Forceplates Data Reliability Tested on Children with Neuromuscular Disabilities

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Keywords: Gait Forces, Gait Cycle, Gait Impulse, Gait Consistency, Pediatric Gait.

Abstract: The "gait cycle" is considered the fundamental repetitive element of locomotion and is often used in comparative analyses between pathological and normal gait. One device that is used to measure ground reaction forces in the gait laboratory is a six degrees of freedom force transducer ("Force Plate"). Gait labs use two or more force plates to measure forces during one or two complete strides. Often, the walker "aims" to step sequentially on the force plates. This aiming may cause significant distortion of the person's gait pattern. To validate the measured result as representative of the individual's gait, a "Gait Consistency Test" was developed by Seliktar et.al with a group of adult individuals. The present study employed the consistency test to the ground reaction force records of two groups of children; typically developing children and children with cerebral palsy. The children's gait consistency study yielded even better results than the adult study; the results showed that the consistency test is useful for screening children's gait data and should be used to ensure higher fidelity of the measured data. The test applied equally to normally developing children and to children with gait pathologies.

1 INTRODUCTION

The hypothesis that is being tested in this work is: Is it legitimate to assume that human being ambulate by performing repetitive patterns (rhythm) of movement, often referred to as "Gait Cycles?" These cycles, if exist, should apply equally to normal gait as well as pathological gait. If such rhythm does not exist, then the term "Gait Cycle" is invalidated and would not be appropriate to be used in comparative gait analysis.

3D human motion analysis relies on the use of dynamic data acquired with the aid of motion tracking and ground reaction forces measurement instruments. The usefulness of the raw data characteristics themselves is often apparent in detection of gait abnormalities. The processing of the force and motion data to yield joint forces, moments and power during gait, further enhances its utility (Gage 2004). The relative simplicity of the ground reaction forces (GRF) characteristics makes them attractive as a clinical assessment tool, as opposed to the abundance of the kinematic data. Moreover, the joint moment information derived directly from these forces, further enhance the utility of these data in understanding the "human gait engine."

Considering the importance of the ground reactions as the main driving force of the overall human mechanism little has been done to address the validity and consistency of the measured GRF data during gait. The awareness of the shortcomings of the force plates as the primary available instrument, has led people to develop devices for continuous measurements of the ground forces. Nevertheless, all the new developments were restricted to measurement of the vertical component only. Seliktar et al. (Seliktar, Yekutiel, Bar 1979) developed a "Gait Consistency Test" to determine if due to the person's aiming towards the force plates or due to any other environmental distractions, the steady state nature (rhythm) of the measured gait is distorted. The test was designed to ensure that the velocity of the body center of mass is "the same" (within certain variation limits) at any two equivalent points of (at least) two consecutive

Rosen S., A. Tucker C. and Seliktar R..
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DOI: 10.5220/0004934303030306
In *Proceedings of the International Conference on Biomedical Electronics and Devices* (TPDULL-2014), pages 303-306
ISBN: 978-989-758-013-0

cycles. The premise of the test was that the velocities of the CM is governed by the ground forces and hence the force-time integral (Impulse) equals the difference in Momenta (Δmv) (the Impulse-momentum theorem):

$$I = \int_1^2 = Fdt = (mv_2 - mv_1) \tag{1}$$

over a full cycle, should be zero, as illustrated in Figure 1. Since the GRFs are vectors, the antero-posterior (A-P) force component was selected as the most adequate to be used for such validation of the results.

According to Newton's 2nd Law, for a system, the ground reaction forces and the gravitational force are driving the center of mass of the body;

$$\sum \vec{\vec{F}} = m\vec{a}_G \tag{2}$$

Since the impulse of the driving forces equals the difference in mass times velocity, the force-time integral between those two points, in rhythmic gait, must be zero. Nevertheless, small variations between cycles are expected and therefore absolute zero is not a feasible expectation.

