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Research Article

Developing A New Parameter to Determine the Performance of Subjects with Various Musculoskeletal Disorders During Standing and Walking

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Received: November 20, 2016; **Published:** December 01, 2016

Abstract

Background: Various musculoskeletal disorders influence the abilities of subjects during standing, walking and running. Depends on the type of disorder, stability, gait and energy consumption may be influenced. The aim of this study was to introduce a new parameter to show the total performance of the subjects based on the afore mentioned parameters.

Method: Four groups of normal subjects, those with flatfoot, Multiple sclerosis (MS), Spinal cord injury (SCI) were recruited in this study. The stability during standing, spatiotemporal gait parameters and energy consumption were evaluated in this study. The new parameter was calculated based on the mean values of stability, gait and energy consumption parameters compared to normal subjects. The difference between the mentioned parameters of the groups was determined by use of two sample t test.

Results: The results of this study showed that although there was no significant difference between the subjects with Flatfoot, and SCI, regarding their standing stability, they had difference based on the new parameter (it was significant for SCI). Standing stability, energy consumption and gait performance of subjects with MS differed significantly from normal subjects. The mean value of the new parameter was 1.96 ± 0.571 and 1.61 ± 0.16 for MS and SCI subjects, respectively.

Conclusion: The results of this study showed that the new parameter seems to represent the effects of musculoskeletal disorders better than other common used method. Therefore, it is recommended to be used in clinical evaluation to determine the effect of musculoskeletal disorders or the effects of some interventions.

Keywords: *Multiple Sclerosis; Spinal Cord Injury; Flatfoot; Stability; Energy Consumption; Gait*

Introduction

Various musculoskeletal disorders influence the abilities of subjects during standing, walking, running and while doing different tasks [1-7]. Depends on the type of disorder one or all of the aforementioned abilities may be involved. The involved subjects suffer from high risk of falling, high energy consumption during walking and reduced walking speed [8-10]. Moreover, some of the patients with musculoskeletal disorders should use some assistive devices to enable them to stand and walk. Therefore, it is very important to use appropriate procedures to monitor the performance in standing, walking and running.

The stability of normal and subjects with musculoskeletal disorders can be evaluated by use of force plate, and accelerometer based on center of pressure (COP) excursions and acceleration of center of mass (COM) while standing, respectively [11,12]. It can be done by

evaluation of COP excursion, velocity and path length of COP sways in the mediolateral and anteroposterior directions [13]. Regarding dynamic stability, it can be determined based on tracing of COM in the anteroposterior and mediolateral directions, or by use of special procedures such as approximate entropy, correlation dimension and Lyaponove exponent [8]. Energy consumption is another approach to determine the efficiency of walking and the effectiveness of various therapeutic interventions. It can be done by heart rate monitoring or by measuring the oxygen consumptions [14].

It should be emphasized that the ability of a subject to stabilize him/herself during quiet standing does not mean to have a good performance during walking and running. Based on the results of some studies done on the subjects with spinal cord injury, their stability during quiet standing may be also better than that of normal subjects; however, they have an impaired dynamic stability [8,12]. Moreover, they have reduced walking speed and too much energy consumption compared to normal subjects. Therefore, it is not too practical to determine the effects of some therapeutic interventions only based on stability analysis or only based on energy consumption, as they may improve one performance but influence the others negatively. Therefore, it is important to evaluate all three performances in studies.

In this research, it was aimed to introduce a new method to represent the performance of the subjects with various disorders compared to normal subjects. The new index represented the total score of subject based on a number, which was hypothesized to be more sensitive than the other methods.

Method

Three groups of normal subjects, those with multiple sclerosis, spinal cord injury and flatfoot participated in this study. Table 1 shows the characteristics of the subjects participated in this study. An ethical approval was obtained from Isfahan University of Medical Sciences, Ethical Committee. Moreover, each subject was asked to sign a consent form before data collection. The stability of the subjects was evaluated by use of force plate during quiet standing. The energy consumption and walking performance were determined based on physiological cost index (PCI, heart rate monitoring) and spatiotemporal gait parameters. Spinal cord injury subjects walked with MTK reciprocal gait orthosis (Mohammad Taghi).

Participants	Normal	Flatfoot	Spinal Cord Injury	Multiple Sclerosis
Age	21.63 ± 3.2	22.3 ± 2.3	33 ± 6.5	36.82 ± 10.85
Sex	Female	Female	Male	Female
Height	1.63 ± 0.05	1.64 ± 0.06	1.77 ± 0.06	1.59 ± 0.07
Weight	58.86±5.6	57 ± 5.8	72 ± 7.5	66.82 ± 18.23
Level of injury	----------	----------	T12, T11, T12, T12, T12, L1	----------
Index of flatfoot (Arch index)	0.21< AI < 0.26	AI > 0.26	----------	----------
Number	17	16	6	36

Parameters: The stability of the subjects during quiet standing was determined based on Center of Pressure (COP) excursions in both mediolateral and anteroposterior directions while subjects standing on a Kistler force plate. The energy consumption was determined based on PCI. The stride length, cadence and walking speed were also collected in this study.

