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ORIGINAL ARTICLE

Comparative study: Parameters of gait in Down syndrome versus matched obese and healthy children

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Abstract Being severely overweight is a distinctive clinical feature of Down syndrome (DS). Down syndrome is a complex multisystem disorder, representing the most common form of genetic obesity. The purpose of this study was to compare the spatiotemporal parameters of gait in genetically obese DS children and non-genetically obese children and compare their results with those obtained in a group of normal-weight control subjects. Fifteen patients with DS, 15 obese matched children and 15 healthy subjects from both sexes represented the sample of this study. Their age ranged from 12 to 14 years. Spatiotemporal gait parameters (total distance, step length, average step cycle, and walking speed) were assessed by using a Biodex Gait Trainer 2™. Obese DS patients walked slower for a short distance, had a shorter step length and a lower cadence compared with both matched non-genetically obese and healthy subjects. Also, non-genetically obese matched children showed spatio-temporal gait parameters significantly different from healthy subjects. Subjects with DS had a gait pattern significantly different from obese children despite that both groups had a similar body mass index (BMI). Gait abnormalities in children with DS may be related to abnormalities in the development of motor skills in childhood, due to precocious obesity. A tailored rehabilitation program in the early childhood of DS patients could prevent gait pattern changes.

1. Introduction

Obesity is a pathological condition associated with impairment in skeletal statics and dynamics. Excess weight is able to induce negative effects on several common daily movements, such as standing up, bending, walking and running [1,2]. Overweight and obesity are chronic diseases characterized by an increase of body fat stores [3]. The primary purposes for defining overweight and obesity are to predict health risks and to provide comparison between populations [4]. In Egypt, the problem is increasing. The overall prevalence of overweight and obesity was 12.1% and 6.2%, respectively, among the Egyptian adolescents, 7% of boys and 18% of girls were overweight and 6% of boys and 8% of girls were obese [5].

Mature gait pattern includes a narrow base of support; a smooth movement with minimal oscillations of the center of

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gravity and reciprocal arm swing, and is present in normal children aged seven years. The criteria which are used include duration of single limb stance, walking velocity, cadence, and step length [6]. Obesity causes alterations in gait that are associated with an increased risk of falls. Several studies have found preferred walking speed, step length, and step frequency to be significantly lower in the obese compared to the non-obese [7–9].

There are conditions in which obesity is part of a recognized genetic defect such as Down's syndrome and congenital leptin deficiency. This is called endogenous obesity [10]. Down syndrome (DS) is a chromosomal disorder characterized by some common clinical features, such as obesity, muscular hypotonia, ligament laxity and mental retardation [11]. All children with Down syndrome have some degree of gross motor delay, delayed postural responses, cognitive and sensory impairments [12].

The prevalence of obesity in individuals with certain developmental disorders was higher than those without developmental disorders [13].

Gait disorders are common in DS syndrome. It tends to progressively worse as the clinical picture advances, severely limiting the patients' quality of life [14,15].

The purpose of the current study was therefore to identify, quantify and compare the spatiotemporal parameters of gait in non-genetically obese children and genetically obese DS children using the Biodex Gait Trainer 2™ and compare their results with those obtained in a group of normal-weight control children. A deeper understanding of the causes of their gait abnormalities, and ultimately of their motor disability, may generate novel spin-offs for rehabilitation planning and treatment.

2. Subjects and methods

2.1. Subjects

Fifteen Down syndrome children, 15 obese children and 15 normal weight children from both sexes matched for age were enrolled in this study. Their ages ranged from 12 to 14 years. Clinical characteristics of the study groups were illustrated in Table 1. Down syndrome children were recruited from the National Institute of Neuromuscular System at Imbaba and from the genetics clinic of Abou El Reesh Hospital. All children were trainable and walk freely without support. They could understand and obey the instructions given to them. All DS patients showed a short stature. Obese children were recruited from National Nutrition Institute.

All children were selected according to BMI-for-age for children and adolescents aged < 20 years (Obese child BMI $> +2SD$) [16]. All children were free from any other illness that may affect gait. Children with any medical condition that would severely limit their participation in the study as vision or hearing loss, cardiac anomalies or musculoskeletal disorders were excluded. A written informed consent form giving agreement to participation and publication of results was signed by the children's parents. This study was conducted under the guidelines and the approval of Ethics Review Committee of the Faculty of Physical Therapy, Cairo University.

This study was conducted at isokinetic lab at the Faculty of Physical Therapy, Cairo University using the Biodex Gait Trainer 2™ to evaluate gait parameters.