The decision to use the A-P component for validation of the consistency is due to the authors' observation that human gait is less cyclical in the medio-lateral (M-L) and the measured vertical force is inconvenient to use, because of the body weight superposition. Moreover, because the A-P force is responsible for the forward progression of the body it is more likely to reflect deviations from rhythmic steady state gait due to environmental biases.

Previously reported results of the study were obtained from 28 adults with normal and pathological gait. Consistency was defined as the sum of the A-P impulse over one full gait cycle divided by the absolute values of impulse for both the braking and propulsion forces, Figure 1 and Equation (2) describe the calculation:

$$Consistency\ [\%] = \frac{A + B + C + D}{|A| + |B| + |C| + |D|} \tag{3}$$

When looking at Figure 1 and Equation (3) it is clear that the contribution of impulse 1; the impulse of the right foot from the time of the left foot heel strike to when the right foot toes off, is not accounted for in the calculation.

This is because only 2 force plates were available and the assumption made was that the areas denoted as 1 and the dashed part of area D are almost equivalent. The consistency threshold value was determined to be 7.3% meaning that values greater than 7.3% for the gait cycle would be considered

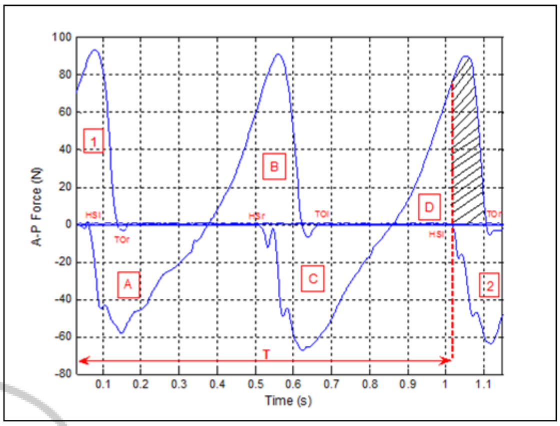

Figure 1: The GRFs in the A-P direction during two force plate strikes of an able bodied individual. HS stands for heel strike and TO for toe off. 'l' and 'r' stand for the left and right sides. T represents the time of duration of the gait cycle.As depicted in the illustration of figure (1), consistency was calculated over two force plate strikes, for both legs, left and right.

inconsistent and should be removed from further analyses. Clinical gait analysis is commonly performed in children with cerebral palsy (CP), and even though the GRF data is typically relatively underutilized in comparison to kinematic data it can provide a useful tool for ensuring the data used is representative. Currently the method used for ensuring representability is by averaging a number, usually three, trials of gait analysis. In the current study, the above approach was applied to three groups of children: typically developed children (TD), children with diplegic CP (DCP) and children with hemiplegic CP (HCP) to determine the utility of the gait consistency test.

2 METHODS

***Subjects**:* Retrospective data from a sample of 53 ambulatory children who underwent gait analysis testing at Shriners Hospital for Children (SHC) – Philadelphia, Motion Analysis Laboratory from 2001-2006 was used in this analysis. The first group, TD, consisted of 8 males and 8 females, 7-17 years of age (Mean=11.2, SD= ±2.1). The second group, DCP), consisted of 8 males and 8 females, 9-17 years of age (Mean=12.5, SD= ±2.0). The third group, HCP, with left (n=8) or right (n=13) sides affected, consisted of 10 males and 11 females, 10-17 years of age (Mean=12.9, SD= ±2.3). The analysis included 2 walking trials for each subject and an average of 2 gait cycles per trial.

