COMPARISON OF VERTICAL GROUND REACTION FORCES BEFORE AND AFTER GAIT TRANSITION

Li Li, Department of Kinesiology, Louisiana State University, Baton Rouge/USA

Introduction
Energetic cost has been proposed as a trigger for gait transition, as walking affords a lower energy cost at lower speeds, while running affords a lower energy cost at higher speeds (Margaria et al., 1963). Hreljac (1993) observed differences between energetically optimal transition speed and preferred transition speed between human walking and running. Subsequently, Hreljac (1995) observed that the maximum ankle joint acceleration changed dramatically during walk to run transition and a kinematic trigger was suggested. Using an equine model, Farley and Taylor (1995) proposed that lower extremity muscle stress could trigger the trot to gallop transition with increased locomotion speed. All of the proposed gait transition mechanisms can only provide a partial explanation for the nature of the gait transition. The study of ground reaction forces, the only contact force during locomotion, may enhance our understanding regarding the mechanism of gait transition.

To differentiate between the influence of speed and the influence of gait type on ground reaction forces during locomotion, Nilsson and Thorstensson (1989) investigated walking and running ground reaction forces at different speeds. The subjects were required to walk at five different speeds ranging from 1.0 to 3.6 m/s, as well as run at seven speeds ranging from 1.5 to 6.0 m/s. The locomotion speed was held constant during each condition. The authors observed that the ground reaction force patterns of walking and running were influenced by locomotion speed.

Due to technological constraints, the aforementioned researchers did not provide information of how the ground reaction forces changed during the steps preceding the gait transitions. Both Hamill et al. (1984) and Nilsson and Thorstensson (1989) collected data using a single force platform fixed within an over ground walkway. As a result, the ground reaction forces were only collected with constant velocities. Although unable to determine shear forces, a treadmill with an imbedded force platform provides a means with which to monitor the vertical ground reaction force continuously. The purpose of this investigation was to explore how the characteristics of the vertical ground reaction force component changes with gait transitions (walk-to-run and run-to-walk) while the locomotion speed is continuously changing. A specific hypothesis to be examined is that the gait parameters associated with steps leading to and immediately after gait transitions would exhibit unique transitional behavior. Since preparation for the gait transition would relate to the specific type of locomotion, the transition behavior would also be different comparing walking from or running.

Methods
Twenty healthy college students served as subjects in this study after signing an informed consent form in accordance with the University policy. Subjects were free of any lower extremity injury that may have affected their gait pattern and had no observable gait abnormalities. The average age, stature and body mass of the subjects were: 24 ± 5 years; 173 ± 9 cm; 74 ± 12 kg, respectively.

The experimental set-up consisted of a Kistler Gateway treadmill (Kistler Inc., Amherst, NY) with two embedded force platforms. A built-in speedometer provided a measure of the actual belt speed during the data collection. The force platforms had a range of 0-3000N and a natural frequency of 240 Hz. Data were collected using a microcomputer interfaced to the force platform and the speed sensor in the treadmill via an A/D board. Data sampling was accomplished at a rate of 1000 Hz. Four channels of data were collected: time, vertical ground reaction force of left and right foot, and belt speed.

Prior to data collection, subjects were weighed on one of the force platforms. They were then allowed to warm up on the treadmill to become familiar with the experimental setting. Each walk-to-run data collection trial required the subject to initially walk for 30 s at a speed of 0.89 m/s, followed by a walk-to-run transition that was induced by increasing the speed of the treadmill at a constant acceleration. Each run-to-walk data collection trial required the subject to initially run for 30 s at a speed of 2.7 m/s, followed by a run-to-walk transition that was induced by decreasing the speed of the treadmill at a
constant deceleration. Data for five walk-to-run transitions and five run-to-walk transitions (10 trials total) were collected for each subject.

