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Analysis of partial body weight support during treadmill and overground walking of children with cerebral palsy

Análise do uso de suporte parcial de peso corporal em esteira e em piso fixo durante o andar de crianças com paralisia cerebral

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Abstract

Objective: To analyze the spatial-temporal characteristics and joint angles during overground walking without body weight support (BWS) and with 0% and 30% BWS, and during treadmill walking with the same BWS in children with cerebral palsy. Methods: Six children with hemiplegic and spastic cerebral palsy (7.70 ± 1.04 years old) were videotaped during overground walking at a comfortable speed with no BWS, with 0% and 30% BWS, and during treadmill walking with 0% and 30% BWS. Reflective markers were placed over main bony landmarks in both body sides to register the coordinates "x", "y", "z". Results: During overground walking, children walked faster and presented longer and faster strides, longer duration of single-stance and swing periods, and shorter duration of double-stance period, than treadmill walking, regardless of BWS use. The hip was the only joint that presented a difference between body sides and experimental conditions; i.e. range of motion (ROM) was reduced in the plegic side when compared to the nonplegic side, and during overground walking without BWS when compared to 30% BWS. Conclusion: Children with hemiplegic and spastic cerebral palsy were able to walk overground and on a treadmill with different percentages of BWS, and their performance was superior during overground walking, regardless of BWS use.

Key words: joint angles; spatial-temporal parameters; hemiplegia; children.

Resumo

Objetivo: Analisar características espaço-temporais e ângulos articulares de crianças com paralisia cerebral andando sem o uso de suporte parcial de peso corporal (SPPC) em piso fixo e com 0% e 30% de SPPC em piso fixo e em esteira. Métodos: Seis crianças com paralisia cerebral hemiplégica espástica (7,70±1,04 anos) foram filmadas andando com velocidade confortável sem o uso de SPPC, com 0% e 30% de SPPC em piso fixo e com 0% e 30% de SPPC em esteira. Marcadores refletivos foram afixados nos principais pontos anatômicos dos dois hemicorpos para registro das coordenadas "x", "y", "z". Resultados: As crianças andaram mais rapidamente e com passadas mais longas e mais rápidas, com duração dos períodos de apoio simples e balanço maiores e apoio duplo menor no piso fixo do que na esteira, independentemente do uso do SPPC. O quadril foi a única articulação que apresentou diferenças entre os hemicorpos e entre as condições, sendo que o hemicorpo plégico apresentou menor amplitude de movimento (ADM) que o hemicorpo não plégico, e a ADM foi maior na condição sem o uso de SPPC do que com 30% de SPPC em piso fixo. Conclusão: Crianças com paralisia cerebral hemiplégica espástica são capazes de andar em piso fixo e esteira com diferentes porcentagens de SPPC, sendo que seus desempenhos foram melhores no piso fixo, independentemente do uso de SPPC, do que na esteira.

Palavras-chave: ângulos articulares; parâmetros espaço-temporais; hemiplegia; crianças.

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Introduction

Systems involving the use of a suspension vest and partial body weight support (BWS) have been used as a form of walking training[1]. In this type of training, subjects practice treadmill walking while their weight is partially supported by a suspension vest. The BWS can be used in different ways that allow various degrees of body motion. The height of the vest and the subject's body weight can be adjusted by the calibration of load cells, counterweights, pneumatic lift, springs, etc. Thus, the system may support a percentage of the subject's body weight (partial BWS) or the total body weight, according to the examiner's wish.

Among the different percentages of BWS that can be used, the majority of studies evaluating treadmill walking adopted a 30% BWS due to its effectiveness in improving walking performance[2-5]. In addition to selecting the appropriate percentage of BWS during training sessions, another aspect to be considered is the type of walking surface, as it should preferably replicate situations encountered during daily life activities in order to facilitate the transfer of skills to that context[6,7].

The differences between overground and treadmill walking without BWS have been investigated in healthy individuals[8-11] and in hemiparetic stroke patients[12,13]. The characteristics of locomotion, such as joint angles or spatial-temporal parameters[8,14,15], foot contact with the surface[11], and muscle activation[13], are influenced by the type of walking surface. Thus, it may be that walking training on a treadmill may interfere with the proper transfer of skills to overground walking[7,10,16], which is the walking surface used by individuals on a daily basis.