2.2. Methods

2.2.1. Methods for child selection

a. *Weight and height scale:* Reliable weight and height scale was used to measure the weight (kg) and height (cm) of each child. Children were asked to wear light cloths, remove their shoes, stand up straight and look straight ahead for both measurements.
b. *BMI-for-age:* Body mass index was conducted after the measurement of weight and height according to the following equation, BMI = Weight in kg/(Body height in meter)^2 [17]. New growth charts from the Centers for Disease Control and Prevention (CDC) include an age and sex-specific BMI reference for children aged 2–20 years. At BMI-for-age, those with BMI $> +2SD$ may be classified as obese [16].

2.2.2. Methods for evaluation

2.2.2.1. Biodex gait trainer. The Biodex Gait Trainer 2™ is a device designed specifically for assessment, rehabilitation and retraining of gait for all patients. It provides both audio and visual feedbacks to facilitate gait training. It is composed of a treadmill with an instrumented deck that monitors and records kinematic gait parameters (step length, walking speed, etc.). A high resolution color touch screen LCD display is attached to the treadmill to control the device settings. Moreover, the Biodex Gait Trainer 2™ is supplied by a serial interface which allows the download of patient data to a computer for archiving, reporting or exporting data. In the assessment mode, the therapist is able to print out objective

Table 1 Clinical characteristics of the study groups.

	Study groups		
	DS group	Obese group	Control group
Sample size (M/F)	15 (8/7)	15 (9/6)	15 (8/7)
Age (years)	13.18 ± 0.81	13.08 ± 0.84	13.09 ± 0.88
Weight (kg)	68.26 ± 3.05*	69.73 ± 1.58*	48.13 ± 2.55
Height (m)	1.47 ± 3.61+*	1.49 ± 0.02	1.51 ± 0.03
BMI (kg/m^2)	31.55 ± 0.66*	31.22 ± 0.73*	21.04 ± 0.68

Data are expressed as mean ± standard deviation.
+* Significant at $P < 0.05$.
+ $P < 0.05$, DS group versus obese group.
* $P < 0.05$ compared with control group.

Table 2 Comparison between the mean values of gait parameters for the study groups (intergroup comparison).

Gait parameters	DS group	Obese group	Control group	*t*-Value (DS vs. obese)	*t*-Value (DS vs. control)	*t*-Value (obese vs. control)	*P*-value
Walking distance	229 ± 10.97	352 ± 14.67	459 ± 12.11	26.01	54.67	21.91	.000 +*
Walking speed	0.63 ± 0.03	0.97 ± 0.04	1.27 ± 0.03	25.69	54.91	21.95	.000 +*
Step cycle	0.73 ± 0.11	0.91 ± 0.09	1.24 ± 0.12	4.61	11.57	8.31	.000 +*
Step length	0.48 ± 0.04	0.69 ± .04	0.77 ± 0.09	12.44	11.11	3.24	.000 +*

Data are expressed as mean ± standard deviation.
+ $P < 0.05$, DS group vs. obese group.
* $P < 0.05$ compared with control group.

measurements about various components of the gait pattern [18].

The following spatio-temporal parameters were evaluated: total distance (m), average walking speed (m/s), average step cycle (cycle/s) and average step length (m/s) which may also be termed the vital signs of gait [19].

3. Procedures for evaluation

For evaluation of gait parameters, each child was first allowed to be familiar with the gait trainer before starting recording the gait parameters. The familiarity of the children with gait trainer was ensured to avoid misinterpretation of any variation of the results between the three groups that might be explained by unfamiliarity of the children with the gait trainer. This was achieved through instructing the child to warm up by walking over the gait trainer with low speed and to follow the tread belt movement for three to five minutes. This might be repeated two or three times till the child became adapted with the apparatus [20].

Each child was instructed to be upright with their feet flat on the treadmill belt looking forward as much as possible. Each child was instructed to discontinue walking when the child felt faint, dizzy or short of breath. Child was not allowed to step onto the gait trainer 2™ while the tread belt is in motion, always stop the gait trainer allowing the subject to step up on the tread belt. All children were capable of understanding commands and walked satisfactorily on the treadmill.

The gait trainer user set up information: At first, certain parameters were fed to the device. The screen allows entry of child information and parameters used for gait evaluation such as name, age, gender, height and gait evaluation time. To start the evaluation process, the tread belt was ramped up slowly to 0.3 m/h with zero degree inclination. The speed setting was then increased gradually to a comfortable speed for the child. Ask each child to walk in the belt with his preferred speed (normal daily walking speed) in a 6-min walking test [21].

