Gait & Posture 71 (2019) 69–73

Contents lists available at ScienceDirect

Gait & Posture

journal homepage: www.elsevier.com/locate/gaitpost

Full length article

The influence of childhood obesity on spatio-temporal gait parameters

Jesús Montes-Alguacil[a], Joaquín Páez-Moguer[a], Ana Maria Jiménez Cebrián[a], Belén Álvarez Muñoz[a], Gabriel Gijón-Noguerón[b,*], José Miguel Morales-Asencio[b]

[a] Podiatry Department, Health Sciences Faculty, University of Malaga, Spain
[b] Podiatry Department, Health Sciences Faculty, Instituto de Investigación Biomédica de Málaga (IBIMA), University of Malaga, Spain

ARTICLE INFO

Keywords:
Obesity
Children
Gait

ABSTRACT

The musculoskeletal and neurosensorial development of children can be affected by excess body weight. Studies have examined how childhood obesity affects gait, but much about the influence of this factor remains to be determined. The aim of our study is to analyse, in a large sample of children, the influence of obesity on the spatiotemporal parameters of the gait cycle, in the most natural way possible, with the subjects walking overground at a self-selected speed.

Method: For this study, the sample was composed of 238 healthy school children, composed of 114 (47.9%) girls and 124 (52.1%) boys, aged 7–11 years. For each one, the body mass index was calculated, according to which the subjects were classified by percentiles as low weight, normal weight, overweight or obese. Anthropometric variables were measured and the spatiotemporal parameters of gait were assessed by the OptoGait® portable photocell system.

Results: The spatial variables did not reveal significant differences between the children with normal weight and those with obesity. However, the differences for stance phase, load response and pre-swing phase (p = 0.0001, p = 0.016 and p = 0.0001, respectively) were clearly significant.

Conclusions: Childhood obesity exerts a significant influence on gait by increasing the duration of load response and that of the pre-swing towards the oscillation phase and therefore the total duration of the support phase. This outcome requires greater energy expenditure to stabilise the gait of children with obesity, and could have biomechanical repercussions.

1. Introduction

Childhood obesity is currently considered a major public health problem [1–3] and its global prevalence is increasing [4]. Obesity and overweight are often related to musculoskeletal disorders, particularly of the lower limbs and feet [5,6]. Excess body mass is an important factor in the progression of angular deformities in varus and valgus of the knee, and can have long-term implications, including an increased risk of osteoarthritis in adulthood [7,8]. In addition, obesity and overweight can interfere with dynamic gait processes. In this respect, Mahaffey et al. [9] reported finding a significant relationship between childhood obesity and the intersegment angular motion of the foot, and a more pronated foot type, while Clark et al. [10] described a significant relationship between obesity and the movement quality characteristic of gait. Similarly, Villarrasa-Sapiña et al. [11] measured a direct relationship between postural control and obesity in children, and Song-hua et al. [12] concluded that these children have less walking stability than those with normal weight. Shultz et al. [13] reasoned that obese children need to produce more energy in the hips, knees and ankles to generate adequate muscular contraction force and thus maintain normal gait. Finally, McMillan et al. [14] observed reduced hip and knee joint flexion during gait and greater valgus positioning of the knee in an obese population.

To date, few studies have addressed the question of gait phases and spatiotemporal parameters in growing children with obesity vs. those with normal weight, and in the research that has been conducted in this field, most investigations have been based on expensive, complex technological systems, such as 3-D image capture apparatus and force platforms [9,11,15–21] but with very small sample sizes. One of the conclusions reached in the latter work is that obese children employ a passive strategy of the hip to achieve forward progression when walking, and that this represents a less efficient means of transferring energy [16]. Therefore, research findings suggest that childhood obesity bears a significant relationship with the spatiotemporal parameters

* Corresponding author at: Department of Nursing and Podiatry, University of Malaga, C/ Arquitecto Francisco Peñalosa 3, Malaga, Spain.
E-mail addresses: jesmonalg@uma.es (J. Montes-Alguacil), joaquinpaez@uma.es (J. Páez-Moguer), amjimenezc@uma.es (A.M. Jiménez Cebrián), belen.a@alu.uma.es (B.Á. Muñoz), gagijon@uma.es (G. Gijón-Noguerón), jmmasen@uma.es (J.M. Morales-Asencio).

https://doi.org/10.1016/j.gaitpost.2019.03.031
Received 5 December 2018; Received in revised form 18 March 2019; Accepted 29 March 2019
0966-6362/

of gait.