Vertical ground reaction forces from both the left and right foot were analyzed for the five steps immediately proceeding and after the transition. The walking (or running) steps prior to the transition were labeled as -5, -4, -3, -2, and -1 thus indicating the steps prior to transition. The five steps after the transition were labeled as step 1, 2, 3, 4, and 5. Within each step, thirteen parameters from walking and six parameters from running were selected as descriptors of the vertical ground reaction force. Due to the page limitation, only peak forces and impulse are reported here. To be consistent with the literature, all forces and force related measures were reported relative to the subject's body mass and the times of these events are reported as a percentage of the stance phase.

Statistical analyses were performed on the walking and running data separately. ANOVA with repeated measures was used in the statistical analysis of walking and running data with significance level set as $\alpha = 0.05$. A post-hoc trend analysis was employed when necessary.

Results and Discussion

Figure 1 illustrates the changes that were occurring with the walking vertical ground reaction forces as the subjects approaching to walk-to-run transitions (WRT). Results indicated that the first peak (mean = 13.6 N/kg) of walking VGRF before WRT was increased linearly with increase of speed. The second peak (mean = 11.3 N/kg) decreased quadratically as approaching to WRT, with the magnitude of the last step significantly less then the previous steps. Meanwhile, the trough between the two peaks was decreased linearly with a mean of 5.6 N/kg. Impulse of walking VGRF (mean = 4.88 Ns/kg) decreased as approaching to WRT with the values of last two steps reduced dramatically and significantly less than the values of the previous steps. After WRT, peak (mean = 20.6 N/kg) of running VGRF increased linearly and the impulse (mean = 4.20 Ns/kg) decreased linearly. Exemplar data of running vertical ground reaction forces for the run-to-walk transition (RWT) are shown in Figure 2. Prior to RWT, peak (mean = 20.4 N/kg) of running VGRF decreased quadratically while the impulse (mean = 4.19) increased linearly. After RWT, the first peak of walking VGRF (mean = 13.9 N/kg) decreased quadratically and the second peak (11.0 N/kg) increased quadratically. The trough (mean = 5.84 N/kg) between the two peaks increased linearly after RWT. Impulse of walking VGRF (mean = 5.00) increased quadratically after RWT.

An important difference between the present study and previous published reports (Farley and Taylor, 1991; Hreljac, 1993,1995; Diedrich and Warren, 1995; Brisswalter and Mottet, 1996; and Turvey et al., 1999) are the unique transitional behaviors observed. A number of mechanisms have been proposed such as a kinematic mechanism (Hreljac, 1995), a mechanical trigger (Farley and Taylor, 1991), energy cost
(Hreljac, 1993 and Turvey et al., 1999) or a non-equilibrium phase transition (Diedrich and Warren, 1995 and Brisswalter and Mottet, 1996). In each case, these researchers all proposed that the gait transition should occur when certain limitations were met. The present study suggest that limitations prompted the gait transition should be a combination of environmental, task and organism constraints rather than any single factor, e.g. ankle joint acceleration - Hreljac, (1995) or muscle stress (Farley and Taylor, 1991). Furthermore, the observation presented here is evidence that the reorganization process that occurred one or two steps prior to the gait transitions is an active rather than a passive behavior. This transitional behavior is clearly demonstrated by the dramatic reduction of the peak forces in the last step before the transitions. For example, the reduction of P2 before the walk-to-run transition is one of evidences for the transition specific behaviors. Furthermore, those observations are different from the behavior of those parameters if there were no approaching gait transition (Hamill et al. 1984; Nilsson and Thorstensson, 1989).

In summary, vertical ground reaction forces of walking and running prior to a gait transition exhibited unique characteristics compared to walking or running at constant speeds.

![Graph showing vertical ground reaction forces vs stance duration](image)

**Figure 2. Exemplar data for running vertical ground reaction forces before run to walk transitions. The arrow indicates that the peak decreases as the subject approaching to the run-to-walk transition.**

**References**