As it is difficult for children with DS to reliably report their comfortable walking speed on a treadmill, therefore based on a pilot work and the work of others and the fact that comfortable speeds on a treadmill are slower than over ground walking [22], a comfortable treadmill speed was selected for all participants which is 75% of their comfortable speed during overground walking [23,24]. In this study the 75% speed on the treadmill was defined as preferred pace. Once the child was comfortable, the data recording was started. Each child was allowed to walk continuously for 6 min, then the evaluation session was finished and the tread belt slowed gradually until it stopped. The results then can be displayed on the screen. This procedure was repeated three times (with a rest period in between) and the average was taken for each gait parameter.

4. Statistical analysis

The collected data from this study represent the statistical analysis of the gait parameters including total distance, average walking speed, average step cycle and average step length for the three groups using the Statistical Package for the Social Sciences (SPSS). The raw data of the measured variables for the three groups were statistically treated to determine the mean and standard deviation. Statistical analysis was performed by the *t*-test for unpaired data, and using the analysis of variance (ANOVA) test to show difference among groups in the measured variables. If a significant *F*-ratio was obtained, then the post hoc comparisons were completed. The results are expressed as mean ± SD. *P* values less than 0.05 were considered significant.

5. Results

As revealed from Table 2 and Figs. 1–4, the obtained results in the current study revealed significant differences when comparing the mean values of the measured gait parameters of DS group with the mean values of the obese group as well as the control group. Children with DS showed a significant decrease in the measured gait parameters in comparison with the obese group as well as the control group ($P < 0.05$). Significant

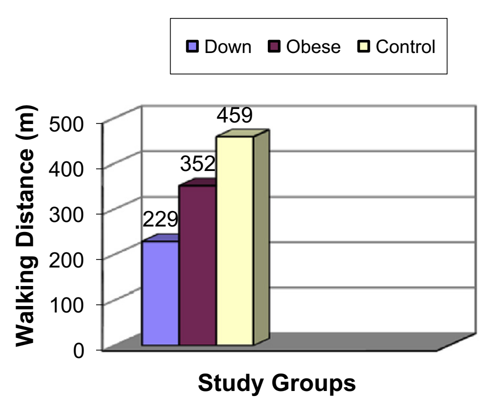

Figure 1 Demonstrating the mean values of the walking distance for the study groups.

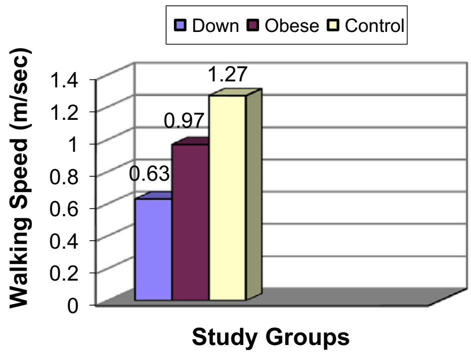

Figure 2 Illustrating the mean values of the walking speed for the study groups.

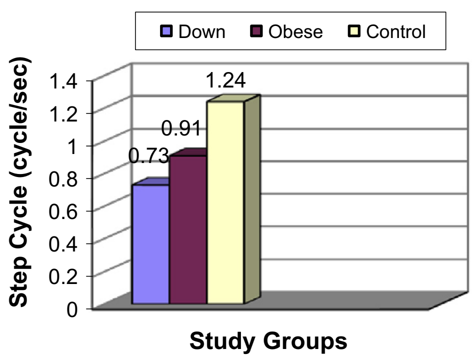

Figure 3 Representing the mean values of the step cycle for the study groups.

reduction was also observed in the mean values of the measured gait parameter for the obese group as compared with the mean values of the control group ($P < 0.05$).

As shown in Tables 3 and 4, the results revealed significant difference among the three groups.

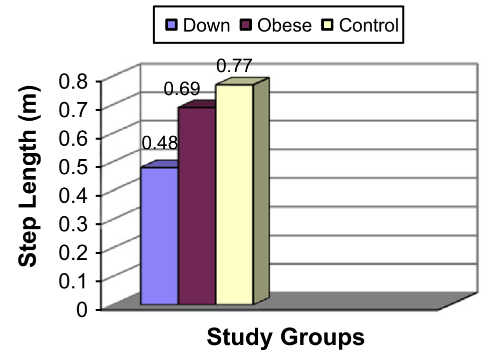

Figure 4 Illustrating the mean values of the step length for the study groups.

6. Discussion

On the basis of literature review there is no enough information to describe the changes of gait parameters for obese children with different causes. The evaluation of gait may also provide an indication of potential problems with the persistence of weight abnormality in order to provide data for developing evidence-based deficit-specific or common rehabilitation strategies.

