower than those in the healthy group. Vertical loading, peak positive and negative free moment, and impulses in all axes were similar in the healthy and the forward head groups (P>0.05).

Conclusion: Overall, the results reveal that gait ground reaction force components (especially time to peak for ground reaction forces) in forward head children may have clinical importance for the improvement of walking mechanics of these individuals. Rehabilitation protocols should be designed to increase time to reach peak ground reaction forces and decrease medio-lateral ground reaction force in forward head children during walking.

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Introduction

Forward head posture (FHP) is defined as an anterior positioning of the head relative to the torso in an anatomical upright posture (1). One of the most prevalent abnormal postures in patients with neck disorders is FHP (2). The prevalence of FHP was reported to be about 66% (3). This poor posture has been linked to many musculoskeletal disorders such as headache, shoulder and neck pain, craniofacial pain, and temporomandibular disorders (4-6).

The main function of the cervical spine is to orient the head against the forces of gravity (7). Head stabilization facilitates optimal conditions for vestibular and visual functions during locomotion (8,9). Furthermore, during normal gait, healthy subjects maintain a high degree of head stability through compensatory mechanisms such as adjustments in head pitch that resist against the linear and angular motions imposed by the whole body (9,10). Head stabilization degree during locomotion is determined predominantly by frequency and velocity of head movements (10). The impact of different lower limb extremity movements as a function of walking speed (11,12), stride rate (12,13), and step length (12) on the frequency characteristics of the head have been well documented during gait analysis. Upper body changes such as arm swing and trunk rotation are also associated with head stability (14,15).

Previous studies have reported balance disorders (16,17), greater lower cervical spine lordosis (18), greater thickness of sternocleidomastoid muscle (19), cervical muscle imbalance (20), weakness in the deep cervical flexors and shortening of the opposing cervical extensors (3), lower thickness of semispinalis capitis (21), higher sustained upper and lower trapezius activity and lower efficiency in serratus anterior activity during loaded shoulder flexion (22), and greater disability (2) in individuals with FHP. However, walking biomechanics (including walking ground reaction force (GRF) characteristics) in children with FHP have not been evaluated in the previous studies.

GRF is an important factor affecting joint moments and forces during translational activities (23,24). The GRF is exerted from the ground up toward the foot and consists of vertical GRF and shear forces (23,24). The most common method used by biomechanists and clinicians to assess and evaluate walking based on GRF components is the computation of peaks and areas in the GRF data (25-28). While the frequency components of the vertical ground reaction force are important for understanding how the body generates impact peaks, the purpose of this study was to understand how GRF characteristics, that have been implicated in the etiology of various skeletal and soft tissue injuries (29,30), are influenced by FHP. Therefore, the aim of this study was to evaluate the effects of FHP on gait GRF characteristics in children. Since FHP is a disorder of the head in sagittal plane, we hypothesized that anterior-posterior components of GRF (e.g. peak anterior-posterior GRF amplitude and Time to peak (TTP), and anterior-posterior impulse) have been influenced during walking.

Material and methods

Participants

Participants' natural FHP was measured using a universal Goniometer (Sorisa, Portugal) as the angle between C7, the tragus of the ear and the horizontal which has been shown to be reliable and valid (31). Participants were asked to tilt their heads forwards and backwards with decreasing amplitude until they achieved what they considered to be their natural head posture. If the craniovertebral angle (CVA) was <48°, the child was considered to have FHP and entered into the study (5). Twelve children with FHP (age: 11.8±1.3 years; height: 148.2±6.6 cm; mass: 39.6±5.4 kg) and sixteen healthy control children (age: 11.7±1.4 years; height: 149.7±6.2 cm; mass: 38.0±4.7 kg), volunteered to participate in this study. A priori power analysis (G*3-Power software) revealed that (for a statistical power of =0.80, effect size = 0.80, and alpha level = 0.05) a sample size of at least 28 subjects was required (32,33). Exclusion criteria were a history of neck pain, fracture of the cervical column, scoliosis, severe thoracic kyphosis, rheumatic disease, torticollis, vestibular or neurological disorder, use of hearing aid and persistent respiratory problems (34). Craniovertebral angle for FHP group was 42.7±1.5° and for the healthy group was 52.6±1.9°.

