EFFECT OF PERFORMANCE LEVEL ON COORDINATION AND COORDINATION VARIABILITY IN TRAIL RUNNING

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Trail running is an emerging endurance discipline. Unveiling differences in motor adaptation between more (MP) and less (LP) proficient athletes represents the first step to I) standardize injury prevention protocols and II) optimize training. The aim of this work was to compare MP and LP trail runners for coordination and coordination variability (CV). Twenty athletes carried out a field test wearing a full body motion capture system. Coordination and CV were assessed for three couplings: I) knee-ankle, II) hip-knee and III) trunk-hip. No differences were found in coordination, but MP runners showed higher hip-knee and trunk-hip CV in downhill sections, as well as higher hip-knee CV in uphill sections. Results indicate superior motor adaptability for MP runners in an unpredictable environment. Future studies may assess whether specific techniques (balance and perturbation training) positively impact CV trail running population.

KEYWORDS: incline running, field study, environmental conditions, adaptability, freezing degrees of freedom

INTRODUCTION: Trail running is a strongly emergent endurance running discipline, previously defined as any running taking place in an open country on unpaved surfaces (i.e. off road, with <20-25% paved surface (Scheer et al., 2020). Trail running competitions typically take place in the mountains and offer a number of possible distances, from 5 up to >100km. Prolonged running on steep terrains results in a heavy physical load, which has been the object of several lab-based investigations (Vernillo et al., 2017). A major shortcoming of lab settings is that it neglects the athletes' interaction with the external environment. Organismic, task and environmental constraints, according to Dynamical Systems Theory (DST), represent the boundary conditions where preferential coordinative states (the so-called *attractors*) originate as the result of self-organizing processes present in the human body (Newell, 1986). Variability in coordination allows for the exploration of different attractor regions (i.e. "movement solutions") and the development of a rich behavioral repertoire, thus enabling flexible and prompt motor adaptation to unpredictable changes in constraints during sport performance (Davids et al., 2006). Consequently, higher coordination variability (CV) may be advantageous in specific sport situations. The large variety of ever-changing constraints in trail running (slope, ground morphology and slipperiness, as well as muscle fatigue, to name a few) poses a significant challenge in terms of coordination and adaptation skills to the athletes. When considering athletes of different performance levels, differences in coordination and CV were found in other disciplines. In fact, better swimmers were reported to differ in coordination and to show CV, compared to slower counterparts (Seifert et al., 2010). Furthermore, experienced runners showed higher CV than novices during level running on a treadmill (Hafer et al., 2019). Therefore, it is plausible that better performancein trail running results not only from higher fitness level, but also from superior motor adaptability, provided the unpredictability of the external environment. Moreover, reduced CV has been associated to overuse injuries in running (Hamill et al., 2012). Based on these premises, gaining insights about coordination and motor adaptation mechanisms of trail runners of different performance levels would represent the first step towards the development of specific protocols aiming to I) prevent injuries and II) optimize training and performance in an emergent endurance discipline. The purpose of this study was to compare trail runners of different performance levels for coordination and CV in a field study. It was hypothesized that differences in coordination and CV would be present between athletes of different performance levels.