Among those individuals with locomotor impairment, one group that can benefit from walking training with BWS is children with cerebral palsy, since the development of an independent and efficient walking is one of the major targets for this group. Cerebral palsy (CP) describes a group of permanent disorders of the development of movement and posture, causing activity limitation[17]. These disorders are attributed to nonprogressive disturbances that occurred in the developing fetal or infant brain[17]. To date, there are few studies using BWS for walking training in children with CP[18,19], and these are mostly case studies[20-23]. In previous studies, the improvement in walking performance was generally evaluated by motor tests, such as the Gross Motor Function Measure[24], and their results suggest that BWS can improve walking in children with CP.

Few studies have investigated the use of BWS during overground walking[3,25-27], and none of them had samples consisting of children. Additionally, little information is available regarding the impact of surface type (e.g. treadmill or overground) on walking performance with BWS. Thus, before recommending walking training with BWS to children with CP, it would be important to evaluate their walking performance in different types of surface.

The aim of this study was to analyze the spatial-temporal characteristics and joint angles during overground walking without BWS and with 0% and 30% BWS, and during treadmill walking with the same BWS in children with cerebral palsy.

Methods

Sample

Six children with hemiplegic and spastic CP, aged between 6 and 9 years, participated in this study. To be included in the study, they had to present spastic hemiplegia without any cognitive, verbal or visual impairments that could interfere with the performance of tasks, and had to be classified as level I to III of the Gross Motor Function Classification System (GMFCS)[28]. Children who were currently attending an intervention program offered by the Universidade Federal de São Carlos (UFSCar), São Carlos (SP), Brazil, or who had previously participated in that program, were contacted through telephone. The characteristics of children are shown in Table 1.

Table 1. Characterization of children with hemiplegic and spastic cerebral palsy in terms of age, gender, plegic side, weight, height, Gross Motor Function Classification System (GMFCS), and Ashworth scale[30].

Participant	Age (yrs)	Gender	Plegic side	Weight (kg)	Height (cm)	GMFCS	Ashworth scale
1	6.3	M	L	21.7	120	I	1
2	6.7	F	R	18.5	112	II	1
3	7.8	M	R	21.9	130	I	1
4	8	F	R	28.1	125	II	2
5	8.3	F	R	26.7	131	II	1
6	9.1	M	L	46.9	142	III	2
Mean	7.70			27.30	126.67		
SD	1.04			10.23	10.27		

GMFCS= Gross Motor Function Classification System; M= male; F= female; L= left; R, right; SD= standard deviation.

Procedures

Children accompanied by their parents or guardians attended the Learning, Biomechanics, Assessment and Training Laboratory (LABAT) of the UFSCar, where the data were acquired. Initially, the objectives and procedures of the study were explained, and each parent or guardian signed a consent form approved by the Ethics Committee of the Cruzeiro do Sul University, São Paulo, Brazil (No. 100/2007). While the parent or guardian was requested to complete the Pediatric Evalualion of Disability Inventory (PEDI)[29], which covers issues related to mobility, self care and social function, study investigators measured children's weight and height, and a physical therapist used the Ashworth scale to assess the degree of spasticity[30]. Then, reflective markers were placed bilaterally over the fifth metatarsal, lateral malleolus, lateral femoral condyle, greater trochanter, and greater tubercle of the humerus for the identification of foot, leg, thigh and trunk segments, respectively, and to calculate joint angles. Thus, the foot and leg segments defined the angle of the ankle, the leg and thigh segments defined the angle of the knee, and the thigh and trunk segments defined the angle of the hip.

Children were videotaped at 60 Hz by four digital cameras (Panasonic, model AG-DVC7P) bilaterally arranged, while walking in five experimental conditions: (1) overground walking without BWS; (2) overground walking with 0% BWS; (3) overground walking with 30% BWS; (4) treadmill walking with 0% BWS; and (5) treadmill walking with 30% BWS.

