Dynamic Parameters Variability: Time Interval Interference on Ground Reaction Force during Running

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Abstract
The aim of this study was to determine the effect of the time between measures on ground reaction force running variability; 15 healthy men (age = 23.8 ± 3.7 years; weight = 72.8 ± 7.7 kg; height 174.3 ± 8.4 cm) performed two trials of running 45 minutes at 9 km/hr at intervals of seven days. The ground reaction forces were recorded every 5 minutes. The coefficients of variation of indicative parameters of the ground reaction forces for each condition were compared. The coefficients of variations of the ground reaction forces curve analyzed between intervals and sessions were 21.9% and 21.48%, respectively. There was no significant difference for the ground reaction forces parameters $F_y1$, $tF_y1$, $TC1$, Imp50, $F_y2$, and $tF_y2$ between intervals and sessions. Although the ground reaction forces variables present a natural variability, this variability in intervals and in sessions remained consistent, ensuring a high reliability in repeated measures designs.

Keywords
running, variability, ground reaction force

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Introduction

The musculoskeletal system is an active structure that can adapt to mechanical demands generated by movements. The redundant nature of the locomotor system in the generation of motor patterns creates normal variations in any human movement across multiple repetitions of a task (Stergiou, Harbourne, & Cavanaugh, 2006; Winter, 1984). This variability is not noise in the system, but an important phenomenon that reflects the neural control of movement (Bartlett, Wheat, & Robins, 2007; Davids, Ounpuu, DeLuca, & Davis, 2004; Latash & Anson, 2006; Stergiou et al., 2006). Optimal movement variability is associated with mature motor skills and healthy states and reflects the adaptability and flexibility of motor control, while reduced movement variability creates rigid, predictable, and less adaptive motor behavior (Stergiou et al., 2006; Stergiou & Descker, 2011).

Many studies of running use experimental protocols with repeated measurements, in which variables are measured on specific days or weeks. In these studies, changes in ground reaction forces (GRF) may be attributed to the studied phenomenon, when in fact they could be an expression of high natural variability (Lake, 2000). According to Winter (1991), the normal coefficient of variation for the vertical component of GRF is about 10% and for its horizontal component is about 21%.

Distinguishing intrinsic and extrinsic variability in human movement while measuring the influence of extrinsic factors such as ground surface, training, footwear type, or disease is difficult (Stergiou, 2004; Stergiou & Decker, 2011). Although some studies have analyzed GRF variability on different days for walking (Kadaba et al., 1989; Winter, 1984) and running (Ferber, Davis, Williams, & Laughton, 2002), there was no control for speed, which affects kinematic and kinetic parameters of running (Brughelli, Cronin, & Chaouachi, 2011; Johnson, Golden, Mercer, Mangus, & Hoffman, 2005; Keller et al., 1996). Controlling speed prevents such effects on movement variability (Jordan, Challis, & Newell, 2007; Masani, Kouzaki, & Fukunaga, 2002; Winter, 1984). When sources of extrinsic variability are removed, the intrinsic variability could be less than the previously reported. In addition, previous studies have not measured the variability over short time intervals; within the same days, variability was evaluated sequentially without reporting the time between trials. The analysis of the within-days variability indicate the necessity of expending a large amount of time performing several repetitions to evaluate the GRF in running, or if a few trials would be enough to estimate a behavior and its variability.

The use of a treadmill allows control of the speed during the tests and also offers a new approach for assessing the variability of discrete parameters of GRF in running. In previous literature, only gait studies were found (Kesar, Binder-Macleod, Hicks, & Reisman, 2011; Masani et al., 2002). Apparently, this is the first study to analyze GRF variability in running at a controlled speed.
Given the difficulty in distinguishing extrinsic and intrinsic variability, and that movement variability is an inherent characteristic of motor control, the stability of GRF in running over time, without any external interference, is of interest. The goal of this study was to assess the effect of the time between measurements (minutes or days) on GRF variability at a constant speed.

**Method**

**Participants**

Fifteen men who were habitual treadmill runners (age = 23.8 ± 3.7 year; weight = 72.8 ± 7.7 kg; height = 174.3 ± 8.4 cm) were recruited on the university campus for the study. All of the participants were submitted to a clinical and orthopedic examination. Those who had any kind of muscular, articular, or bone dysfunction were excluded.