Equipments: The equipments which were used in this study included: Force plate (Kistler force plate) used for evaluation of standing stability, Motion analysis system (Qualysis motion analysis system with 7 high speed camera) and Polar heart rate monitoring system for energy consumption analysis (Polar Finland).

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Procedure: In order to evaluate the stability, the subjects were asked to stand in front of a force plate and then asked to stand on it for 60 seconds. They were asked to stand in a comfortable position and to look straight ahead on a point located 2 meter far from the subjects. The data were collected with frequency of 120 Hrz. The data were filtered with Butterworth low passed filter with frequency of 10 Hrz. The first 15 and last 15 seconds of the data were deleted to remove the effects of sudden standing on force plate and also muscle fatigue. The following equations were used to calculate the excursions of COP in the anteroposterior and mediolateral directions. The stability testes were repeated to collect 5 trials.

$$\text{COP Excursion AP} = \text{COPxmax} - \text{COPxmin}$$
$$\text{COP Excursion ML} = \text{COPymax} - \text{COPymin}$$

The walking performance of the subjects was determined by use of a motion analysis system. A marker was attached on heels of right and left sides. The subjects were asked to walk with a comfortable speed to collect 5 successful trials. The energy consumption of the subjects was determined based on heart rate monitoring. A polar heart rate monitor was used to store the heart rate during resting and walking. The subjects were asked to sit on a chair in a comfortable position for 5 minute, then stand up and remain in this position for 2 minutes. In the next stage the subjects were asked to walk with comfortable speed along an 8 figure for 10 minutes. Finally, the subjects were asked to sit on a chair to collect the heart rate in another resting position for 5 minutes.

The mean values of the stability, spatiotemporal and energy consumption parameters were determined for normal and other groups of patients participated in this study. For the new parameter, the mean values of each parameter of patient groups was divided to the mean of the parameter of normal subject. The new parameter is the total of ratio of each parameter of the patients compare to normal subject. Therefore, the maximum value of this parameter should be 3. The new parameter can be determined based on the following equations.

$$\text{Stability Index} = \left(\frac{\text{COP Excursion of AP of control}}{\text{COP Excursion of AP of group}} + \frac{\text{COP Excursion of ML of control}}{\text{COP Excursion of ML of group}} \right) / 2$$

$$\text{Gait Index} = \left(\frac{\text{Walking velocity of group}}{\text{Walking velocity of control}} + \frac{\text{Stride length of group}}{\text{Stride length of control}} + \frac{\text{Cadence of group}}{\text{Cadence of control}} \right) / 3$$

$$\text{Energy Index} = \frac{\text{PCI of control}}{\text{PCI of group}}$$

$$\text{New parameter} = \text{Stability Index} + \text{Gait Index} + \text{Energy Index}$$

The mean values of the afore mentioned parameters were determined. The normal distribution of the parameters was evaluated by Shapiro-Wilk test. As the parameters had a normal distribution, two sample t test was used to check the difference between control and patient groups. (Table 1)

Results

The mean values of stability parameters, gait (spatiotemporal parameters) and energy consumption are shown in table 2. As can be seen from this table there is a significant difference between excursions of COP in both mediolateral and anteroposterior directions of control and those with multiple sclerosis (MS) disorder (P-value = 0.0). Moreover, their walking speed significantly decreased and energy

consumption increased. Although the stability of flatfoot subjects did not differ significantly from that of normal subjects, they walked faster than normal subjects. The mean value of PCI of flatfoot subjects was 0.368 ± 0.073 beats/meter compared to 0.29 ± 0.11 beats/meter of normal subjects. The interesting point was that the stability of SCI in anteroposterior direction was more than that of normal subjects (p-value = 0.04). Moreover, their energy consumption of SCI subjects was 7 times more than that of normal subjects (p-value = 0.0).

Parameter	COP Excursion AP (mm)	COP Excursion ML (mm)	Walking Velocity (m/sec)	Stride length (m)	Cadence (steps/min)	PCI (beats/m)
Control	25.26 ± 10.85	13.76 ± 5.32	1.01 ± 0.165	1.25 ± 0.95	96.8 ± 12.1	0.29 ± 0.11
MS	46.1 ± 19.23	39.63 ± 34.91	0.774 ± 0.405	1.018 ± 0.287	85.06 ± 26.74	0.832 ± 0.64
SCI	17.06 ± 7.94	22.6 ± 21.7	0.316 ± 0.003	0.635 ± 0.22	43.2 ± 8	2.26 ± 0.48
Flatfoot	26.16 ± 6.4	13.21 ± 4.3	1.065 ± 0.015	1.27 ± 0.099	100 ± 11.62	0.368 ± 0.073
p-value Control & MS	0.00	0.00	0.00	0.04	0.005	0.00
P-value Control & SCI	0.04	0.07	0.00	0.00	0.00	0.00
P-value control & Flatfoot	0.08	0.157	0.003	0.17	0.045	0.04