For overground walking, children walked at a self-selected and comfortable speed over a 10-meter course. Before videotaping, the children were given the chance to practice each experimental condition to familiarize themselves with the procedures. For treadmill walking, the treadmill was positioned at the center of the 10-meter course and children were requested to walk at a comfortable speed, while one investigator progressively increased the speed and checked if the child could accomplish the task. After reaching the speed that was adequate for each child, the practice of the five experimental conditions commenced. The children wore shoes and did not use any kind of orthoses during all experimental conditions.

Four repetitions of each experimental condition were videotaped, and the procedure always started with children walking overground without BWS (control condition). To reduce the time spent in the laboratory, experimental conditions involving BWS were first performed overground and then on the treadmill. The sequence for the percentage of BWS (0% or 30%) was chosen at random by the child. All children were allowed to rest between tasks, when needed.

The BWS system used in this study consists of a vest with adjustable belts and coated handles in the pelvis and thigh, which is suspended by a steel cable attached to a motor that slides on a rail of approximately 10 meters fixed to the ceiling. A load cell, positioned between the vest and the steel cable, was used to determine the approximate percentage of BWS. To adjust the percentage of BWS, the motor was used to reduce or increase the length of the steel cable according to the desired percentage.

Data treatment

Videotaped data were transferred to a computer through a capture card (ieee1394). One stride of both the plegic and nonplegic limbs were selected from two trials under each experimental condition using the Ariel Performance Analysis System Program (APAS). These data were digitized using the same program to obtain the coordinates *x*, *y* and *z*, which corresponded to the markers placed over children's anatomical landmarks. The procedure for processing the real coordinates of the acquired data was the direct linear transformation (DLT). These coordinates were filtered with a fourth-order Butterworth lowpass filter (10 Hz), and the following variables were calculated using the Matlab program (MathWorks, Inc.): walking speed; stride length; speed and cadence; duration of the single-stance, double-stance and swing periods; range of motion (ROM) of the hip, knee and ankle joints during the walking cycle. The data corresponding to the coordinate *x* of the marker placed over the greater trochanter (referring to the plane of progression) were used to calculate mean walking speed, and the markers placed over the right and left lateral malleolus were used to calculate stride length. Stride speed was calculated by the ratio between stride length and duration. ROM was calculated by the difference between the maximum and minimum angles of each joint.

Statistical analysis

To compare the walking performance among the five experimental conditions in children with hemiplegic and spastic CP, univariate (ANOVA) and multivariate (MANOVA) repeated-measures analyses of variance were employed. For the first ANOVA, the factor was the experimental condition and the dependent variable was the mean walking speed; for the second ANOVA, the factors were the experimental condition and body side (plegic or nonplegic), and the dependent variable was cadence. For all the MANOVAs, the factors were the experimental condition and body side; the dependent variables were stride length and speed for the first MANOVA, duration of single-stance, double-stance and swing periods for the second MANOVA, and ROM of the hip, knee and ankle joints for the third MANOVA. When necessary, Tukey's *post* *hoc* tests were employed. The significance level (α) was set at 0.05 for all statistical tests, which were performed with the software Statistical Package for Social Sciences (SPSS version 10.0, SPSS Inc.).

Results

Table 2 shows the values for all variables, except for ROM, which is shown in Figure 1. The ANOVAs indicated that the experimental condition was significantly associated with different walking speeds ($F_{4,20}$ = 19.33, p<0.001) and cadence ($F_{4,20}$ = 29.21, p<0.001). There was no indication of differences in cadence between body sides ($F_{1,5}$ = 1.84, p>0.05), and no association between the experimental condition and body side ($F_{4,20}$ = 0.48, p>0.05). *Post hoc* analyses indicated that children walked faster and with a higher cadence overground without BWS and with 0% BWS than on the treadmill with 0% or 30% BWS. When BWS was set at 30%, the children also showed higher cadence walking overground than on the treadmill.