The Optogait system is more readily accessed and can be used in the primary care consultation. It is based on a photoelectric cell and is validated for the assessment of the phases of gait, in clinical and research settings [22–24]. According to Lee et al. [22], the test-retest reliability of Optogait in assessing gait parameters presents a high level of correlation, ranging from 0.785 to 0.952. The coefficient of variation of method error values was low, ranging from 1.66% to 4.06%, and all parameters presented standard errors of measurement between 2.17 and 5.96%, indicating strong reliability. However, very few studies have evaluated the spatiotemporal parameters of gait with this system in children [25–27]. In the latter studies, moreover, the sample size was very small and/or the study data were obtained using a treadmill. Walking on a treadmill is not natural; its surface is unstable and the subject needs a period of adaptation in order to match the treadmill speed [28].

The aim of the present study is to determine the influence of childhood obesity on the phases of gait, at a self-selected walking velocity. To our knowledge, this study is the first of its kind to analyse this relationship using the Optogait system, under the following circumstances: a large sample, with the children walking overground when the gait data are obtained, and at a natural speed (self-selected walking velocity).

2. Method

2.1. Participants

The study was carried out in Spain, with children of primary school age (7–11 years). The exclusion criteria included the presence of pain or injury in the foot and lower limbs at the time of physical examination, or during the previous six months, and/or the presence of musculoskeletal diseases, congenital structural abnormalities, cerebral palsy, motor dysfunction or prior surgery affecting the foot.

No sampling was carried out, but the whole eligible population (n = 238), recruited at ten primary schools in Malaga, a city with 569,009 habitants, was included. All the children who met the inclusion criteria were selected and evaluated during 2017. Age, gender, height, weight (Table 1) and body mass index (BMI) were determined and classified. The following variables and gait phases were obtained: stance phase, swing phase, single support, double support, step length and time, load response phase, pre-swing phase, contact phase, foot flat phase, propulsive phase, gait cycle, stride length, speed, acceleration, cadence and total distance.

2.2. Data collection

Height was measured to the nearest millimetre using a SECO 7710® calibrated portable apparatus, and body weight was measured using calibrated Digital Pegasus Scales, with the subjects wearing minimal clothing. The BMI was calculated from the subjects' height and weight (BMI = weight(kg)/height^2(m)). Since the subjects were all from Spain, where the Orbegozo classification [29] is widely used, they were then classified by BMI score, using the four-category Orbegozo classification system as follows; underweight: percentile less than 3 (P < 3), normal weight: percentile between 3 and 90 (P 3–90), overweight: percentile between 91 and 97 (P91–97) and obesity: percentile greater than 97 (P > 97), based on BMI according to age. Table 2 shows the number of children classified in each BMI group by age.

After determining the anthropometric variables, the spatiotemporal gait parameters were assessed using the OptoGait® portable photocell system [22–24]. This system provides real-time numerical parameters related to stepping, running and jumping. The device was always calibrated and checked for accuracy prior to each measure.

Previously, participants were instructed to walk barefoot in a natural way, for a distance of five metres between two parallel bars. Six to eight strides are sufficient to obtain representative data for unimpaired adults [24], and, in our case, ten strides were measured. After three trials, the data were acquired. A highly-experienced podiatrist(JPM) (with more than 1000 Optogait® tests examinations performed), controlled the measurement process at all times.

2.3. Ethical issues

The children's parents or tutors were previously informed about the characteristics of the study and provided signed consent for their children to participate. This study was carried out in accordance with the relevant provisions of the Declaration of Helsinki and was approved by the Ethics Committee of the University of Malaga (CEUMA 91/2016-H) (Spain).