Participants and their parents were fully informed about the aim and protocol of the study and gave their informed consent. Ethics approval was obtained from the research council of the University of Mohaghegh Ardabili.

Instruments and examination

Participants were given some practice trials before actual trials. Each participant was asked to walk 10 m in six trials with self-selected speed. The GRFs were measured by two Kistler Force Platforms (Type 9281, Kistler Instrument AG, Winterthur, Switzerland) at a sampling rate of 1000 Hz. Based on residual plot analysis, the GRF data were then filtered using a fourth-order low-pass Butterworth filter with a 20 Hz cut-off frequency (23).

The GRF data were recorded along vertical (z), medio-lateral (x) and anterior-posterior (y) axes. The vertical GRF bimodal curve in normal walking contained two peaks including the first peak on the heal contact (Fz_{HC}) and the second peak on the push-off phase (Fz_{PO}). There is also a minimum value (downfall) between the two peaks (Fz_{DF}) (35). Also, from the medio-lateral curve, three values were recorded corresponding to the positive peak (lateral GRF) which occurred initially (Fx_{HC}), followed by the two consecutive negative peaks (medial GRF) at the middle (Fx_{MS}) and the final (Fx_{PO}) portions of the walking cycle (29). Additionally, on the anterior-posterior curve, two peaks were recorded as the posterior reaction force (Fy_{HC}) and anterior (Fy_{PO}) forces. Loading rate was defined as the line slope between the initial and Fz_{HC} points on the vertical GRF curve (36). Impulse was calculated using the trapezoidal integration method for x, y, and z axes as follows (24):

$$(1) \quad Impulse = \Delta t \left(\left[\frac{F1+\mathrm{fn}}{2} \right] + \sum_{i=2}^{n-1} Fi \right)$$

Free moment (FM) of the foot was computed as the following (37):

$$(2) \quad Free\ moment\ (FM) = M_z - F_y(CoP_x) + F_x(CoP_y)$$

Where M_z is the moment related to the vertical axis; x and y are the horizontal components of the center of pressure (COP); Fx and Fy are the mediolateral and anteriorposterior components of the GRF, respectively. Then in FM curve, the first peak (negative; abductor moment) and the second peak (positive; adductor moment) were recorded for the statistical analysis. All GRF and free moment values were normalized with respect to the body weight (BW) and BW×Height, respectively (38).

Statistical analysis

Firstly, the normality of the variable distributions was verified using Kolmogorov-Smirnov test. MANOVA tests were used for between group comparisons (39). The significance level was set at $p<0.05$ for all analyses. Statistical analyses were performed using SPSS software (version 16, SPSS Inc, Chicago, Il). Additionally, the effect size (d) was calculated as a ratio of mean difference divided by the pooled standard deviation (40).

Results

The descriptive analysis of the data obtained about the participants of the study indicated that there were no statistical differences between the groups for age, height, and mass ($p>0.05$). During walking, both healthy (1.17±0.09 m/s) and FHP (1.16±0.07) groups demonstrated similar walking speeds ($p>0.05$).

Peak GRF variables for all groups are presented in Table 1. Peak GRF amplitudes in Fz, Fy, and Fx (except for non-dominant Fx_{PO}) were similar between the healthy and the FHP groups ($p>0.05$). In non-dominant limb, the Fx_{PO} in the FHP group was greater than that in the healthy group by 22.1% ($P=0.049$, $d=0.70$; 95%CI: 0.0, 1.7).

Table 1. GRF of Z, X, and Y axes in different stance phases for healthy and forward head groups. Data are shown as mean±SD.

