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Short communication

Variability of the impact transient during repeated barefoot walking trials

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Abstract

Most studies of human gait assume that the normal gait patterns are consistent and therefore that it is adequate to assess the baseline condition once. However, recent research has brought this assumption into question. The purpose of this study is to evaluate the repeatability of components of the ground reaction force, peak force loading rate and percent of ground reaction force at impact above 60 Hz, across repeated walking trials throughout the experiment. Twenty-two subjects walked barefoot 10 times across a force platform interspersed between trial blocks of three different shod conditions. We used traditional grouped data analysis (ANOVA) as well as a more novel single-subject analysis. The grouped analysis revealed one statistically significant comparison between barefoot trials for the root mean square greater than 60 Hz variable. The single-subject analysis revealed that approximately 5% of the barefoot trials were significantly different for each of the peak force loading rate and percent of impact transient signal above 60 Hz variables. We suggest that these results, from both data analysis techniques, are not biologically relevant because the magnitudes of most of the changes were not large enough to have a biological significance (peak force loading rate differences less than 50%, and less than 0.05-fold differences in the percent of the ground reaction force above 60 Hz). In conclusion, our data suggest that baseline impact force measurements during walking are stable and do not need to be recorded between experimental conditions in walking studies.
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Keywords: Biomechanical experimental designs; Barefoot; Baseline measures; Ground reaction forces; Gait; Human subjects; Single-subject analysis

1. Introduction

Multiple research studies have shown that many gait parameters are reliable and repeatable within a single day for walking (Kadaba et al., 1989) and running (Diss, 2001; Ferber et al., 2002; Queen et al., 2006). Recent studies have also questioned this repeatability (Queen et al., 2006; Stergiou and Scott, 2005). The study by Stergiou and Scott (2005) has proposed widespread use of repeated baseline measures between test conditions, assuming that the control condition is unstable over time when experimental conditions are applied. The authors observed statistically significant differences between representative kinematic and kinetic baseline measures, therefore concluding that the control condition is not stable over time (Stergiou and Scott, 2005).

Stergiou and Scott (2005) employed a single-subject experimental design to examine if baseline measures are altered between conditions in a study evaluating lower extremity kinematic and kinetic data when running at different speeds over obstacles of different heights. Single-subject testing is a method of assessing differences between conditions for each individual subject; it is fundamentally different from the standard ANOVA procedures which assess differences between groups of subjects. The tenets of single-subject analysis are explained in a number of sources (Backman and Harris, 1999; Backman et al., 1997; Bates et al., 2004; Bates, 1996; Dufek et al., 1995; Gonnella,

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1989), but are based on the idea that subjects respond individually, and that the group mean does not well describe any individual subject's response (Bates et al., 2004; Dufek et al., 1995). Additionally, the Stergiou and Scott (2005) paper evaluated the consistency of multiple baseline measures. They concluded that baseline measures are altered between conditions in biomechanical studies. Furthermore, they recommended that multiple baselines should be used when a repeated measures or a single-subject experimental design is being utilized.

The purpose of this study was to investigate whether baseline measurements during normal walking are inherently unstable, or whether they remain consistent, between experimental conditions. We are extending the work of Stergiou and Scott (2005) to evaluate whether there are similar changes in baseline measures of the impact transient during walking gait trials, and hence directly evaluating whether repeated baseline conditions should be used whenever a repeated measures or a single-subject experimental design is being utilized, as suggested by Stergiou and Scott (2005).

2. Methods

Twenty-two subjects (14 females and 8 males) participated in this study. All subjects verbally confirmed that they were healthy with normal proprioception on the plantar surface of their feet. The mean age, height and weight are 21.9 (S.D. 2.2) years, 170.7 (S.D. 8.3) cm and 67.0 (S.D. 9.5) kg, respectively. The Institutional Research Ethics Board approved the experimental procedure. All participants gave written informed consent prior to starting the experimental procedures.