2.4. Statistical analysis

The descriptive statistics obtained included measures of central tendency and dispersion, and the distribution of percentages. Exploratory analysis, by the Kolmogorov-Smirnov test and by examining symmetry and kurtosis, was performed to confirm the normality of the distributions. Subsequently, bivariate analysis of differences of the means, using Student's t test, was applied to evaluate differences in gait parameters according to gender, and differences in the gait parameters were identified by ANOVA, according to the four BMI groups established. The homoscedasticity of the distributions was determined by the Levene test. In addition, the Browne-Forsythe test of robustness was applied and post-hoc analysis performed by the Bonferroni test. Differences of the means were also obtained by Student's *t*-test of paired measures in the analysis of gait parameters by left/right side. The level of statistical significance was 95% in all cases, and all analyses were conducted using SPSS v.23 statistical software (SPSS Inc., Chicago, II, USA).

3. Results

The sample in this study was composed of 238 healthy school children, with 114 (47.9%) girls and 124 (52.1%) boys, aged 7–11 years (mean age: 9.25 years, SD: 1.38). One subject refused to participate in the study. The mean BMI was 20.41 kg/m^2 (SD:3.89) for the girls and 20.54 kg/m^2 (SD:4.34) for the boys. The difference between the genders was not statistically significant (t = −0.23; p = 0.814). The mean values obtained for each parameter, for total gait and for each foot, are detailed in Table 3. There were no significant differences between left and right feet in any case. The average velocity recorded was 1.24 m/s.

Significant differences were obtained between normal weight and obese children for the temporal stance phase, pre-swing phase ($p < 0,0001$) at total, left and right sides, and for the load response phase at total ($p < 0,016$), left side ($p < 0,0001$) and right side ($p < 0,011$). There was a significant difference in the load response

Table 1
Anthropometric characteristics of the sample by gender.

		Mean	95% Confidence Interval Lower	95% Confidence Interval Upper	SD
Age (years)	Female	9,29	9,03	9,55	1,40
	Male	9,19	8,94	9,43	1,38
Height (m)	Female	1,37	1,34	1,39	0,13
	Male	1,35	1,33	1,37	0,11
Weight (kg)	Female	39,30	36,92	41,67	12,78
	Male	38,55	36,30	40,81	12,68
Body Mass Index (kg/m^2)	Female	20,41	19,69	21,13	3,89
	Male	20,54	19,77	21,31	4,33

Table 2
BMI classifications by age.

Age (y)	n (%)	Underweight (n/%)	Normal weight (n/%)	Overweight (n/%)	Obese (n/%)
7	35/14.70	–	28/11.70	07/02.94	–
8	45/18.90	1/0.42	25/10.50	06/02.52	13/05.46
9	44/18.48	–	22/09.24	11/04.62	11/04.62
10	57/23.94	2/0.84	32/13.44	09/03.78	14/05.88
11	57/23.94	–	29/12.18	12/05.04	16/06.72

Table 3
Descriptive statistics for gait phases. Mean values, by left and right feet.

	Total Mean (SD)	Left Mean (SD)	Right Mean (SD)	p	r*
Step length_cm	59.24 (7.21)	58.86 (7.9)	59.21 (8.38)	0.391	0.70
Stance phase_s	0.58 (0.07)	0.58 (0.07)	0.58 (0.07)	0.292	0.90
Swing phase_s	0.38 (0.04)	0.38 (0.04)	0.37 (0.04)	0.145	0.72
Single support phase_s	0.38 (0.04)	0.37 (0.04)	0.37 (0.05)	0.899	0.76
Double stance phase_s	0.21 (0.06)	0.21 (0.05)	0.21 (0.06)	0.511	0.92
Step time_s	0.48 (0.06)	0.48 (0.06)	0.48 (0.05)	0.669	0.82
Load response_s	0.10 (0.07)	0.10 (0.03)	0.10 (0.07)	0.288	0.83
Pre swing phase_s	0.10 (0.03)	0.10 (0.03)	0.10 (0.03)	0.506	0.84
Gait cycle_s	0.95 (0.13)	–	–		
Stride_cm	112.79 (23.26)	115.44 (17.01)	115.06 (17.46)	0.670	0.69
Speed_m/s	1.25 (0.17)	1.25 (0.17)	1.25 (0.17)	0.973	0.97
Cadence step/min	127.79 (20.9)	127.22 (17.68)	127.29 (17.03)	0.891	0.91
Distance_cm	412.1 (27.63)	–	–		
Heel contact phase_s	0.08 (0.02)	0.08 (0.02)	0.08 (0.02)	0.461	0.43
Footflat phase_s	0.29 (0.09)	0.29 (0.09)	0.30 (0.09)	0.224	0.80
Propulsive phase_s	0.21 (0.08)	0.21 (0.08)	0.21 (0.08)	0.915	0.68