Side	GRF	Groups		P	d
		Healthy	Forward head		
Dominant	Fz_{HC}	107.72 ± 24.04	102.54 ± 20.09	0.504	0.23
	Fz_{DF}	63.63 ± 20.18	65.06 ± 18.88	0.833	0.07
	Fzpo	96.50 ± 18.83	103.78 ± 23.21	0.321	0.35
	Fxhc	3.26 ± 1.60	3.53 ± 0.99	0.567	0.21
	Fxms	-5.22 ± 1.46	-4.49 ± 1.43	0.149	0.51
	Fxpo	-4.65 ± 1.75	-4.95 ± 1.75	0.616	0.17
	Fyhc	-0.0136 ± 0.0058	-0.0129 ± 0.0058	0.736	0.12
	Fypo	0.0185 ± 0.0073	0.0195 ± 0.0089	0.7٠7	0.13
Non-dominant	Fzhc	111.56 ± 22.58	96.47 ± 23.74	0.067	0.65
	Fz_{DF}	64.28 ± 17.63	65.98 ± 20.87	0.798	0.09
	Fzpo	96.03 ± 22.97	104.72 ± 20.45	0.255	0.40
	Fxhc	3.26 ± 2.32	3.00 ± 1.27	0.697	0.14
	Fxms	-5.05 ± 1.35	-4.90 ± 1.72	0.783	0.10
	Fxpo	-3.92 ± 1.03	-4.79 ± 1.43	0.049 *	0.70
	Fyhc	-18.19 ± 4.56	-17.10 ± 5.48	0.533	0.22
	Fypo	14.89 ± 3.10	13.68 ± 2.74	0.243	0.41

* Significance at level $p<0.05$.

Table 2 shows the TTP in both groups. In dominant limb, TTP for Fz_{HC}, Fz_{PO}, Fx_{MS}, Fx_{PO}, and Fy_{PO} in the forward head group were significantly lower than those in the healthy group. In non-dominant limb, TTP for Fz_{HC}, Fz_{DF}, Fz_{PO}, Fx_{Ms}, Fx_{PO}, Fy_{HC}, and Fy_{PO} in the forward head group were significantly lower than those in the healthy group. Other TTP variables between healthy and forward head groups were not statistically different ($p>0.05$) (Table 2).

Table 2. The time to peak (TTP) of GRF components for healthy and deaf groups. Data are shown as mean ±SD.

Side	TTP	Groups		P	d
		Healthy	Forward head		
Dominant	Fzhc	32.41 ± 5.55	27.95 ± 4.42	0.015 *	0.90
	Fzms	65.60 ± 10.13	59.32 ± 7.70	0.052	0.70
	Fzpo	113.87 ± 16.89	97.64 ± 13.29	0.004 *	1.08
	Fxhc	8.25 ± 2.26	7.42 ± 1.63	0.224	0.43
	Fxms	43.12 ± 13.21	31.85 ± 8.02	0.006 *	1.06
	Fxpo	99.40 ± 23.40	84.32 ± 16.25	0.039 *	0.76
	Fyhc	22.60 ± 5.86	19.60 ± 3.19	0.078	0.66
	Fypo	124.45 ± 17.74	109.87 ± 15.33	0.016 *	0.88
Non-dominant	Fzhc	31.51 ± 3.80	27.83 ± 5.47	0.028 *	0.79
	Fzms	67.05 ± 10.05	58.64 ± 10.12	0.021 *	0.83
	Fzpo	113.89 ± 15.14	98.29 ± 14.56	0.005 *	1.05
	Fxhc	9.06 ± 2.84	9.07 ± 3.10	0.989	0.00
	Fxms	67.05 ± 10.05	58.64 ± 10.12	0.021 *	0.83
	Fxpo	100.87 ± 17.97	83.36 ± 17.96	0.008 *	0.97
	Fyhc	22.83 ± 3.69	18.07 ± 4.38	0.002 *	1.18
	Fypo	123.77 ± 15.17	109.47 ± 15.95	0.012 *	0.92

* Significance at level $p<0.05$.