**Procedure**

An instrumented treadmill (GAITWAY Instrumented Treadmill System 9810S1, and TROTTER Treadmill Model 685, 01–06560201) with two piezo-electric force plates (KISTLER Inc.) was used to obtain the GRF parameters. As a strategy to determine movement variability, participants ran on the treadmill for a period of 45 minutes at 9 km/hr, using their usual sports footwear. Although their shoes were different brands, they had the same construction characteristics and same condition. The speed of 9 km/hr was chosen as a comfortable speed for all participants and to avoid fatigue.

The vertical GRF were registered at different time intervals. After familiarization with the treadmill, 14 strides were measured every 5 minutes between the initial measurement (t = 0) and the final one (t = 45). The experimental procedures were repeated one week after the initial assessment to determine the variability over a longer time period.

**Measures**

The vertical GRF parameters were: the first peak force (Fy1), the time between the heel strike and Fy1 (tFy1), load rate (Fy1/tFy1 (LR1), the Fy impulse until 50 msec (Imp50), the higher peak force after Fy1 (Fy2), and the time between the heel strike and Fy2 (tFy2).

The impulse of the first 50 msec of Fy was chosen because the impact forces are usually arbitrarily defined as high-frequency forces where the peak value is reached in less than 50 msec. The reaction time of the neuromuscular system to a stimulus has been reported to vary from 50 to 75 msec (Jones & Watt, 1971). The passive impact forces, reaching a peak in less than 50 msec, have been suggested...
to cause bionegative effects such as microtrauma in muscles, ligaments, and bone (Nigg, Denoth, & Neukomm, 1981); these could be of interest in studies of sports injuries.

Analysis

The mathematical procedures to obtain the selected variables were carried out in MatLab6.5. Data normality and the equality of variance were verified by the Kolmogorov-Smirnov and Levene tests, respectively. The means, standard deviations, and coefficients of variation (CV) for each variable were calculated. The CV is a standardized measure of dispersion obtained normalizing the standard deviation (SD) by the mean ($\bar{M}$); it permits comparison of distributions of different conditions and variables (equation (1)).

$$CV = \frac{100SD}{\bar{M}}$$ (1)

The CV differences between the experimental conditions (5-minute durations at the first and last evaluations) were tested with a two-way analysis of variance (ANOVA) with repeated measures with factors interval and session. Tukey’s test was applied when a main effect was detected. Minitab 15.0 was used for all of the statistical procedures. Data reliability was calculated by intraclass correlation (ICC; Weir, 2005). The significance level was set at $p < .05$.

Results and discussion

The goal was to verify the effect of the time between measurements on GRF variability. The research question was supported: there were no significant differences between Fy1, tFy1, LRLR, Imp50, Fy2, and tFy2 coefficients of variation by interval and session. Therefore, the variability was similar between all experimental conditions for all GRF variables. The ICCs for the GRF parameters were .87 for Fy1, .86 for tFy1, .89 for Fy2, .73 for tFy2, .82 for LR1, and .90 for Imp50. The means and standard deviations for all trials at first (a) and last (b) evaluation are shown in Figure 1.

The GRF vertical component CVs in the first and last sessions were 21.9% and 21.48%, respectively. The similarity between these values suggested a similar variability in the GRF data of the two experimental conditions.

The two-way repeated measures ANOVA found no main effects of interval for GRF selected parameters: Fy1, $F(9,266) = 0.023, p = .88$, tFy1, $F(9,266) = 0.44, p = .51$, Fy2, $F(9,266) = 0.07, p = .79$, tFy2, $F(9,266) = 0.99, p = .32$, LR1, $F(9,266) = 0.10, p = .75$, and Imp50, $F(9,266) = 0.08, p = .78$. There were also no main effects of session: Fy1, $F(1,266) = 0.03, p = .86$, tFy1, $F(1,266) = 0.40, p = .53$, Fy2, $F(1,266) = 0.06, p = .80$, tFy2, $F(1,266) = 0.32, p = .57$,
LR1, $F(1,266) = 0.16, p = .69$, and Imp50, $F(1,266) = 0.07, p = .79$. The results of the interval and session factors are presented in Tables 1 and 2, respectively.