* $p < 0.001$.

between normal weight and overweight children at left side ($p < 0,011$), stance phase at total and right side ($p < 0,080$; $p < 0,050$) and pre-swing phase at total, left and right sides ($p < 0,007$; $p < 0,005$ and $p < 0,019$), respectively. The heel contact phase did not show significant differences between normal weight and overweight children, but the total and right side showed a significant shorter duration in obese children ($p < 0,027$; $p < 0,042$, respectively). No differences were found for any of the spatial parameters among the BMI groups.

Table 4 shows the details of the differences for the other parameters.

4. Discussion

Our study aim was to determine the influence of childhood obesity on the phases of the gait cycle, for children walking over ground at a self-selected velocity, taking into account the largest possible number of spatiotemporal gait parameters, and using the Optogait measurement system. Although each participant intuitively decided his/her own walking speed, as was found most comfortable, there were no significant differences in this respect. This finding is important to our assessment of the other results since, according to Roche-Seruendo et al. [30], the walking speed necessarily increases with an increase in the swing phase and in step length, and with a decrease in the stance phase. It is notable that the gait parameters relative to space did not present significant differences. However, there were significant differences related to time. The stance, load response and pre-swing phases all had a significantly greater duration for the obese and overweight children than for those with normal weight, while the heel contact phase was significantly shorter in the children with obesity.

The stance phase normally accounts for 60% of the stride, and the swing phase, the remaining 40%. The stance phase is composed of three elements: initial double support 10%, single support 40% and final double support 10%. The heel contact and the load response are the temporal phases of the initial double support [31]. Our study results show that among the obese children, the heel contact time is shorter and the downward movement of the forefoot is slower, as the first reaction of support in this direction. The pre-swing phase is the last temporal phase of the final double support, when the toes are finally released from the ground and the contralateral foot is supported. In children with obesity, this phase preparatory to that of oscillation is slowed down, which increases the duration of the stance phase. The pre-swing phase and the load response phase in the contralateral foot coincide at the moment of greatest oscillation of the centre of gravity, both laterally and forwards. According to Nantel et al. [16], obese children transfer mechanical energy less efficiently from the stance phase to the swing phase. In this respect, it has been reported that the influence of obesity on the phases of gait might be related not only to the optimisation of energy consumption, but may also respond to a strategy of balance stabilisation and the prevention of falls [11,12,27,32,33].

Previous studies based on the use of complex systems of 3-D analysis and/or force platforms have recorded a significant increase in the stance phase in the gait of obese children [9,14,19,20], an increase in the pre-swing phase [19]. Although most of these studies were focused in other parameters, and spatiotemporal parameters of gait were secondary variables, their findings agree with ours. A greater amplitude of movement in the frontal plane was obtained in similar studies [19–21]. Our study did not assess this variable, but it is coherent with load response and pre-swing phases occurring at the same moment of the gait. In our opinion, the increase of body mass in obesity simply generates an increase of moment oscillations forces and it results in an instinctive response to maintain stability. Indeed, acceleration did not show significant differences with weight increases.

To our knowledge, few previous studies, methodologically comparable, have been conducted with photoelectric systems such as Optogait, in study populations of children or adults. One such is Beulertz et al. [25], who compared the phases of gait in children treated for cancer vs. a control population. Interestingly, their results coincided with ours, with a significant increase observed in the stance and pre-swing phase among the group of cancer survivors, due to the weakness secondary to chemotherapy. In another study, Galli et al. [26] compared the phases of gait among children with Down Syndrome (DS) with and without obesity and a control group with normal weight. These authors recorded a significant increase in the stance phase among the children with obesity (63.69%), compared to those with normal weight with DS and the control group (59.00% and 59.57%, respectively). Unfortunately, our literature research did not reveal any previous studies clearly similar to ours, with which to compare the results of the statistically significant variables considered in our analysis.

