Gait & Posture 50 (2016) 190–195

Contents lists available at ScienceDirect

Gait & Posture

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

Do fitness and fatigue affect gait biomechanics in overweight and obese children?

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ARTICLE INFO

Article history:
Received 4 January 2016
Received in revised form 15 August 2016
Accepted 7 September 2016

Keywords:
Children
Obesity
Gait
Kinetics
Fitness
Fatigue

ABSTRACT

The purpose of this study was to determine how an overweight or obese child's cardiorespiratory fitness level and a state of fatigue affect gait biomechanics.
Methods: Using a three-dimensional motion analysis system, twenty-nine (female and male) overweight and obese children aged 8–11 years walked on force plates before and after being fatigued from the Progressive Aerobic Cardiovascular Endurance Run (PACER) protocol. Joint moments were calculated for the knee and hip in the frontal and sagittal planes.
Results: In a non-fatigued state, peak hip and knee adductor moments showed a negative relationship with cardiorespiratory fitness level ($R^2 = 0.26, 0.26$). After the subjects were fatigued, peak hip extensor ($p = 0.02$), peak knee extensor moments ($p = 0.02$) and peak knee adductor moments ($p = 0.01$) showed a significant increase.
Conclusion: This trend illustrates that as an overweight or obese individual's fitness improves, the lower limb joint moments in the frontal plane decrease when walking. However, with the introduction of cardiorespiratory fatigue, lower limb joint moments tend to increase in the frontal and sagittal planes. Increased joint stress may have potential implications for obese children performing physical activity, as well as for clinicians who are attempting to intervene in the cycle of obesity.

1. Introduction

Despite continued medical and colloquial attention, obesity affects nearly 20% of the United States' population under 18 years old [1]. Kinematic data for obese children are fairly consistent, concluding that they demonstrate a slower preferred walking pace, shorter single limb stance, decreased step length, and less angular displacement of lower extremity joints [2,3,4,7–9]. Previous studies on the kinetics of gait have suggested that obese children exhibit increased stress at the hip and knee joints than their normal weight counterparts [2,10]. Children who are obese experience musculoskeletal issues at an increased rate compared with their healthy weight peers such as pes planus, abnormal knee alignment, increased risk for fractures, slipped capital femoral epiphysis, and general musculoskeletal pain [5].

Without considering aerobic fitness in the discussion of childhood obesity, medical professionals might be neglecting a vital component of a child's health. As recommendations from the American Heart Association continue to escalate the physical activity demands on obese children, it is imperative to explore the effect of cardiorespiratory fitness on the amount of stress across weight-bearing joints. Fitness is one of the strongest determinants of health because of its ability to predict functionality in multiple body systems [12]. Throughout multiple studies, a correlation has been suggested between cardiorespiratory fitness, BMI, and physical activity [13,14]. None of the studies to date in this field of research have considered the association between fitness and biomechanics for obese children. Considering cardiorespiratory fitness may likely provide important information to address potential biomechanical and gait-related issues in obese children [2].

Clinical conjecture suggests that gait mechanics will also be affected when a child reaches a state of cardiorespiratory fatigue. Without inducing fatigue, it may be difficult to obtain a clinically significant gait evaluation in obese children during a sub-maximal walking trial. Muscle fatigue has commonly been studied in the adult and children populations and shows a tendency to increase

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http://dx.doi.org/10.1016/j.gaitpost.2016.09.006
0966-6362/

lower extremity joint moments and faulty gait biomechanics [15,16]. Surprisingly, cardiorespiratory fatigue has not been considered in the literature as a variable for obese children's gait kinetics. Even studies that have performed walking trials over an extended period of time are not doing so with the purpose of inducing cardiorespiratory fatigue [11]. Thus, implementing a protocol that induces cardiorespiratory fatigue will likely produce a comprehensive evaluation of an obese individual's gait for health professionals.

The **purpose** of this study was to determine how cardiorespiratory fitness and fatigue influence lower extremity gait mechanics in overweight and obese children from ages 8–11 years old. The unique aspect of this study was that it examines cardiorespiratory fitness (an attribute) and cardiorespiratory fatigue (a temporary state) in obese children and the related association to physical performance (gait). It was hypothesized that gait biomechanics, as measured by lower extremity moments, would:

a Have an **inverse relationship** to cardiorespiratory **fitness** in overweight and obese children, and,
b Increase after cardiorespiratory **fatigue** in overweight and obese children.

2. Methods

2.1. Subjects

Twenty-nine individuals (14 females, 15 males) ages 8–11 years old (mean 9.8 ± 0.9 years old), with BMI scores above the 85th percentile, volunteered for the study. Based on pilot data, 30 subjects were needed to detect significant correlations and differences with 80% power. Children with any musculoskeletal injuries, neurological deficits, and cardiopulmonary diseases were excluded from the study. The study was approved by the University Institutional Review Board.