The first MANOVA indicated that the experimental condition was significantly associated with different stride length and speed (Wilk's Lambda = 0.15, $F_{8,38}$ = 7.57, p<0.001). There was no indication of differences in stride length and speed between body sides (Wilk's Lambda = 0.37, $F_{2,4}$ = 3.34, p>0.05), and no association between the experimental condition and body side (Wilk's Lambda = 0.87, $F_{8,38}$ = 0.33, p>0.05). The univariate analyses of the experimental condition showed significant differences in stride length ($F_{4,20}$ = 21.19, p<0.001) and speed ($F_{4,20}$ = 22.99, p<0.001). *Post hoc* analyses indicated that children walked with longer and faster strides overground without BWS and with 0% BWS, than on the treadmill with 0% or 30% BWS.

The second MANOVA indicated that the experimental condition was significantly associated with different durations of stance and swing periods (Wilk's Lambda = 0.11, $F_{12,47}$ = 5.31, p<0.001). There was no indication of differences between body sides (Wilk's Lambda = 0.75, $F_{3,3}$ = 0,80, p>0.05), and no association between the experimental condition and the body side (Wilk's ambda = 0.63, $F_{12,47}$ = 0.76, p>0.05). The univariate analyses of the experimental condition showed significant differences in the duration of single-stance ($F_{4,20}$ = 12.84, p<0.001), double-stance $F_{4,20}$ = 25.57, p<0.001) and swing periods ($F_{4,20}$ = 9.33, p<0.001). *Post hoc* analyses indicated that the single-stance period (without BWS and with 0% BWS) was longer when children walked overground than on the treadmill. The duration of the double-stance period was shorter when children walked overground without BWS and with 0% BWS than on the treadmill, and shorter when they walked overground with 30% BWS than on the treadmill with 0% BWS. The duration of the swing period was longer during overground walking without BWS and with 0% BWS than on treadmill walking with 0% BWS.

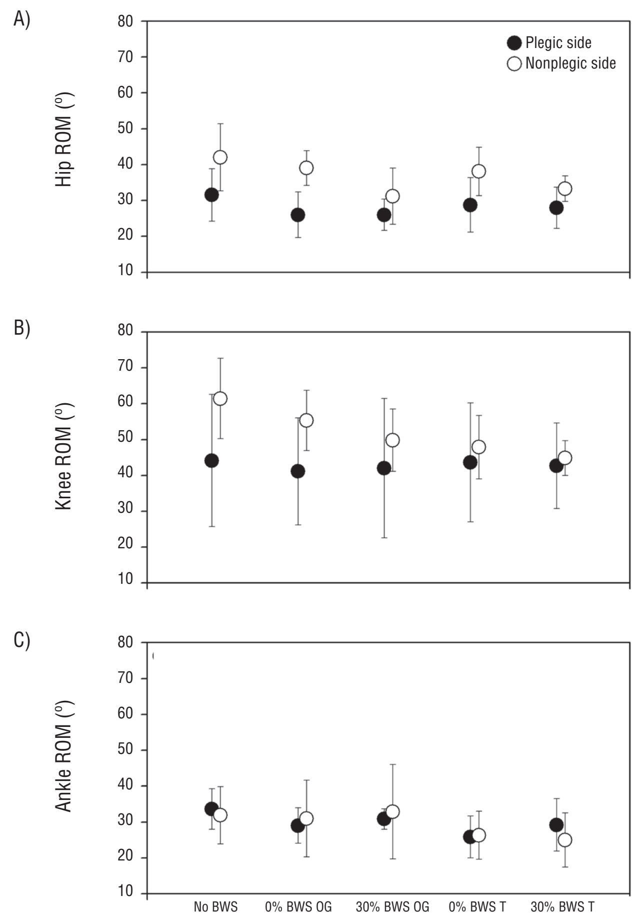
The third MANOVA indicated that the experimental condition was significantly associated with ROM (Wilk's Lambda = 0.15, $F_{12,47}$ = 4.25, p<0.001). There was an indication of differences between body sides (Wilk's Lambda = 0.05, $F_{3,3}$ = 18.66, p<0.05), but no association

Table 2. Walking speed, stride length and speed, cadence, and duration of single-stance, double-stance, and swing periods during five experimental conditions in children with hemiplegic and spastic cerebral palsy (n=6).