The main limitation of our study is that the Optogait system detects rearfoot loading and forefoot unloading at 3 mm above ground level. This results in stance phase overestimation and swing phase underestimation [23], a factor that should be taken in account when comparing our data with those published elsewhere. Moreover, we did not evaluate the step width variable, a parameter which has been shown to be significant in similar studies examining children, in which 3D systems were used. Another limitation of this study is the walking distance

Table 4
Phases of gait with significant differences in relation to BMI.

Dependent Variables			Mean Difference	p	95% Confidence Interval	
					Lower Bound	Upper Bound
Load Response_t	Normalweight	Underweight	−.024	1.000	−.13	.08
		Overweight	−.021	0.468	−.05	.01
		Obese	−.032	0.016	−.06	.00
Load Response_l	Normalweight	Underweight	−.019	1.000	−.06	.02
		Overweight	−.014	0.011	−.03	.00
		Obese	−.024	0.000	−.03	−.01
Load Response_r	Normalweight	Underweight	−.020	1.000	−.13	.09
		Overweight	−.023	0.383	−.06	.01
		Obese	−.034	0.011	−.06	−.01
Stance Phase_t	Normalweight	Underweight	−.032	1.000	−.13	.07
		Overweight	−.029	0.080	−.06	.00
		Obese	−.044	0.000	−.07	−.02
Stance Phase_l	Normalweight	Underweight	−.021	1.000	−.12	.08
		Overweight	−.027	0.136	−.06	.00
		Obese	−.045	0.000	−.07	−.02
Stance Phase_r	Normalweight	Underweight	−.044	1.000	−.15	.06
		Overweight	−.032	0.050	−.06	.00
		Obese	−.044	0.000	−.07	−.02
Pre Swing_t	Normalweight	Underweight	−.016	1.000	−.05	.02
		Overweight	−.014	0.007	−.03	.00
		Obese	−.025	0.000	−.04	−.02
Pre Swing _l	Normalweight	Underweight	−.013	1.000	−.05	.02
		Overweight	−.015	0.005	−.03	.00
		Obese	−.026	0.000	−.04	−.02
Pre Swing _r	Normalweight	Underweight	−.018	1.000	−.06	.02
		Overweight	−.013	0.019	−.03	.00
		Obese	−.024	0.000	−.03	−.01
Heel Contact Ph_t	Normalweight	Underweight	.006	1.000	−.02	.03
		Overweight	.001	1.000	−.01	.01
		Obese	.007	0.027	.00	.01
Heel Contact Ph_r	Normalweight	Underweight	.019	0.479	−.01	.05
		Overweight	.003	1.000	−.01	.01
		Obese	.008	0.042	.00	.02

Abbreviations: t (total), l (left side), r (right side).
Note: Heel contact phase left side : no statistically significant differences were found.

of the protocol. König et al. [34] studied the variability of differences of parameters of gait with a continuous and over ground protocol, to avoid limitations of treadmill and non-consecutive protocols. Ten cycles were the minimum observations carried out in the study, with an excellent ICC (0,88–0,98). The inclusion of more cycles did not improve the ICC values for any of the mean gait parameters. Moreover, they suggest that mean parameters of gait can be assessed reliably with relatively few steps.

Although more studies are necessary to improve knowledge of gait in overweight and obese children, especially in symptomatic cases, we suggest that they could be focused towards postural evaluation and proprioceptive treatments at foot level, for the sake of better understanding of the relationship between gait behaviour in the presence of increased body mass and postural stability.

5. Conclusions

Childhood obesity significantly influences the duration of gait support, as regards load response and the upward movement of the contralateral foot towards the oscillation phase. This reflects the fact that persons with obesity tend (unconsciously) to adopt gait patterns that provide greater stability and optimise energy consumption while generating forward movement. The results of our study provide evidence of gait characteristics and of their possible clinical implications in children with obesity.

From a clinical standpoint, this approach could help clinicians interpret and understand findings in their examination of children with overweight or obesity, with particular regard to postural dysfunctions produced by bodily instability. However, further studies, specifically designed for this purpose, are needed in order to extend our understanding of this relationship.

Our findings show that the Optogait system or similar provides an economical and practical means of assessing the spatiotemporal parameters of the gait cycle in children, at the clinical level.

Ethics approval

The University of Malaga Ethics Committee approved this study (CEUMA 91/2016H). Participants gave written informed consent before data collection began.