Conducting the study on children aged from twelve to fourteen years may be attributed to the fact that walking experience increases as the child grows. Also the body structure changes and there is an improvement in strength and neurologic maturation. As the child grows, there is an improvement of stability and dynamic balance. Also their step length and mentality were more suitable for the requirements of the evaluation program [25].

Increased body fatness in obese children has a negative influence on children's physical performance that there is an inverse relationship between body fat and the ability to move total body weight. This is due to the fact that body fat adds to the mass of the body without making a contribution to force

Table 3 ANOVA test of gait parameters' mean values for the study groups.

Item	SS	DF	MS	*F*	*P*	Sig.
Walking distance						
Between groups	399876.933	2	199938.467	1.24	< 0.05	Sig.
Within groups	6753.067	42	160.787			
Total	406630.000	44				
Walking speed						
Between groups	3.077	2	1.538	1.237	< 0.05	Sig.
Within groups	0.052	42	0.001			
Total	3.129	44				
Step cycle						
Between groups	1.961	2	0.980	79.795	< 0.05	Sig.
Within groups	0.516	42	.012			
Total	2.477	44				
Step length						
Between groups	0.654	2	0.327	81.044	< 0.05	Sig.
Within groups	0.169	42	0.004			
Total	0.823	44				

SS: sum of squares; DF: degree of freedom; MS: mean square; *F*: *F* ratio; Sig.: significance.

Table 4 Post hoc test among the study groups.

Group	Mean difference	Std. error	Sig.
Walking distance			
DS vs. obese	123.066*	4.63	.000
DS vs. control	230.733*	4.63	.000
Obese vs. control	107.666*	4.63	.000
Walking speed			
DS vs. obese	0.341*	0.012	.000
DS vs. control	0.640*	0.012	.000
Obese vs. control	0.298*	0.012	.000
Average step cycle			
DS vs. Obese	0.177*	0.040	.000
DS vs. control	0.504*	0.040	.000
Obese vs. Control	0.326*	0.040	.000
Step length			
DS vs. Obese	0.202*	0.023	.000
DS vs. control	0.287*	0.023	.000
Obese vs. control	0.084*	0.023	.000

* The mean difference is significant at the 0.05 level. Std. error: standard error.

generating capacity, subsequently becoming additional weight to be moved during tasks like walking and running [26].

Overall, the results of the current study revealed that both obese DS and non-genetically obese groups are characterized by different gait patterns with regard to spatio-temporal parameters. Both obese and DS children walked for a short distance with reduced step length and lower velocity of progression when compared to the control group. These parameters indicate a cautious, abnormal gait in both groups, aiming at balance and stability in individuals who bear an excessive body weight [27]. Comparison between obese and DS outlined significant differences in terms of cadence, step length and progression velocity. Obese children were in fact characterized by values somewhat closer to normal than DS and were able to walk with a more ‘‘stable’’ strategy.

The significant reduction in the measured gait parameters in the DS group as compared to the obese and control groups might be attributed to hypotonia and ligament laxity which are thought to be the hallmarks of DS. This combination had a disruptive effect on proprioceptive feedback from sensory structures in the muscles and joints. Therefore, it can influence the intrinsic information regarding posture and movement and can have a negative effect on the appropriateness of co-contractions and postural reactions [28]. It impedes dynamic joint stabilization and explains the increased incidence of musculo-skeletal deformities. Hypotonic characteristics of persons with DS could influence the achievement of motor milestones that may limit physical activity during infancy. Later in childhood, poor gross motor performance may limit the amount of sports activity and organized play. There may be an element of the vicious cycle at which decreased physical activity results in excess weight, which then leads to an even further decrease of activity [29].

The DS-related obesity may contribute to the reduced motor skills observed in this population [30]. Generally the posture and gait of a child with Down syndrome differ from that of a typical child. They tend to have a wider base of support, out-toeing, smaller step length, increased flexion at hips and knees during stance [31]. Gait becomes unsteady, and the increased cautiousness during walking may lead to low velocity and short strides as observed in the present study [15].

There was a decrease in the total distance in DS children when compared with total distance that obese and normal children walked. Children with DS showed a limited excursion that may be linked to the anatomical configuration of their pelvic girdle: the so-called ‘‘mongol pelvis’’ which is characterized by a deeper acetabulum and a decrease in the cephalo-caudal diameter and acetabular angle. Children with DS were characterized by an increased plantar flexion and reduced dorsal flexion throughout the gait cycle with a globally limited ankle range of motion This would limit step length affecting the total distance and possibly lead to a relative prolongation of the stance phase of the gait cycle [32,33].