METHODS: Participants: twenty athletes (10M, 10F) were recruited from local trail running associations (age [years]: 32.8±8.3 M, 33.4±8.1 F; height [cm]: 177.2±6.0 M, 166.3±6.9 F; mass [kg]: 71.9±5.8 M, 61.6±6.9 F, experience in trail running [years]: 3.3±1.5 M, 4.1±1.2 F). All participants were injury free in the previous 3 months. Minimum training frequency and volume: 2/week and 30km/week, respectively. Study design: participants completed a 9.1km trail running test consisting of 7 laps of the same 1.3km route at maximal effort. Every lap presented an ascent of 60m, resulting in 420m across the entire test. Performance level of the athletes was determined according to finish time: the fastest 5 men and the fastest 5 women were assigned to the more proficient (MP) athletes´ group; the slowest 5 men and the slowest 5 women were assigned to the less proficient (LP) athletes´ group. Materials: participants were equipped with a GPS watch (Garmin Forerunner 935), a chest belt (Garmin HRM Pro) and a full body motion capture system (Xsens Link, Xsens Technologies BV, Enschede, The Netherlands), consisting of 15 lightweight inertial measurement units (MTx, size 36x24.5x10mm, mass 10g), sampling frequency 240Hz. Data analysis: data from specific uphill and downhill sections was retained for further analysis. Such sections (slope ~15%, length = 80m) were selected so not to present abrupt changes in steepness and ground morphology. In the present study, three joint couplings were considered: trunk axial rotation vs hip flexion/extension; hip flexion / extension vs knee flexion / extension; knee flexion / extension vsankle plantar- / dorsiflexion. Such couplings were selected based on their relevance in determining running speed (Schache et al., 2014) and representing a link between lower and upper body. Data was processed via MVN Analyze© software in HD mode and No-Level scenario, thus yielding joint angle trajectories as recommended for biomechanical applications (Schepers et al., 2018) and validated in previous works (Krüger et al., 2010). All subsequent analysis was performed in a Python environment.Gait events were identified by means of a previously validated algorithm (Benson et al., 2019), and joint angular velocities were calculated. Stance phase data (i.e. between foot strike and toe off) was resampled to 100 data points and retained for further analysis. From a temporal perspective, stance phase was also subdivided in load response phase (LRP) and thrust phase (TP). LRP was defined from initial contact (0% stance) to the first zero crossing of knee angular velocity (Figure 1 (1)). TP was defined from the end of LRP to toe-off (100% stance). For the 5 central laps (the first and last were discarded), in each uphill and downhill section 20 strides per leg for each subject were analyzed. Coordination: as previously proposed, it was calculated from angular velocities according to four patterns (Stock et al., 2022). Referring to Figure 1 (1): in phase (IP, with both joints flexing or extending) and anti-phase (AP, with one joint flexing or extending and the other joint doing the opposite). Coordination variability (CV): the Velocity Ellipse Method (VEM) was used (Stock et al., 2022). In brief, angular velocities of the two coupling joint angles are plotted so to yield a velocity-velocity plot; next, at each time point, an ellipse is fitted around the pertinent data points (Figure 1 (2)). For methodological details about ellipse calculation, please refer to Stock et al., 2022. Importantly, the larger the ellipse area the higher the CV. Statistics: for each subject, data from all strides in each section and in each lap of the trail running route was averaged, then the same was done across different laps, separately for uphill and downhill sections. Differences in CV were assessed with Statistical Parametric Mapping (SPM), t-test with alpha=0.05. Differences in coordination were assessed via Mann-Whitney U-test, alpha=0.05.

RESULTS: One female athlete was not able to finish the trail running test, thus resulting in a sample size of 10 for the MP athletes´ group (5M, 5F) and 9 for the LP athletes´ group (5M, 4F). Finish times for the trail running test were 51.1±6.3min for MP athletes and 60.0±5.5min for LP athletes. Average duration of LRP was 0-35% stance in uphill sections and 0-31% stance in downhill sections. Coordination: no differences were found between MP and LP athletes in any coupling and terrain, indicating a qualitatively similar movement pattern between athletes of difference performance levels. CV: only figures presenting significant differences between groups are reported. *Knee-ankle coupling*: no differences were found. *Hip- knee coupling* Uphill: MP athletes showed significantly higher CV in LRP (Figure 1 (4)); Downhill: MP athletes showed higher CV in late LRP and TP (Figure 1 (5)). *Trunk-hip coupling*: MP athletes showed significantly higher CV in late LRP and early TP in downhill sections (figure 1 (6)).