Condition	Walking Speed (m/s)	Stride Length (m)	Stride Speed (m/s)	Cadence (steps/min)	Single-stance (%)	Double-stance (%)	Swing (%)
Overground walking							
No BWS Plegic side	1.03±0.28	1.01±0.19	1.08±0.29	128±16	38.03±4.86	21.92±6.37	40.06±2.83
Nonplegic side		1.00±0.20	1.05±0.30	126 ±17	40.83±3.45	21.43±7.23	37.74±4.41
0% BWS							
Plegic side	0.87±0.21	0.86±0.16	0.90±0.20	126±10	36.66±2.00	19.71±4.50	43.62±4.99
Nonplegic side		0.84±0.15	0.89±0.18	127±13	39.77±4.57	20.44±5.82	39.80±6.79
30% BWS							
Plegic side	0.67±0.15	0.79±0.15	0.72±0.17	110±17	39.03±6.88	23,51±5,76	37,46±4,61
Nonplegic side		0.77±0.16	0.70±0.17	110±17	39.64±6.51	23,07±6,78	37,29±4,21
Treadmill walking							
0% BWS							
Plegic side	0.41±0.07	0.59±0.09	0.40±0.06	82±6	30.61±3.17	43.05±8.92	26.33±7.92
Nonplegic side		0.58±0.11	0.38±0.07	79±5	29.41±3.42	42.58±8.31	28.01±7.62
30% BWS							
Plegic side	0.41±0.05	0.56±0.13	0.37±0.06	81±9	30.28±4.06	36.52±6.38	33.20±6.63
Nonplegic side		0.56±0.11	0.37±0.05	80±9	29.32±3.43	36.66±4.51	34.01±4.65

Values are means or percentages and standard deviations. BWS= body weight support.

was found between the experimental condition and the body side (Wilk's Lambda = 0.38, $F_{12,47}$ = 1.77, p>0.05). The univariate analyses of the experimental condition showed significant differences in the ROM of the hip ($F_{4,20}$ = 5.91, p <0.005), knee ($F_{4,20}$ = 3.75, p<0.05), and ankle joints ($F_{4,20}$ = 3,87, p<0.05). The univariate analysis of body sides also indicated a significant difference in the ROM of the hip joint ($F_{1,5}$ = 32.64, p<0.005); i.e. the plegic side showed a more limited ROM than the nonplegic side. *Post hoc* analyses indicated that the ROM of the hip was greater during overground walking without BWS than with 30% BWS. There was no indication of such differences in the ROM of the knee and ankle joints.



ROM=range of motion; BWS=body weight support; OG=overground walking; T=treadmill walking.

Figure 1. Range of motion of the hip (A), knee (B), and ankle (C) joints during five experimental conditions in children with hemiplegic and spastic cerebral palsy (n=6).

Discussion

This study analyzed the spatial-temporal characteristics and the joint angles of children with CP during overground and treadmill walking and under different contexts of BWS. Few studies have investigated the use of BWS during overground walking[3,25,27], and their focus was on patients who had suffered a stroke. The present study was the first to analyze overground walking performance of children with CP using a BWS system, and to compare it to walking without BWS and with treadmill walking with BWS. According to our findings, the children walked faster and had longer and faster strides when walking overground than on the treadmill, regardless of BWS use. In terms of joint angles, the hip was the only joint showing differences between the body sides and among the experimental conditions, with the plegic side showing a more limited ROM than the nonplegic side, and overground walking without BWS showing a greater ROM than walking with 30% BWS.

Regarding the type of walking surface, most of the differences found in spatial-temporal variables may have been due to the characteristics of the treadmill and the speed at which children walked. For example, the length of the treadmill may interfere with the length of the stride[31]. Additionally, due to the fact that the treadmill is a moving surface, walking on that surface is more unstable than walking overground, and this may also decrease the length and speed of the stride[32]. Because the mean walking speed interferes with spatial-temporal characteristics of walking[33], the stride length and speed could have been similar between the two types of surfaces if the treadmill speed had been set closely to the speed at which children walked overground. However, because children with CP are not used to walk on the treadmill, this may have prevented them to feel comfortable walking at a faster speed.