The slow speed of walking for children with DS also could be due to a hypotonic leg action, problems of balance and a wide-legged gait with exorotated and abducted hips without trunk rotation. This leads to lack of stabilizing co-contractions as a result of which inadequate postural control, insufficient trunk rotation and balance developed. Relative muscle weakness inducing earlier fatigue has also been described in obese down patients [34].

The results of this study showed that children with DS showed less ability to adjust the stride frequency and some difficulty in adapting the movement speed of their stride. This finding may be attributed to increased body weight which is correlated with anterior displacement of the center of mass (COM). This places DS children closer to their boundaries of stability and at a greater risk of falling during walking. At lower step cycles subjects may feel that they are moving sufficiently and more safe [35–37].

There was also a significant decrease in average step length of DS children which might be due to the decrease in average walking speed. Every feature of walking usually changes when the speed changes, as there is a strong positive relationship between speed and step length [38]. Weakness of hip extensors in children with DS increases the tendency for excessive hip flexion and anterior pelvic tilt causing the child to lean the trunk backward to shift the ground reaction force vector (GRFV) behind the axis of the hip joint and to prevent the trunk from falling forward. The long term effects of compensation lead to excessive lumbar lordosis and this causes the step length to be very short [23].

Also, obesity limits their abilities to produce sufficient step length similar to their normal peers. Obesity is associated with increased oxidative stress and that oxidative damage has been hypothesized as a contributor to the neurologic, endocrine, and immunological problems, observed in this population [39,40]. Increased levels of oxidative stress lead to dampening and decelerating capability of the lower limb musculature. Consequently DS children cover less ground with each stride and are likely to use higher metabolic energy similar to adults with DS during treadmill walking [41].

The significant differences in the measured gait parameters in the obese group as compared to the control group might be attributed to various factors. Significant decrease in the total distance that the obese children walked might be due to the increase in oxygen consumption and energy expenditure as a result of greater body mass which leads to decreased distance of walking. Obese children usually require higher oxygen uptake to perform submaximal tasks such as walking or running. The high cost of locomotion may reflect a wasteful walking style [42]. Obese subjects demonstrate greater mediolateral center of mass (COM) displacement that could induce an increase in the external mechanical work. Therefore, the net metabolic cost of walking increased which lead to decreased distance of walking [43].

There was a decrease in average walking speed for obese children when compared with their normal peers. At each walking speed, peak vertical ground reaction force (GRF) values were approximately 60% greater for obese subjects versus normal weight subjects. The major joints of the lower extremity were exposed to greater loads. Greater sagittal-plane knee joint moments in the obese subjects also suggest that they walked with greater knee joint loads than normal weight subjects. Walking slower reduced GRF and net muscle moments [44,45].

There was also a decrease in the average step cycle for obese children. Obese children have been consistently slower with a reduction in step cycle [8]. Also, obese individuals showed slower speed of walking as represented by longer cycle duration and lower relative velocity. These results confirm the commonly held subjective view of a slower, safer and more tentative walking gait in obese and overweight children relative to normal weight children [26].

There was a decrease in average step length of obese children in relation to normal weight children and this might be attributed to the decreased joint range of motion (ROM) and increased subcutaneous adipose tissue blocking joint excursion. Decreased ROM may lead to a subsequent reduction in flexibility and suboptimal postural alignment which make an obese child walk with low step frequency and decreased step length [46,47]. Increased body weight has been shown to be inversely associated with lower limb range of motion which leads to reduced level of activity [48]. Reduced muscle strength in obese children can predispose them to musculoskeletal fatigue. A positive relationship exists between muscle strength and activity and a negative relationship exists between muscle strength and obesity. The resistance offered by the body's weight could increase the rate of joint loading and make it difficult for such children to walk with high step length [49,50].

In conclusion, the gait pattern of obese DS children strongly differs from that of the obese subjects; despite both groups having similar BMI. DS children's ability in sitting, kneeling, standing and walking is delayed compared with children with the same age. In addition, these patients develop their gait pattern already influenced by obesity. These changes in gait pattern of both obese groups when compared with their non-obese counterparts have been interpreted as representing underlying instability in obese children with different causes, with a slower walking speed, lower step cycle and shorter step length in obese DS.

From a clinical point of view, quantitative characterization of gait patterns in obese DS children and non-genetically obese children is important to develop, differentiate and enhance the rehabilitative options. The quantification of their peculiar gait deficits strongly supports the issue that obese and DS patients need targeted rehabilitation and exercise prescription. Both patient groups should be encouraged to walk for its positive impact on the muscle mass and strength and energy balance. Evidence-based rehabilitation programs would contribute to improve daily functioning, quality of life and weight management issues in those patients.

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