2.2. Protocol

Initially, basic demographics and anthropometric body measurements were collected by a single clinician. Waist circumference was measured at the level of the right iliac crest and hip circumference was measured at widest part of the hip with a tape measure (Gulick II, Country Technology Inc., Gays Mills, WI).

Next, the subjects performed a 3-dimensional gait analysis on force plates and a fitness protocol. In preparation for the force plate data collection, the subjects' step length was measured using a GAITRite mat, which is a valid tool for measuring both average and individual step parameters of gait and has excellent reliability [17,18]. Succeeding three practice trials of walking along an 8-m line in a hallway, subjects were instructed to maintain a constant walking pace and walk back and forth 3 times on the GAITRite mat. Corresponding to the calculated step length data, colored tape was placed at four and three stride lengths prior to the force plate on the floor plate walkway. The force plates were embedded in the floor and subjects practiced walking using the tape marks in order to make it more likely that they would naturally land on the force plates during the gait trials.

A single clinician placed markers of infrared emitting diodes (IREDs) on each individual's pelvis, trunk, and lower extremities. The markers for the lower extremities were affixed in triads to the lateral aspect of the foot, shaft of the tibia, and lateral aspect of the thigh. The markers for the pelvis and trunk were attached in triads to 5-cm extensions with base plates affixed over the sacrum and lower cervical vertebrae. The placement of the marker sets were similarly used in other studies with similar populations to collect three-dimensional kinetic data [11,19]. Five trials of walking biomechanics were recorded prior to the fatigue-inducing PACER protocol.

To collect 3-dimensional motion analysis data, a link-based model was created for tracking each body segment during the force plate gait trials, as recorded in similar studies [19,20]. The hip joint center was estimated using the functional method based on the isolated motion of the femur relative to a stable pelvis during separate movement trials [21]. Gait kinematic data was collected using an Optotrak motion analysis system (Model 3020, Northern Digital Inc., Waterloo, Ontario, Canada) operating at 60 Hz and filtered at 6 Hz, using a zero phase lag, fourth-order, Butterworth low pass filter. Kinetic data was obtained using a Kistler force plate (Kistler Instruments, Inc., Amherst, NY). The force plate data was sampled at 300 Hz, and filtered at 6 Hz to get rid of noise and undesirable portion of any kinematic waveform [20]. Visual 3D software (C-Motion Inc. Germantown, MD) was used to process lower limb kinematic and kinetic data on the force plates.

Between the two force plate gait data collections, The PACER protocol was implemented to fatigue subjects and estimate physical fitness, measured by VO_2 max [22]. The protocol required subjects to move between two markers, placed 15 m apart, within a progressively decreasing time interval. The activity was terminated if the subject failed to reach the 15 m marker in the allotted time twice or could no longer maintain the required speed. Physical fitness was estimated using a Quadratic Model ($VO_2\text{max} = 41.76799 + (0.49261 \times \text{PACER laps}) - (0.00290 \times \text{PACER squared}) - (0.61613 \times \text{BMI}) + (0.34787 \times \text{gender} \times \text{age})$) [22]. The IRED markers remained in place on the subjects' body throughout the PACER protocol. Instructions of the protocol were explained to the subjects, and then they performed the testing protocol. PACER is often completed by groups of students simultaneously, a research team member completed the PACER with each subject. This strategy was used to reduce any embarrassment the subject might feel by being observed by researchers as well as to provide motivation for the subject to provide maximal effort. The number of laps and heart rate at the end of the PACER were recorded. All subjects were required to achieve at least 80% of their maximal heart rate in order to achieve maximal effort in a maximal-intensity exercise protocol. Within 1 min of completing the PACER protocol, the subjects returned to the force plate walkway for the second data collection. An additional 5 trials of walking biomechanics were recorded while the subjects were fatigued.

2.3. Statistical analysis

The right side of the body was used as the side of interest for analysis. The primary outcome measure for both hypotheses was hip and knee moments in the frontal (adduction) and sagittal (extension) planes. Peak hip and knee moments, adjusted for body mass and speed, were calculated for each of the gait trials [2]. Average lower limb kinetic values of all 5 walking trials were used for further analysis.

An initial descriptive analysis for Hypothesis 1 estimated the Pearson correlation coefficients between fitness level and lower extremity joint moments. Graphical displays were used to show the association between peak moments (corrected for speed and body mass), and fitness levels, as measured by estimated VO_2 max in a non-tired state. For Hypothesis 2, paired *t*-tests were used to compare the pre- and post- fatigue lower limb moments for the gait trials.

3. Results

A total of 28 children completed the study (15 boys, 13 girls). One subject refused to complete the second lap during the first