Gait & Posture 35 (2012) 378–382

Contents lists available at SciVerse ScienceDirect

Gait & Posture

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

Does load carriage differentially alter postural sway in overweight vs. normal-weight schoolchildren?

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ARTICLE INFO

Article history:
Received 3 June 2011
Received in revised form 5 September 2011
Accepted 21 October 2011

Keywords:
Postural sway
Load carriage
Children
Obesity
Backpack

ABSTRACT

Among a wide range of negative consequences stemming from excess mass in children, recent studies suggest an impairment of postural control, including basic capabilities such as static and dynamic balance. Such impairment may be compounded when additional tasks are performed, such as carrying localized loads as occurs among children using a backpack. To investigate this, postural control was measured among 77 overweight and obese children (6–11 years old), and an equal number of normal-weight children matched for gender, age, and height. Testing was conducted at school, in which center of pressure (COP) time series during quiet standing were obtained in the presence and absence of each student's backpack. A traditional postural control measure derived from COP (mean velocity) did not indicate significant differences between overweight and normal-weight children, regardless of backpack presence. In contrast, a complexity index (derived from multiscale entropy) suggested the existence of different postural strategies and reduced balance capabilities among overweight children, whose consequences need to be further clarified.

1. Introduction

Most industrialized countries have experienced a recent increasing prevalence of childhood obesity over the last thirty years, particularly in North America, Europe and the Western Pacific [1]. While the chronic effects of obesity are well identified and widely investigated, especially as related to several metabolic and cardiac diseases [2], relatively less is known about how childhood overweight and obesity affect musculoskeletal development and function [3]. Apart from the fact that obesity requires higher rates of energy expenditure for movement, thus likely reducing an individual's willingness to participate in physical activity, the young obese might undergo alterations in basic motor tasks like standing and walking [4,5].

In particular, prepubertal overweight/obese children appear to have poorer dynamic and static postural stability, especially when visual input is suppressed [4,6], the base of support reduced [7] or when specific dynamic tasks (such as sit-to-stand) are performed [6]. Obese children, moreover, exhibit a substantial impairment in proprioception, one of the major sensory systems involved in postural control [8], and some evidence of alterations in hip, knee, and foot structures [3,9].

While such evidence suggests a degradation in postural control with obesity, it remains unclear whether it influences neuromuscular function and organization, or rather leads to inadequate muscular function. Further, the influence of obesity may only be evident under certain conditions or tasks demands. For example, when balance is assessed for simple tasks (e.g., bipedal stance with eyes open) the performance of obese children does not appear to differ from that of non-obese children [10]. This is in contrast to adults, for whom postural instability with obesity has been generally reported for quiet stance conditions [11], and the discrepancy may be a result of adaptations among children and/or the lack of chronic effects that are present among adults.

Among the daily activities performed by children that challenge the postural system, a relevant role is certainly played by load carriage, mostly in form of a backpack, and which is routinely performed to attend school activities. Previous studies reported that such load carriage significantly alters static postural control and gait patterns [12,13]. Hence, it is reasonable to surmise more substantial alterations among overweight and obese children, given that their musculoskeletal systems already support an excess mass that challenges the postural and locomotor systems. In other words, are there any systematic differences in the adverse effects of load carriage on posture control when an individual (child) is either overweight or obese?

To addresses this question, the static balance abilities (in terms of postural sway features) were assessed among a sample of

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doi:10.1016/j.gaitpost.2011.10.354

overweight and obese Italian primary schoolchildren. Two specific questions were addressed. First, does postural control differ for normal-weight vs. overweight/obese children? Second, does the influence of load carriage (via a backpack) differentially affect postural control depending on the presence of overweight/obesity? Based on distinct anthropometric features among obese children (especially in terms of fat mass distribution), we hypothesized that such basic tasks such as static upright posture would not be altered by the mass excess in the same manner as has been observed for adults, even when a external, localized load is added to body weight.

2. Methods

2.1. Participants and obesity assessment

In 2009, a project entitled "Backpack with Wings" was established by the University of Cagliari (Italy) in collaboration with three primary schools in the city of Cagliari (region of Sardinia, 180,000 inhabitants). The main purpose of the project is to assess the influence of backpack carriage on postural control and foot-ground pressure distribution, to highlight possible adverse situations (i.e., increased risk of unintentional falls or anomalous plantar stress concentrations) and to drive future interventions in terms of the organization of school activities. Participants in the current study were recruited from among the three participating schools. An invitation letter, containing a detailed description of the study purposes and procedures, was sent to the families of all of the 579 students enrolled in the schools. Of these, approximately 75% (231 male and 216 female students) expressed acceptance by signing an informed consent form. An initial screening was conducted, based on height and body mass, to determine the body mass index (BMI = body mass/height^2) of each child; subsequent classification into normal, overweight, or obese categories was according to age-specific criteria provided by Cole et al. [2].

Only children who used a backpack on a regular basis (~80% of the total) were included here, yielding a sample of 77 overweight or obese participants (45 males and 32 females). The same number of children was used to form a control group of normal-weight participants, matched for gender, age, and height. Four age groups were formed with roughly equal numbers in each: 6–7, 8, 9, and 10–11. Both overweight and obese children were grouped, for comparison to those of normal weight. Summary data for the study sample are provided in Table 1.