Table 2: *The mean values of stability, gait and energy consumption of the subjects participated in this study.*

Table 3 summarizes stability, gait and energy consumption indexes of all groups of subjects. Moreover, the mean value of the new parameter is presented in this table. As can be seen from this table, there was a significant difference between stability index of normal and Ms Subjects. However, the difference between stability index of normal and flatfoot and SCI was not significant (P-value > 0.05). The new parameter showed a significant difference between control, MS and SCI subjects.

Parameter	Stability Index	Gait Index	Energy consumption Index	New Parameter
Control	1 ± 0.00	1 ± 0.00	1 ± 0.00	3 ± 0.00
MS	0.613 ± 0.273	0.82 ± 0.293	0.533 ± 0.3	1.96 ± 0.571
SCI	1.04 ± 0.02	0.443 ± 0.1	0.128 ± 0.02	1.61 ± 0.16
Flatfoot	1.15 ± 0.448	1.02 ± 0.163	0.885 ± 0.129	2.88 ± 0.328
p-value Control & MS	0.00	0.00	0.00	0.00
P-value Control & SCI	0.07	0.04	0.00	0.00
P-value control & Flatfoot	0.125	0.452	0	0.093

Table 2: *The mean values of stability, energy and gait indexes and new parameter of the subjects participated in this study.*

Discussion

The performance of normal and those with various musculoskeletal disorders can be evaluated by stability analysis during quiet standing, gait parameters (walking speed, stride length and cadence) and by evaluation of energy consumption. It should be noted that having good abilities in one of the afore mentioned performance does not support the abilities in other performances. It means that if a subject has a good ability to control his posture during quiet standing, it does not mean he/she has good ability during walking. Therefore, in order to evaluate the performance of subjects with various musculoskeletal disorders and in order to check the effects of various interventions on the performance of a subject, the stability during standing, gait parameters and energy consumption should be evaluated. The aim of this study was to introduce a new index to show the total abilities of subjects with various disorders based on stability, gait and energy consumption analysis.

The results of this research showed that although the stability of subjects with SCI did not differ significantly from normal subjects (they had better stability in AP plane), they consumed too much energy during walking and had a significantly reduced walking speed, due to a decrease in cadence and stride length, Table 2. The new parameter showed that SCI subjects had nearly half of the abilities of normal subjects. Therefore, comparison of their abilities based on only one parameter could not represent their abilities to do their performance during daily activities. There is no doubt that during daily activities, subjects should stand, walk with a comfortable speed with little energy consumption and force to cardiovascular system. The SCI subjects in this study used MTK RGO orthosis (Mohammad Taghi Karimi Reciprocal Gait orthosis) to stand and walk [12]. Therefore, it can be concluded that although the design of the orthosis enable SCI to stand and walk, they have still lots of problems during walking due to reduced walking speed and high energy consumption (which may be due to lack of dynamic stability) [8].

As can be seen from the results of the current study subjects with MS disorder had impaired stability, slow walking speed and high energy consumption while walking, Table 2. In comparison of the mean values of the afore mentioned parameters, energy consumption increased more than other parameters. It means that they have to contract more muscles to walk compared to normal subjects to enhance their stability while walking. The new parameter also showed a significant difference and confirmed that MS subject only had nearly 2/3 of performance or ability of normal subjects, Table 3. Therefore, it can be concluded that for this group of subjects rehabilitation should be focused on improving their standing stability, gait performance and conformability during long term walking.

For the subjects with flatfoot, they had high record of stability and gait performance but their energy consumption was more than that of normal subjects. It means that they also had to contract more muscles to stabilize their unstable foot while walking [15]. The new parameter also showed that this group of subjects had slightly decreased performance compared to normal subjects.

The results of the current study showed that it is not practical to evaluate the performance of the subjects with musculoskeletal disorders only based on their stability or gait parameters. Measuring all of stability, gait performance and energy consumption is recommended. In this paper a new parameter was developed to represent the total performance of subjects. The new parameter show the performance of subjects compared to normal. It can be used to plane the treatment procedure to enhance the abilities of the subjects with various musculoskeletal disorders. It should be emphasized that the new parameters can be included other important parameters as well, which is dependent on the subjects studied.

The new developed parameter seems to represent the total performance of subjects better than other traditional approaches. It is recommended that the abilities of the subjects should not be evaluated only based on one performance. Although subjects with some musculoskeletal disorders may have the same performance as normal subjects during standing, they may have problems during walking and also high energy consumption. The new parameter can be used to represent the abilities of the subjects and also to plane treatment approaches.

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Volume 4 Issue 5 December 2016
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