Competing interests

Nil.

Source(s) of support

No external funding for this manuscript.

Acknowledgement

None.

References

[1] S.A. Jebb, J. Lambert, Overweight and obesity in European children and adolescents, Eur. J. Pediatr. 159 (September (Suppl. 1)) (2000) S2–S4.
[2] B. Livingstone, Epidemiology of childhood obesity in Europe, Eur. J. Pediatr. 159 (September (Suppl. 1)) (2000) S14–S34.
[3] M.B. Zimmermann, C. Gübeli, C. Püntener, L. Molinari, Overweight and obesity in 6–12 year old children in Switzerland, Swiss Med. Wkly. 134 (September (35–36)) (2004) 523–528.
[4] M. de Onis, M. Blössner, E. Borghi, Global prevalence and trends of overweight and obesity among preschool children, Am. J. Clin. Nutr. 92 (November (5)) (2010) 1257–1264.
[5] W.P. James, What are the health risks? The medical consequences of obesity and its health risks, Exp. Clin. Endocrinol. Diabetes 106 (Suppl. 2) (1998) 1–6.
[6] S.P. Messier, D.J. Gutekunst, C. Davis, P. DeVita, Weight loss reduces knee-joint loads in overweight and obese older adults with knee osteoarthritis, Arthritis Rheum. 52 (July (7)) (2005) 2026–2032.
[7] G. Strutzenberger, A. Richter, M. Schneider, A. Mündermann, H. Schwameder, Effects of obesity on the biomechanics of stair-walking in children, Gait Posture 34 (May (1)) (2011) 119–125.
[8] S.P. Shultz, E. D'Hondt, P.W. Fink, M. Lenoir, A.P. Hills, The effects of pediatric obesity on dynamic joint malalignment during gait, Clin. Biomech. Bristol Avon 29 (August (7)) (2014) 835–838.
[9] R. Mahaffey, S.C. Morrison, P. Bassett, W.I. Drechsler, M.C. Cramp, The impact of body fat on three dimensional motion of the pediatric foot during walking, Gait Posture 44 (February) (2016) 155–160.
[10] C.C.T. Clark, C.M. Barnes, M. Holton, H.D. Summers, G. Stratton, Profiling movement quality and gait characteristics according to body-mass index in children (9–11 y), Hum. Mov. Sci. 49 (October) (2016) 291–300.
[11] I. Villarrasa-Sapiña, X. García-Massó, P. Serra-Añó, C. Garcia-Lucerga, L.-M. Gonzalez, E. Lurbe, Differences in intermittent postural control between normal-weight and obese children, Gait Posture 49 (2016) 1–6.
[12] S. Yan, K. Zhang, G. Tan, J. Yang, Z. Liu, Effects of obesity on dynamic plantar pressure distribution in Chinese prepubescent children during walking, Gait Posture 37 (January (1)) (2013) 37–42.
[13] S.P. Shultz, E. D'Hondt, M. Lenoir, P.W. Fink, A.P. Hills, The role of excess mass in the adaptation of children's gait, Hum. Mov. Sci. 36 (August) (2014) 12–19.
[14] A.G. McMillan, A.M.E. Pulver, D.N. Collier, D.S.B. Williams, Sagittal and frontal plane joint mechanics throughout the stance phase of walking in adolescents who are obese, Gait Posture 32 (June (2)) (2010) 263–268.
[15] V. Cimolin, P. Capodaglio, N. Cau, M. Galli, C. Santovito, A. Patrizi, et al., Computation of spatio-temporal parameters in level walking using a single inertial system in lean and obese adolescents, Biomed. Tech. (Berl.) 62 (October (5)) (2017) 505–511.
[16] J. Nantel, M. Brochu, F. Prince, Locomotor strategies in obese and non-obese children, Obes. Silver Spring Md. 14 (October (10)) (2006) 1789–1794.
[17] S.P. Shultz, R.C. Browning, Y. Schutz, C. Maffeis, A.P. Hills, Childhood obesity and walking: guidelines and challenges, Int J Pediatr Obes IJPO Off J. Int. Assoc. Study Obes. 6 (October (5–6)) (2011) 332–341.