The results are not in agreement with those obtained by Queen, Gross, and Liu (2006) who found higher GRF parameters variability between days and in within days. However, Queen et al. tried to control the speed with a self-selected speed and an imposed standard speed. Their assessment was carried out on a fixed force-plate, which could hamper the speed control; variability in the self-selected pace speed condition was significantly higher than the imposed standard condition. This fact may support the present findings because it was possible that the strict speed control provided by the treadmill reduced GRF variability.

The observed high-GRF reliability was also obtained by Kadaba et al. (1989) and Ferber et al. (2002) in walking and running, respectively. These authors stated that the GRF parameter variability was lower than kinematic or electromyographic parameter variability, suggesting the need to assess these other parameters’ reliabilities.

Although Ferber et al. (2002) investigated running, the speed was not controlled. Controlling the speed removes a source of extrinsic variability, making the present results more unequivocally measures of intrinsic variability, which is relevant to assure the reliability in running evaluations at different times. Frequently, between-days analyses aim to verify the influence of an external phenomenon in running, therefore, knowing natural variability absent external interference is imperative.

The lack of significant effects of intervals and sessions suggests that variability in repeated-measures designs does not affect the results. On the other hand, in studies that do not use the same participants among treatments, the absolute

**Figure 1.** GRF mean of 14 attempts (full line) and standard deviation (dashed line) at (a) the first measurement time $t = 0$ minutes, and (b) the last measurement time, $t = 45$ minutes.
Table 1. Coefficients of variation (CV) during the 5-minute intervals in the two sessions.

<table>
<thead>
<tr>
<th>Minute</th>
<th>Fy1</th>
<th>tFy1</th>
<th>Fy2</th>
<th>tFy2</th>
<th>LR1</th>
<th>Imp50</th>
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<td>22.15</td>
<td>26.65</td>
<td>18.85</td>
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</table>

Table 2. Means and standard deviations of the coefficient of variation (%) in the two data collection sessions.

<table>
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<th>GRF</th>
<th>Session 1</th>
<th>Session 2</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>SD</td>
</tr>
<tr>
<td>Fy1</td>
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<td>0.73</td>
</tr>
<tr>
<td>tFy1</td>
<td>24.22</td>
<td>5.07</td>
</tr>
<tr>
<td>Fy2</td>
<td>8.75</td>
<td>0.91</td>
</tr>
<tr>
<td>tFy2</td>
<td>26.91</td>
<td>7.05</td>
</tr>
<tr>
<td>LR1</td>
<td>26.92</td>
<td>1.89</td>
</tr>
<tr>
<td>Imp50</td>
<td>16.42</td>
<td>1.25</td>
</tr>
</tbody>
</table>
variability could confound the results. This is true especially for tFy1, tFy2, and LR1, which showed high variability (24.22%, 26.91%, and 26.92%, respectively).

The use of a treadmill for GRF recording allowed precise control of the speed and the acquisition of a series of strides not possible using force plates. However, it presents some limitations. The treadmill measures only the vertical component of GRF, and the running pattern on the treadmill may be different than over-ground running (Elliott & Blanksby, 1976; Nigg, De Boer, & Fisher, 1995; Riley et al., 2008). Although the speed is an intervenient variable, controlling it reduces the ecological validity of the study, since typically speed is varied during running.

Results showed natural variability of movement influenced the selected GRF variables. However, the variability was consistent over intervals and sessions, ensuring a high reliability in repeated-measures designs.

Declaration of Conflicting Interests
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References


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Alberto C. Amadio completed his graduation in physical education. He is specialized in athletics. He has a master’s degree in physical education, PhD in Sports Science – Biomechanics. He is an associate professor and professor at the School of Physical Education and Sports, University of São Paulo (EEFE-USP). He acts in scientific research in the field of biomechanics of sport and has intellectual production by the Biomechanics Laboratory (EEFE-USP) which has formed Masters, PhDs, and post-docs.

Júlio C. Serrão completed his graduation, in 1993, in physical education from the School of Physical Education and Sport at the University of São Paulo (EEFE-USP), master’s in Science of Motricity, in 1996, at the Biosciences Institute of the São Paulo State University, PhD in 1999, and Habilitation in 2007 by EEFE-USP. He is currently a vice director of EEFE-USP, where he also exerts the coordination of Biomechanics Laboratory. It has experience in biophysics with emphasis on Biomechanics. His research involves the Biomechanics of Sport and Locomotion, the Biomechanics of Exercise, and Biomechanics and Footwear.