Vertical loading rates were similar in the healthy and the forward head groups (P>0.05) (Figure 1). For the both dominant (Figure 2A) and non-dominant limbs (Figure 2B), x, y and z impulses in both groups were similar (P>0.05). In both limbs, the peak positive and negative free moment amplitudes (% BW × Height) between the groups were similar (P>0.05) (Figure 2C and D; Figure 3).

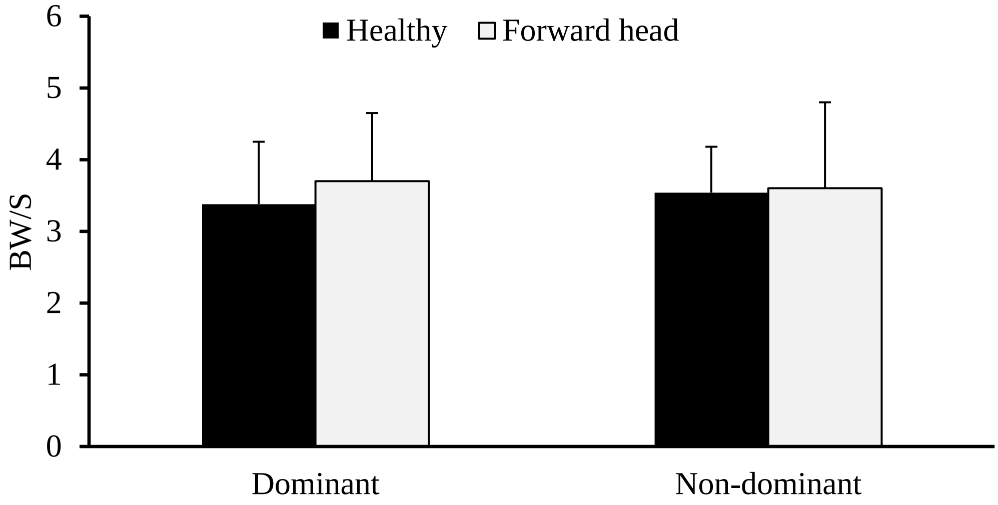

Figure 1. Vertical loading in both healthy and the forward head groups (30).

