COORDINATION VARIABILITY - FORCE RELATIONSHIPS DURING A TEMPO RUN

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As people fatigue, impact force characteristics experienced during running are thought to increase and thus may place the individual at a greater risk for an overuse injury. It is still largely unknown as to how the vertical ground reaction forces may impact the intra-segmental coordination variability, a component in the production of movement which has been linked to adaptability and flexibility. Therefore, the purpose of this study was to determine how load characteristics interact with the coordinative variability during a tempo run at a self-selected pace. Fourteen individuals participated in the study and completed a 25 min run at a high level of exertion (RPE > 14). Results demonstrated that the impact characteristics did not change over time but that coordinative variability changed during the initial portion of the run. This suggests that the participants adapted their coordination variability to counteract the forces incurred during the run.

KEYWORDS: dynamical systems, coordination, injury risk

INTRODUCTION: In 2014, 18,750,000 people crossed the finished line in U.S running events with approximately 44% of those runners (8,300,000) finishing a 5k race (Running USA, 2015). With an increasing volume of recreational runners each year, a large emphasis has been placed on overuse injuries. One of the most commonly cited risk factors that may lead to injury is the loading of the lower limbs during the foot-ground contact (Hamill et al., 2012). Traditionally the foot-ground contact has been studied using the ground reaction force and loading rate accompanied by a kinematic description of segmental motion. However, this description provides no information pertaining to how the movement was organized. Understanding the nature of movement production in healthy participants is vital for understanding the fluctuations introduced into movement with disease, aging and fatigue (Hamill et al., 2012). For example, Mercer et al. (2003) reported that shock attenuation decreased after a fatiguing run while Derrick et al. (2002) reported kinematic adjustments were made throughout the course of an exhausting run to preserve a degree of shock attenuation. These examples highlight the ambiguity introduced when the description of movement is not functionally nested.

Over the last 20 years, a growing body of literature in the etiology of injury has suggested that variability observed within limbs during the course of a movement is not noise (as traditionally thought) but has a functional role (Hamill et al., 1999). Evidence suggests that a decrease in variability may be the sign of a system that is ailing, growing frail, or injured (Lipsitz and Goldberger, 1992). Work done in lower limb coordinative variability has led to the identification of segment couplings related to injury experienced during running but has yet to demonstrate the link between forces experienced during the foot-ground contact and the change in variability seen throughout the stance phase during an exhaustive run.

The purpose of this work was twofold: 1) to identify changes in coordinative variability and kinetics during a tempo run; and 2) to understand how changes in kinematic couplings (i.e. thigh-leg, leg-foot) relate to the force during the foot ground contact. We hypothesized that coordinative variability will decrease as runners fatigue and that impact peak will increase with fatigue.

METHODS: Fourteen healthy participants from the University community (see Table 1) participated in a 25 minute tempo run after signing an approved informed consent form (note: a tempo run is defined as a self-paced high intensity run). Prior to beginning the run, subjects were given a 5 minute warm-up period. Following the warm-up period, markers were placed on the pelvis and on the right thigh, leg, and foot sufficient for a 3D kinematic analysis. Afterward, participants were given another five minute period to select their preferred speed. The speed set at the end of this period remained constant for the remainder of the run. A 15 second video recording was taken every 5 minutes. Kinetics were collected using an instrumented Bertec (Columbus, Ohio, U.S.A) split-belt treadmill. Kinematics were recorded using 6 Oqus cameras (Qualisys, Goteborg, Sweden). Kinematic and kinetic data were collected at 100 and 2000 Hz respectively. The kinematic and kinetic data were low-pass filtered at 8 and 50 Hz respectively. Heart rate and RPE were also recorded throughout the run to ensure participants were running at a high rate. The orientation of the lab coordinate system was such that movement in the sagittal plane corresponded to the X-axis, frontal plane corresponded to the Y-axis, and the transverse plane was Z-axis.

Table 1. Mean subject characteristics (Mean ± SD)

Age (yrs)	Height (m)	Mass (kg)	Gender	Running Experience (yrs)	Running Speed (m/s)
22.9±3.3	1.73±0.09	69.4±9.9	7 F 8 M	7.5±3.9	3.18±0.43

DATA ANALYSIS: To assess changes in coordination as individuals fatigued during the run, a modified vector coding technique was used to determine coordinative variability during early stance. Ten strides for each subject at each time point were used for each participant (Hafer and Boyer, unpublished data). The following couplings were assessed based on their history in the gait injury literature:1) leg (Z)/foot (Y); 2) thigh (X)/leg (X); and 3) thigh (X)/leg (Z) (Hamill et al., 1999; Heiderscheit, 2002)

STATISTICAL ANALYSIS: To assess the effects of fatigue on coordinative variability, a one-way repeated measures ANOVA was used for each coupling across time. The first 1/3 of support (i.e. during the impact phase of support) was analyzed. Changes in force with time were evaluated using two one-way ANOVA models with loading rate and impact peak as the factors in the models respectively. A criterion alpha level of 0.05 was established.