Subjects walked across a force platform (Model 9281B11, Kistler, Amherst, NY, USA), with a natural resonance of 700 Hz, which was embedded flush within a wooden walkway. They walked at their normal cadence assisted by a metronome. Individual starting points were laid out for each subject so that the subject's natural footfalls landed on the center of the force platform. Subjects had a number of practice trials to ensure they were comfortable with the protocol before beginning data collection. The protocol consisted of at least 10 barefoot trials interspersed between each of three different shod conditions in a single-subject (ABACADA) design, where A represents the repeated barefoot baseline conditions and B, C and D represent different experimental shod conditions. This is a variant of the ABA design which permits evaluation of more than one experimental condition (Gonnella, 1989), and is similar to the design used by Stergiou and Scott (2005). Four barefoot conditions (with 10 repeats in each condition) were collected. The shod conditions consisted of three different types of insoles made for a Rockport walking shoe, tested in random order: (1) a commercially available Dr. Scholl's insole, (2) a flat insole made of viscoelastic material and (3) an insole made of the same material as (2) but now having a raised ridge around the midfoot and heel region (see Maki et al., 1999 for further description). Similar to previous studies, trials which appeared abnormal, such as stretching to hit the force platform, were discarded and extra trials were therefore collected in some cases (Bates et al., 1983). Data was sampled at 1000 Hz using a 12-bit A/D converter (NI PCI-6023E) to collect appropriately the high-frequency component of the impact transient (Gillespie and Dickey, 2003).

The current study only evaluated the four "control" barefoot conditions that were interspersed between the different insole experimental conditions. Analysis of the footsteps included examination of time and frequency-dependent variables. A detailed description of the LabVIEW software used to calculate vertical ground reaction forces and frequency parameters has been given previously (Gillespie and Dickey, 2003). Peak force loading rate (pFLR; the greatest rate of force change during the first 20 ms of the gait cycle) was calculated instead of force loading rate (FLR) due to the absence of a clear peak during the first 20 ms after initial contact (impact transient) in most of the shod conditions. The second parameter measured in this study was the percent of the ground reaction force that was greater than 60 Hz (Gillespie and Dickey, 2003). These two parameters are sensitive measures describing the impact transient in walking (McCaw et al., 2000; Gillespie and Dickey, 2003).

Although the subjects completed a single-subject (ABACADA) design, statistical analysis was limited to the repeated baseline conditions (single-subject AAAA design). The first analysis involved single-subject analysis (Stergiou and Scott, 2005). Secondly, the data was pooled across subjects for a more traditional repeated measures ANOVA analysis. Both statistical approaches were implemented using GraphPad Prism version 4.0 for Windows (Graphpad Software, San Diego, CA; alpha equal to 0.05).

3. Results

We observed a large amount of variability between subjects in the pFLR, as well as the percent of the ground reaction force that was greater than 60 Hz (%GRF > 60 Hz) (Fig. 1A and B). The more traditional statistical analysis, examining the differences between groups using an ANOVA, revealed no statistically significant differences between baseline conditions for the pFLR variable (Fig. 2A); only one of the six possible pair-wise comparisons for the %GRF > 60 Hz variable was statistically significant (Fig. 2B). Similarly, considering the single-subject analysis, only six of the possible 144 pair-wise comparisons for the pFLR variable were statistically significant (Fig. 1A); only eight pair-wise comparisons for the %GRF > 60 Hz variable were statistically significant (Fig. 1B). Of the six statistically significant pFLR differences, three were also significantly different in the %GRF > 60 Hz variable. It is interesting to note that a relatively few number of subjects demonstrated any statistically significant differences using the single-subject analysis (four of 22 subjects for pFLR, and five subjects for the %GRF > 60 Hz variable). In total, 4.17% and 5.56% of the possible comparisons in the single-subject analysis were statistically significant for the pFLR and %GRF > 60 Hz variables, respectively.

4. Discussion

The purpose of this study was to investigate whether baseline measurements during normal walking are inherently unstable, or whether they remain consistent, between experimental conditions. We observed that the baseline measurements were in fact stable and therefore do not need to be repeated between different experimental conditions. That is to say, there did not appear to be clear and consistent differences in certain gait parameters (pFLR at heel strike and the high-frequency component of the GRF at initial contact) during repeated baseline measures for subjects walking at their normal cadence over level ground.

Our conclusion contradicts a paper which reports that repeated baseline measurements need to be incorporated

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