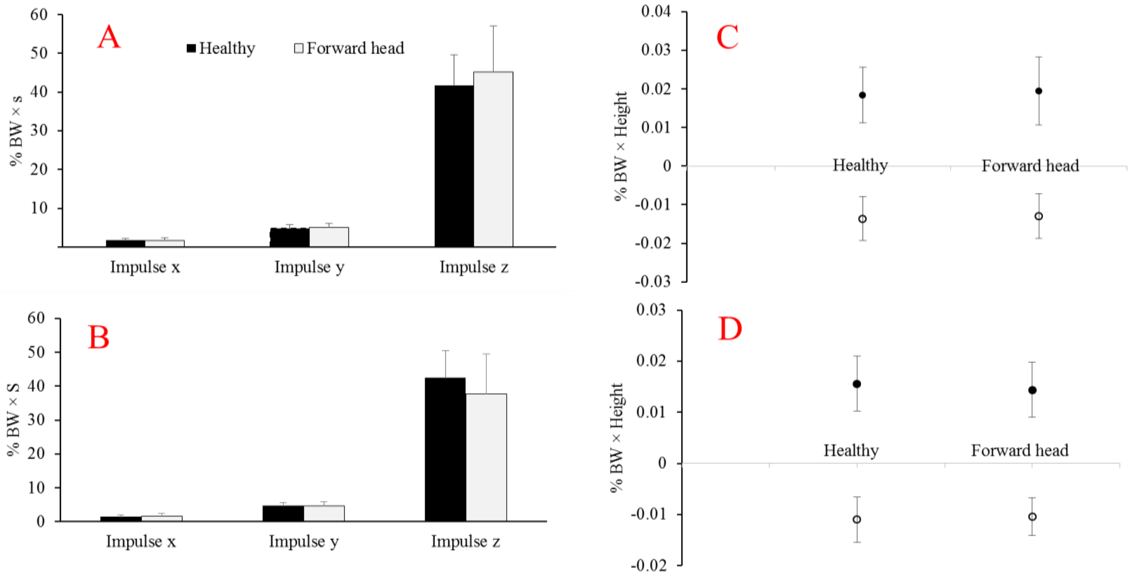

Figure 2. Impulses in dominant (A) and non-dominant (B) limbs and the free moment in dominant (C) and non-dominant (D) limbs in both healthy and the forward head groups.