RESULTS: By the end of the run, on average, participants were running at 96% of their maximal heart rate and had an RPE of 17 corresponding to “working very hard”. There were no changes in impact peak ($F_{5,76}$=0.074, p=0.99) or loading rate ($F_{5,76}$=0.162, p=0.97) (Table 2).

Table 2. Mean ± SD for Load Rate (N) and Impact peak (N) for each data acquisition

	5^{th} min	9^{th} min	13^{th} min	17^{th} min	21^{st} min	25^{th} min
Loading Rate (N/s)	3.27±23	3.37±.28	3.13±.14	3.35±.22	3.25 ± .20	3.34 ± .20
Impact Peak (N)	1128.78 ± 68.24	1149.71 ± 75.70	1117.74 ± 58.80	1165.67 ± 65.82	1151.45 ± 65.85	1159.90 ±66.87

There were no significant differences in the leg (Z)/foot (Y) coupling across time (p=.54) (Figure 1). For thigh (X)/leg (X) coupling, there was a difference across time (p < 0.01). Post hoc analysis indicated that between the baseline value and the 13th minute there was a significant decrease in coordination variability and a significant increase there after (note with exception of the comparison between the 9th and 13th minute (p=. 206), the comparison between each of the successive points were significantly different with p < .001). For the thigh (X)/leg (Z) coupling, the baseline value was significantly different from the rest of the run (p<0.001). Post-hoc analyses revealed that there was a significant decrease in coordination variability between the baseline and the 9 and 13 minute values. At the 17th minute, there was a significant increase in the coordination variability for the rest of the run.

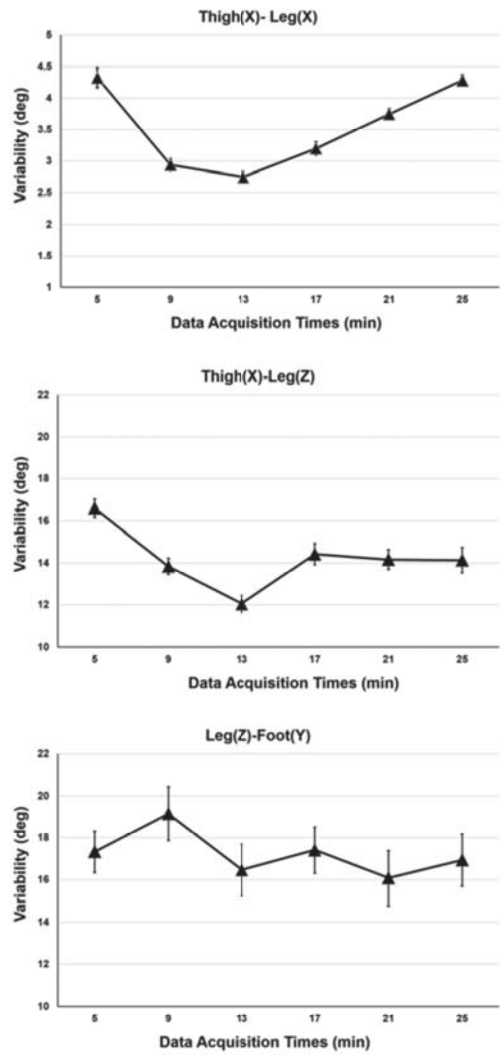

Figure 1. Coordinative variability of the first 3rd of the stance for the thigh-shank and the leg-foot across the entire run. (Note the bars correspond to the standard error of the mean).

DISCUSSION/CONCLUSIONS: The purpose of this study was to determine the changes in coordination variability and impact characteristics in individuals running to fatigue. We hypothesized that, as individuals became more fatigued, coordinative variability would decrease and the loading rate and impact peak would increase. As indicated by the average percent of maximum heart rate and RPE the individuals participating in the study could be considered fatigued. Contrary to our hypothesis, the impact peak and loading rate did not change across the entire 25 minute duration. The changes in the coordination variability in two of the three couplings indicated that changes occurred early in the run (i.e. either 9 or 13 minutes). In lieu of this, our hypothesis that coordinative variability would decrease with fatigue was not entirely supported. These data suggest that there may have been an adaptation period for coordination variability during the second half portion of the run.

To the best of our knowledge, there has not been a study which links coordinative variability of lower limb extremities to force being produce during the movement. This work is a step in the direction at understanding the interaction between the reactive forces experienced during running and how they affect lower limb coordination. However, this line of research does not fully address how the change in limb loading affects the coordination. It appears that an adaptation period occurs during the initial portion of the run resulting in a decrease in coordinative variability.

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