***Data Collection**:* Data were obtained from motion analysis database and report reviews. Data were only included for children with CP who did not use assistive devices during ambulation, and completed two trials during which consecutive gait cycles for each of the four force plates was available.Only trials during which only a single foot landed on each of the force plates was deemed acceptable (e.g. trials during which 2 feet or more landed on a single force plate were discarded). This retrospective data used in this study was collected during gait analysis utilizing motion capture and force plate data collection during level ground ambulation. The Motion Analysis Laboratory at SHC–Philadelphia is equipped with an 8-camera MX-Vicon motion capture system (Vicon Motion systems, Lake Forest, CA) and 4 AMTI force plates (Advanced Mechanical Technology Inc., Watertown, MA). Analog force plate data were synchronized and collected through the Vicon system software. Each subject wore shorts and a T-shirt throughout the evaluation and gait analysis was performed with the subject walking barefooted and walking at his/her freely chosen walking speed along an 8.4-meter level walkway. Force data were collected when the subject traversed the middle 5 meters.

Data Analysis: Force plate data in the A-P direction that had been collected at 1200Hz sampling rate, was extracted from the Vicon's c3d files and imported into Matlab 7.1 (The Mathworks Inc. Natick MA) for further analysis. A custom-written Matlab program was used to calculate gait consistency, as defined in Equation (2). A one-way ANOVA test was used to determine significant differences in the consistency values between the three populations (Portney & Watkins 2009).

3 RESULTS

Data extraction resulted in a total of 2 trials for each of the 53 subjects. The ANOVA test revealed the values for the three populations were not significantly different ($F=1.18$, $p=0.31$). An average consistency value was calculated for the three populations separately, and for the entire population as a whole. Results for the pediatric population demonstrate that children can consistently ambulate within a motion analysis laboratory setting. The consistency test values can be found in Table 1 and Figure 2. These results were extremely close to the findings of Seliktar et al. (Seliktar, Yekutiel, Bar 1979) and show consistency is achieved with a ratio below 6.33%.

Table 1: Results of the consistency test for typically developed children, children with diplegic CP and children with hemiparetic CP.

Population	Average Consistency value [%]
Children with Typical Development	3.44 ± 2.48
Children with Diplegic CP	3.59 ± 2.47
Children with Hemiparetic CP	4.09 ± 2.58
Entire population with no regards to condition	3.77 ± 2.56

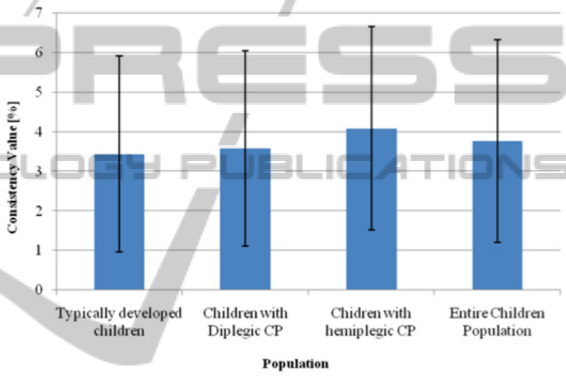

Figure 2: Results of the consistency test for typically developed children and children with diplegic and hemiplegic CP. Results are presented as the mean with the standard deviation.

4 CONCLUSIONS

The results of the study support the application of a gait consistency test to children with typical development and with CP. Our findings are consistent with those found by Seliktar (Seliktar, Yekutiel, Bar 1979) supports the definition of an inconsistent gait in children to be one in which the consistency value is above 6.33%. Given no significant differences in the consistency values for each of the three populations, it appears gait consistency is not dependent on the presence, or absence, of pathological conditions. The consistency test reflects ambulation at a constant speed of progression (velocity averaged per cycle), and many gait parameters are affected by gait velocity – or relative changes in gait velocity over consecutive cycles (e.g. speeding up or slowing down during gait analysis trials). The application of such a consistency test to ensure gait trials are compared across steady state trials, this measure provides a simple means to assess whether a specific gait cycle, chosen for analysis is in fact a representative gait of the child.

ACKNOWLEDGEMENTS

The authors would like to thank the staff at Shriners Hospitals for Children - Philadelphia Motion Analysis Laboratory for its assistance in this study and the support obtained from the Calhoun Fellowship Fund of the School of Biomedical Engineering Science and Health Systems at Drexel University.

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