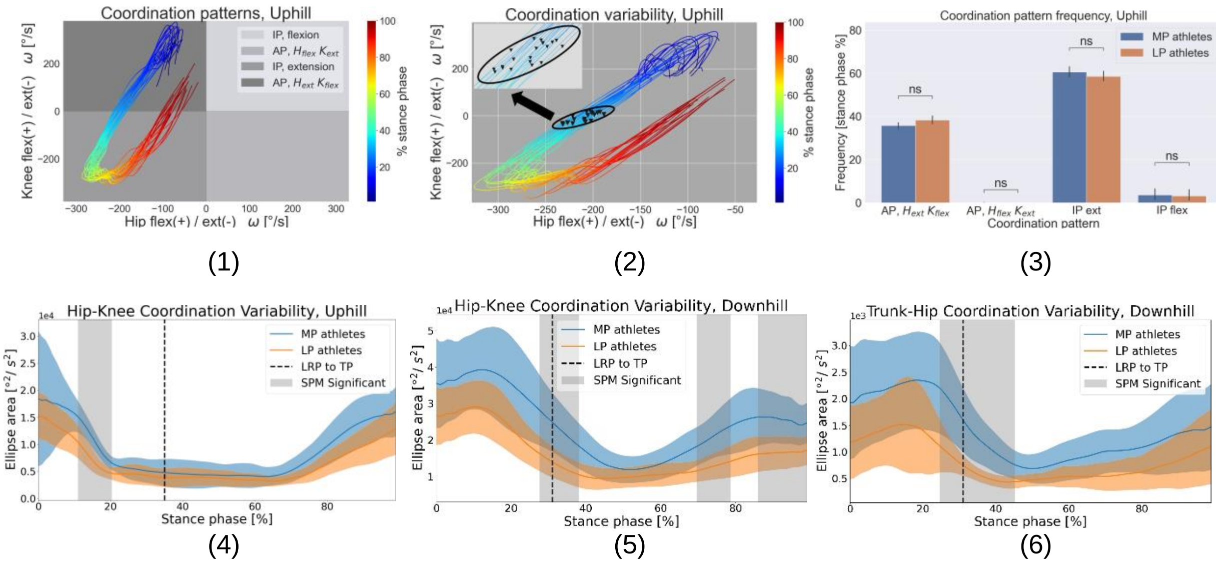

Figure 1: 1) Example of coordination for a single athlete: each trajectory represents a stride. 2) Example of CV for a single athlete: each trajectory represents a stride; here the ellipse is fitted at 30% of stance phase. The same was done at all time percentages. 3) Example of frequency distribution of coordination pattern according to performance level. No differences were found in any coupling and terrain (ns = not significant) 4-6) Time series of ellipse area (quantifying CV) presenting significant between-groups differences. Knee-ankle coupling was not reported, as SPM did not highlight any significant difference between groups.

DISCUSSION: To the best of our knowledge, we are the first to measure full body kinematics ina trail running field study. Athletes of different performance levels developed different adaptation mechanisms during trail running performance. The two groups showed similar coordination patterns, but LP athletes showed lower CV. This is consistent with previous lab-based running investigations (Hafer et al., 2019). The present results can be explained by a motor strategy referred to as *freezing the degrees of freedom (DOF)* (Bernstein, 1966): provided the DOF redundancy at muscle and joint level in the human body, LP athletes hold some joints rigid (i.e. "freezing" them) while performing a complex task. Due to the irregular ground morphology in trail running, athletes do not know exactly what to expect at the ground-foot interface when landing: the lower CV observed in LP athletes in LRP is most likely the consequence of a higher muscular pre-activation (to "freeze" lower limb joints), resulting into a less efficient muscle tuning. These findings may have important implications in terms of injury prevention, asinadequate muscle tuning at landing was reported to increase injury rates during physical performance (Nigg et al., 2017). As for early TP, group differences in CV were observed in downhill sections (figure 1 (5-6)). Negative slopes are characterized by higher running speed and higher normal ground reaction force (GRF) (Vernillo et al., 2017). Normal GRF trajectory can be approximated by a bell shape, with higher values in middle stance phase compared to very late stance phase. Moreover, when close middle stance phase (namely at 31%) the transition from LRP to TP occurs, with knee switching from flexion to extension action, i.e. from negative work and power absorption to positive work and power generation (Vernillo et al., 2017). Therefore, freezing the DOF is most likely a strategy of LP athletes to cope with the challenging constraints represented by the combination of high running speed, high GRF and phase switch, ultimately resulting in lower CV. In late TP, differences were observed in hip-knee coupling only, meaning that only distal DOF are maintained "freezed" as a consequence of the less challenging constraints, as GRF values is lower in late stance phases and no phase switch at the knee occurs. Overall, the present findings indicate superior motor adaptability of MP athletes in ecological conditions. Based on these findings, future studies may address the effects of specific training techniques (e.g., balance training and perturbation training) on trial running population and whether such trainings positively impact CV. If so, coaches and practitioners may consider combining traditional running training with specific protocols aiming to improve this specific aspect.

CONCLUSIONS: Trail runners of different performance levels carried out a 9.1km field test. More proficient trail runners showed higher coordination variability, indicating superior adaptability to constraints during performance in a constantly changing environment. Less proficient counter-parts exhibited lower coordination variability, as a result of "freezing" (holding rigid) some joints in response to challenging boundary conditions during execution. The present findings represent a first step towards standardization of injury prevention protocols and training optimization in a strongly emergent endurance running discipline. Future works may investigate potential benefits of balance and perturbation training in trail running preparation.

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