The differences found in the duration of the stance and swing periods between overground and treadmill walking may also be a reflection of a greater degree of instability associated with the latter. It is well established that a longer single-stance period indicates the ability to sustain the limb[34], and in the same way, a shorter double-stance period indicates stability to walk. Because the treadmill is a moving surface, the children needed to spend more time with both feet on the surface during the walking cycle than when they walked overground. Consequently, they spent less time with only one foot on the surface during treadmill walking than during overground walking. One factor that contributes to improved stability and balance is the increase in the base of support[35]. In the case of this study, the children spent more time with both feet on the treadmill to ensure greater stability while walking on that surface.

The use of the treadmill for walking training in children with CP has advantages and disadvantages. In terms of the advantages, the treadmill can be used in a limited space, it favors the practice of complete walking cycles with symmetrical and consistent steps[36], the number of walking cycles per training sessions can be high given that the child cannot stop walking while the treadmill is in motion, and the speed of locomotion can be precisely controlled.

In terms of the disadvantages, treadmill walking requires a higher control of propulsion and balance compared to overground walking[37]. In terms of propulsion, while walking overground requires the application of enough force to alternately move the right and left limbs forward, walking on a treadmill using some type of external support (e.g. BWS, side bars) generates a force that is not necessarily proportional to the speed[38]. It is also possible that in this situation the limbs might be passively moved by the treadmill without any change in muscular activation[13], with the child simply raising and lowering the limbs while the treadmill belt is moving. In terms of balance control, because the treadmill is a moving surface, the walking strategy to keep stability can be different from that used for overground walking. This aspect was observed in this study through the variables duration of single-stance and double-stance periods, which were previously discussed. The disadvantages of using a treadmill may limit the transfer of skills to overground walking[37], since the strategies required for treadmill walking are not necessarily the same for overground walking, which is the type of surface that we normally walk.

In the case of walking training in children with CP, one should be concerned with the conditions imposed to these children and should work for enabling a more effective learning from this form of locomotion. And perhaps most importantly, one should understand whether the different types of training facilitate or hinder the transfer of learning to the child's daily context. Thus, studies like the present one are important because they compare the walking training in different types of surfaces to verify the impact of each procedure on the ability of locomotion, and consequently on the activities of daily living in children with CP.

Regarding the joint ROM, the absence of differences observed for the knee and ankle joints may be due to the small sample size and the variability among the children, as reflected by the standard deviation values (Figure 1B and 1C). On the other hand, there was less variability for the hip ROM, possibly because it is a more proximal joint than the knee and ankle joints. The hip ROM showed differences between the plegic and nonplegic sides, and the differences found between the experimental conditions may be attributed to the use of the suspension vest, which can restrict the movement of this joint[26,37].

Finally, for most of the parameters examined, no differences were found between the two selected percentages of BWS for treadmill and overground walking. This result contradicts a previous study investigating the use of BWS during overground walking in hemiplegic subjects[26]. Again, this result can be attributed to the small sample size and the wide variability among the children.

To our knowledge, there are currently no published studies to investigate walking parameters under different percentages of BWS in children with CP. For future studies, it is important to include a larger number of children with CP, especially because there is great variability in the type of brain injury in these children. This study demonstrated that it is possible to use BWS systems for walking training overground and on the treadmill in children with hemiplegic and spastic CP, and that differences in walking parameters can be observed between these types of surfaces.

This study has some limitations that need to be acknowledged, such as the nonrandomized sequence of surface types, the limited time to familiarize with the experimental conditions, the differences between the speed of treadmill and overground walking, and the small sample size. In this study, only children who were able to walk independently were selected to participate, but they showed great variability in task execution in the different experimental conditions.

Future studies should be performed with larger sample sizes and with children presenting different types of CP and greater impairment in locomotion. These studies should also include other walking parameters in their analyses. Finally, studies that investigate the effects of walking training in different types of surfaces must be conducted to clarify whether BWS systems are effective *per se* or whether it is the combination of the system and the type of surface that favors walking performance in children with CP.

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