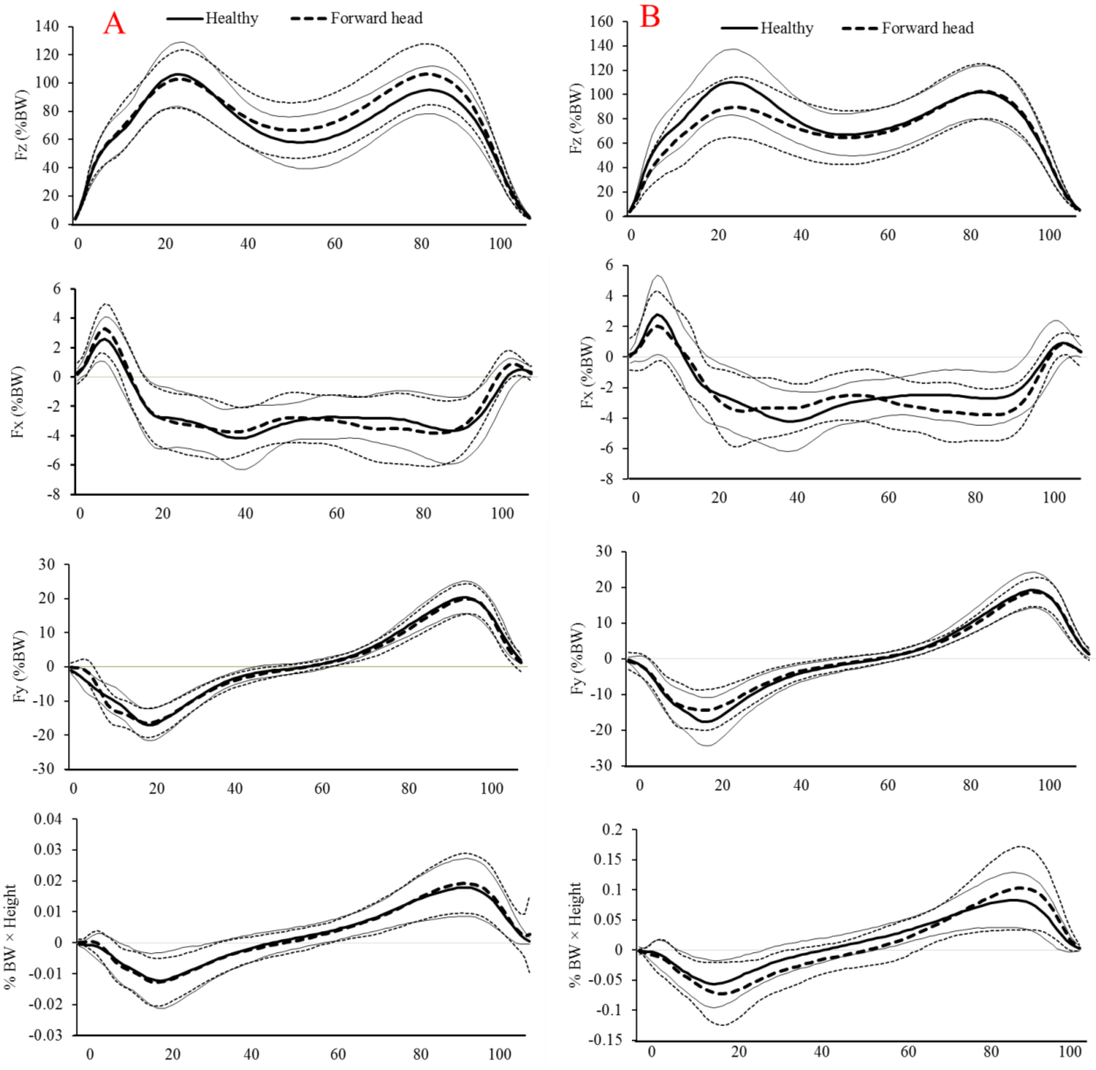

Figure 3. mediolateral ground reaction force; Fy: anteriorposterior ground reaction force) and free moment (%BW×Height) in both dominant (A) and non-dominant (B) limbs during walking.

Discussion

It was hypothesized that forward head posture is associated with altered GRFs characteristics. Overall, the GRF patterns in both groups were similar to those of the previous studies in level walking (41-44). This study is the first to identify that Fx_{PO} amplitude and its related TTP in non-dominant limb in the forward head subjects are significantly lower than those in the healthy subjects. Moreover, dominant TTP of Fz_{DF}, dominant TTP of Fy_{po}, non-domonant TTP of Fx_{ms}, non-dominant TTP of Fx_{po}, and TTP of Fz_{po} of both limbs in the forward head subjects are significantly higher than those in the healthy subjects.

This research provides the first reference data of gait GRF characteristics in forward head children. Similar walking velocity and higher medial GRF (Fx_{po}) in children with forward head posture may be associated with less gait efficiency and higher proximal joints load, respectively (23). John et al. (45) reported that muscles are accounted for more than 92% of the mediolateral ground reaction force over all walking speeds. Thus, it is possible that this has been caused by muscular activation disorders during gait. Therefore, more investigation on lower limb muscular activity in children with FHP during walking is warranted. In contrast to ours results, Jafarnezhadgero et al. did not demonstrate any significant difference in running medio-lateral GRF between healthy and genu varus children (38). With respect to the timing of the force peaks, the most consistent differences were the dominant TTP of Fz_{DF}, dominant TTP of Fy_{po}, non-domonant TTP of Fx_{ms}, non-dominant TTP of Fx_{po}, and TTP of Fz_{po} for both limbs that happened later in the forward head group. These findings may give further support to the hypothesis that the magnitude and timing of the GRF components will vary substantially between the healthy and the forward head children. Rehabilitation protocols should be designed to increase time to reach peak ground reaction forces in forward head children during walking.

In the present study, the subjects in the forward head group displayed similar impulses and similar vertical loading rate compared to the subjects in the healthy group. We were not able to find other studies addressing this issue.

The present study showed that the peak amplitudes of positive and negative FM curve in the forward head group were similar to those in the healthy group. In general, the negative peak of FM curve produces external rotation and positive FM generates internal rotation (37). However, it would be difficult to conclude that there is a direct relationship between these variables and injury based on our data and further study is needed.

This study has some limitations that must be regarded. The number of participants of the study was relatively small. However, the study had sufficient power on statistical tests to determine the group differences. This study did not address other kinetic variables (such as joint moments and powers), kinematic and muscle activities during gait in both groups. The combination of kinematics and other kinetic variables with electrical activities of the effective muscles on walking may bring additional insights to the investigation of the risk factors in forward head children.

Conclusion

Rehabilitation protocols should be designed to increase time to reach peak ground reaction forces and decrease medio-lateral ground reaction force in forward head children during walking.

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Conflict of interest

There is no conflict of interest.

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