[18] M. Diop, A. Rahmani, A. Belli, V. Gautheron, A. Geyssant, J. Cottalorda, Influence of speed variation and age on ground reaction forces and stride parameters of children's normal gait, Int. J. Sports Med. 26 (October (8)) (2005) 682–687.
[19] V. Cimolin, M. Galli, L. Vismara, G. Albertini, A. Sartorio, P. Capodaglio, Gait pattern in lean and obese adolescents, Int. J. Rehabil. Res. 38 (March (1)) (2015) 40–48.
[20] L. Huang, P. Chen, J. Zhuang, S. Walt, Metabolic cost, mechanical work, and efficiency during normal walking in obese and normal-weight children, Res. Q. Exerc. Sport 84 (December (Suppl. 2)) (2013) S72–S79.
[21] Y.-C. Hung, S.V. Gill, G.S. Meredith, Influence of dual-task constraints on whole-body organization during walking in children who are overweight and obese, Am. J. Phys. Med. Rehabil. 92 (June (6)) (2013) 461-467-471.
[22] M.M. Lee, C.H. Song, K.J. Lee, S.W. Jung, D.C. Shin, S.H. Shin, Concurrent validity and test-retest reliability of the Optogait photoelectric cell system for the assessment of spatio-temporal parameters of the gait of young adults, J. Phys. Ther. Sci. 26 (January (1)) (2014) 81–85.
[23] K. Lienhard, D. Schneider, N.A. Maffiuletti, Validity of the Optogait photoelectric system for the assessment of spatiotemporal gait parameters, Med. Eng. Phys. 35 (April (4)) (2013) 500–504.
[24] A. Gomez Bernal, R. Becerro-de-Bengoa-Vallejo, M.E. Losa-Iglesias, Reliability of the Optogait portable photoelectric cell system for the quantification of spatial-temporal parameters of gait in young adults, Gait Posture 50 (2016) 196–200.
[25] J. Beulertz, W. Bloch, A. Prokop, V. Rustler, C. Fitzen, L. Herich, et al., Limitations in ankle dorsiflexion range of motion, gait, and walking efficiency in childhood cancer survivors, Cancer Nurs. 39 (April (2)) (2016) 117–124.
[26] M. Galli, V. Cimolin, C. Rigoldi, C. Condoluci, G. Albertini, Effects of obesity on gait pattern in young individuals with Down syndrome, Int. J. Rehabil. Res. 38 (March (1)) (2015) 55–60.
[27] N. Pathare, E.M. Haskvitz, M. Selleck, Comparison of measures of physical performance among young children who are healthy weight, overweight, or obese, Pediatr. Phys. Ther. 25 (3) (2013) 291–296.
[28] S.C. White, H.J. Yack, C.A. Tucker, H.Y. Lin, Comparison of vertical ground reaction forces during overground and treadmill walking, Med. Sci. Sports Exerc. 30 (October (10)) (1998) 1537–1542.
[29] B. Sobradillo, Curvas y tablas de crecimiento: (estudios longitudinal y transversal), Fundación Faustino Orbegozo Eizaguirre, 2004.
[30] L.E. Roche-Seruendo, F. García-Pinillos, J. Haicaguerre, A.V. Bataller-Cervero, V.M. Soto-Hermoso, P.Á. Latorre-Román, Lack of influence of muscular performance parameters on spatiotemporal adaptations with increased running velocity, J. Strength Cond. Res. 32 (February (2)) (2018) 409–415.
[31] J. Perry, J.R. Davids, Gait analysis: normal and pathological function, J. Pediatr. Orthop. 12 (6) (1992) 815.
[32] M. Pau, S. Kim, M.A. Nussbaum, Does load carriage differentially alter postural sway in overweight vs. normal-weight schoolchildren? Gait Posture 35 (March (3)) (2012) 378–382.
[33] E. D'Hondt, V. Segers, B. Deforche, S.P. Shultz, A. Tanghe, I. Gentier, et al., The role of vision in obese and normal-weight children's gait control, Gait Posture 33 (February (2)) (2011) 179–184.
[34] N. König, N.B. Singh, J. von Beckerath, L. Janke, W.R. Taylor, Is gait variability reliable? An assessment of spatio-temporal parameters of gait variability during continuous overground walking, Gait Posture 39 (1) (2014) 615–617.