2.2. Experimental procedures

Tests of postural control were performed during eight sessions (coincident with the 5-h morning lesson periods) in the period of May–June 2009. Care was taken to not inform children and families of the exact day of testing, to ensure that both the amount and weight of items carried in the backpack was not influenced. Children were usually called in pairs into a dedicated test room with the bag loaded as at the entrance to school, while the rest of the class stayed in a separate waiting room. The stature and body weight of a child were recorded without shoes, and the backpack weighed. Participants stood on a pressure plate (see below), with the feet placed on two 30° oriented foot shapes drawn on a paper sheet, to ensure a common reference position, and following the International Society of Posturography recommendation [14]. An instructor helped the children find a stable and comfortable standing position, with their arms freely positioned along their legs and their gaze fixed on their reflected image in a mirror.

After an adaptation time (~20 s), a 30 s measurement was obtained without the backpack. While the room was kept quiet, the instructor reminded the participant to avoid any movement, particularly if early signs of distraction or impatience were observed. At the end of the first measurement, a short rest break was provided, and participants wore their backpack while a second measurement was obtained using the same procedures. Use of this consistent order was intended to minimize potential fatigue effects (i.e., by testing unloaded following loaded).

2.3. Data acquisition and processing

COP time series measurements were performed using a Footscan® 0.5 system (RS Scan International, Belgium), composed of a pressure-sensitive plate (4096 7.62 mm × 5.08 mm piezoresistive sensing elements arranged in a 64 × 64 matrix) and a USB interface box connected to a Personal Computer. The sampling frequency was set by the system to 33 Hz, as each trial is automatically subdivided in 1000 temporal events (frames) regardless of duration. The plate was controlled by dedicated software (BALANCE®), which allowed for extraction of the raw COP time series.

Postural control during bipedal static conditions is often assessed by quantitative analysis of COP time series using a number of spatiotemporal measurements such as sway area, distance, and velocity. Such measures and methods have been shown to be useful and reliable to investigate general features of upright postural control [15]. In particular, among the several traditional measurements available, COP mean velocity seems to be the most reliable one, especially in younger individuals [16]. Previous studies have also found that alterations in COP velocity are associated with a decreased efficiency of postural control among those with non-specific low back pain [17]. Considering that backpack carriage is thought to play a relevant role as risk factor for low back pain among children and adolescents, it is reasonable to hypothesize that an increase in COP velocity would reflect a possible balance impairment due to load carriage [18,19] and, to some extent, indicate situations involving an increased risk of low back pain.

Thus, COP mean velocities (COP MV) in both the AP and ML directions were determined (according to Prieto et al. [20]) for each trial. Values of COP MV were further normalized (nMV) to participant height to account for differences between age groups simply related to stature differences [21] and thereby better isolate the effects on sway related to age and obesity. Further, and to capture additional information about postural control that may not be reflected in traditional measures such as MV, the complexity index (CI) was determined in the AP and the ML directions, using multiscale entropy (MSE) analysis (see details in Costa et al. [22]). MSE analysis is used to measure the complexity of time series by approximating entropy over multiple scales, and was performed separately here on the differenced AP and ML COP time series to minimize temporal correlation and/or non-stationarity [23]. CI was calculated for the largest scale (= 5) using the Physionet toolkit software [24], while the required parameters (length $m = 2$, and specific tolerance $r = 0.4$) were set following the procedures of Ramdani et al. [23].

Separate four-way, full-factorial, mixed-factor analyses of variance (ANOVA) were used to assess the effects of age, gender, obesity, and backpack on the four dependent measures. To achieve normally distributed and homogenous residuals, both MV measures were log transformed prior to analysis. For significant age effects, post hoc paired comparisons were done using Tukey's HSD, and simple effects analyses were used to explore significant interaction effects. Significance for all statistical tests was concluded when $p < 0.05$. All summary statistics are reported as means (SD) in original units.

3. Results

A summary of ANOVA results for all COP-based measures is presented in Table 2. The conventional COP-based measures were affected significantly by the main effects of age, gender, and backpack, and the age × backpack interaction. There was a decrease in nMV with age, and an increase when wearing a backpack, though the youngest children (age group = 6–7) were less affected by the backpack than the other groups (Fig. 1). In addition, boys exhibited higher nMV values than girls [AP: 0.0010

Table 1
Age and anthropometric characteristics of the children involved in the study; values are means (SD).

	Age (yrs)	Stature (cm)	Body mass (kg)	BMI (kg/m^2)
6–7 years old				
Non obese (N = 17)	7.3 (0.4)	125.1 (3.8)	25.3 (2.5)	16.2 (1.2)
Obese (N = 17)	7.3 (0.4)	125.0 (6.5)	32.1 (5.1)	20.4 (1.8)
8 years old				
Non obese (N = 15)	8.5 (0.3)	130.1 (4.6)	27.2 (3.8)	16.0 (1.4)
Obese (N = 15)	8.5 (0.3)	132.0 (6.9)	36.8 (5.9)	21.2 (3.5)
9 years old				
Non obese (N = 24)	9.5 (0.3)	135.9 (7.7)	31.2 (5.1)	16.8 (1.2)
Obese (N = 24)	9.5 (0.3)	137.2 (5.6)	40.7 (4.3)	21.5 (1.2)
10–11 years old				
Non obese (N = 21)	10.5 (0.4)	142.9 (7.7)	35.5 (5.8)	17.3 (1.6)
Obese (N = 21)	10.7 (0.3)	145.3 (6.7)	48.3 (6.3)	22.8 (2.0)