JOINT MOVEMENT PATTERNS DIFFER AMONG MALE RECREATIONAL RUNNERS WITH DIFFERENT RUNNING STYLE

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The purpose of this study was to analyse the differences in joint patterns among runners with different spatiotemporal characteristics in the running cycle. Lower extremity kinematic and spatiotemporal parameters were collected for ninety-two recreational runners during a treadmill run at a self-selected speed. A K-means clustering analysis was conducted on normalized stride cadence and Duty Factor to identify running style. The runners were distributed into three clusters with different combinations of spatiotemporal parameters. Only the runners who displayed a high stride cadence and long stance times showed a different movement pattern compared to the rest of the clusters. This study has demonstrated that the combination of several spatial-temporal parameters of the running cycle should be considered when analysing the movement pattern of the lower limb.

KEYWORDS: spm1d, cadence, duty factor, stance time.

INTRODUCTION: Running speed is the product of cadence and stride length and both have a curvilinear relationship with running speed (van Oeveren et al., 2021). Cadence and stride length are determined respectively, by the time and distance travelled in the flight and stance phases of the stride. Multiple combinations of flight and stance time may achieve the same cadence; therefore no unique or ideal combination is related to greater performance (Moore et al., 2019). The runner naturally adapts to one running form or another based on the theory of self-optimization, by subconsciously adjusting his/her running biomechanics to minimize the metabolic cost (Moore et al., 2019).

Recently, van Oeveren et al. (2021) proposed that the spatiotemporal strategies of the running stride determine the runner's style and specifically suggested that cadence and duty factor (the ratio of stance time and stride time) for a given speed can distinguish the full spectrum of running styles. This suggests that the combination of spatiotemporal parameters could determine the movement pattern of the runner. Previous studies have analysed the relationship between joint kinematics and spatiotemporal parameters, such as cadence (Hafer et al., 2015; Heiderscheit et al., 2011; Lenhart et al., 2014) or stance time (Gindre et al., 2015; Patoz et al., 2020), although these have been studied in isolation. Consequently, the purpose of this study was to analyse the differences in joint patterns among runners with different spatiotemporal characteristics in the running cycle. It was hypothesized that the spatiotemporal profile of a runner can explain the variance in the shape and amplitude of his/her joint-angle time series.

METHODS: Ninety-two healthy recreational runners (age 36 ± 10 years, height 1.76 ± 0.06 m and body mass 73 ± 8 kg) volunteered to participate in this study. All participants ran two or more times per week and considered running to be their primary physical activity. All participants were free from any lower extremity musculoskeletal injury in the previous 12 months. The study had ethical approval from the University Research Ethics Committee and all participants signed informed consent forms before participating in the study.

A 5-camera VICON motion capture system was used to collect 3-dimensional kinematic data at 120 Hz during treadmill running. 14 anatomical markers were attached bilaterally to the

following landmarks: the greater trochanters, medial and lateral knee joint lines, medial and lateral malleoli, 1st metatarsal heads, and 5th metatarsal heads. Technical marker clusters, glued to a rigid plastic shell, were placed on the pelvis, and bilateral thigh and shank. Three markers were taped to the heel counter of each of the test shoes.

Following markers placement, the participants were asked to stand for a static trial. All participants had time to familiarize themselves with treadmill running. Running kinematic data were collected while participants ran at a self-selected comfortable speed wearing standard shoes (Nike, Air Pegasus). A treadmill was used to capture between 30 and 45 consecutive strides in a limited motion capture area. Marker trajectories were filtered with a 10 Hz low-pass 2nd order recursive Butterworth filter, 3D rigid body kinematics were calculated using 3D GAIT software (Gait Analysis Systems Inc., Calgary, Alberta, Canada). Spatiotemporal stride characteristics and joint angles during stance were calculated. Spatiotemporal characteristics included speed, stride cadence (normalized to leg length), flight and stance times, and duty factor. The right leg lengths were measured from the anatomical markers of the greater trochanter to the medial malleoli. The joint angles included hip, knee, and ankle in the sagittal plane. Data were averaged over ten consecutive strides for each participant, and only right strides were included for analysis. Joint angle data were normalized to 101 points using a linear length normalization procedure and an ensemble average curve was calculated for each participant.

K-means clustering analysis was applied to determine running style. The spatiotemporal parameters used were normalized stride cadence and duty factor. Calinski–Harabasz scores were used to evaluate the optimal number of clusters within the data set. Three clusters were determined as optimal. Joint kinematics differences between runner clusters were determined using one-dimensional statistical parametric mapping (SPM1D) and one way analysis of variance (ANOVA) with planned post-hoc Bonferroni adjusted pairwise comparisons. Random field theory, which describes the probabilistic behaviour of random curves and accounts for the smoothness of the data, was used to set a critical threshold ($\alpha = 0.05$). If the SPM {t} curve exceeded this critical threshold, joint kinematics could be considered different between clusters. All SPM analyses were implemented using the open source spm1d code (v.M0.1, www.spm1d.org) in MATLAB

RESULTS: The K-means allocated 41 runners in the Cluster 1, whereas 26 and 25 runners were allocated in clusters 2 and 3, respectively (Table 1). Differences between clusters runners were reported in all the spatiotemporal parameters analysed ($F > 43.744$; $p < .001$). Cluster 1 was primarily characterized by reduced stance times ($t > 6.503$; $p < .001$; $ES > 1.7$) and a low duty factor ($t > 6.424$; $p < .001$; $ES > 1.6$) in comparison to clusters 2 and 3. Cluster 2 showed the most extended stance times ($t > 2.787$; $p < 0.018$; $ES > 0.8$) and the lowest stride cadence ($t > 7.823$; $p < .001$; $ES > 2.0$) of the three clusters. Finally, the runners allocated in Cluster 2 showed the highest values of duty factor ($t > 4.442$; $p < .001$; $ES > 1.2$) and stride cadence ($t > 6.843$; $p < .001$; $ES > 1.7$).

Table 1: Spatiotemporal characteristics (mean ± SD) of the clusters identified by k-means.

Style	N	Speed (m·s⁻¹)	Stance Time (s)	Flight Time (s)	Duty Factor	Stride Cadence (SC·L⁻¹)
Cluster 1 (*Bounce*)	41	$3.34 \pm 0.31^{\#}$	$0.241 \pm 0.014^{\#*}$	$0.111 \pm 0.014^{\#*}$	$0.34 \pm 0.02^{\#*}$	$52 \pm 1^{\#*}$
Cluster 2 (*Push*)	26	$2.96 \pm 0.32^{\dagger}$	0.286 ± 0.020	$0.092 \pm 0.018^{\dagger}$	$0.38 \pm 0.02^{\dagger}$	$49 \pm 2^{\dagger}$
Cluster 3 (*Stick*)	25	3.34 ± 0.53	0.272 ± 0.023	0.063 ± 0.018	0.41 ± 0.03	56 ± 3

The statistical parametric mapping revealed significant differences in all joints analysed between clusters 1 and 3. Higher plantarflexion was observed in runners allocated in Cluster 3 than Cluster 1 during 59-97% of stance phase (p < 0.001; Figure 1a). Knee flexion angle was lower in Cluster 3 than Cluster 1 runners during 51-75% (p = 0.004), while in the final instants of stance phase (96-100%, p = 0.016), greater knee flexion was observed in Cluster 3 compared to runners allocated in clusters 1 and 2 (Figure 1b). A significant higher hip extension was observed during the midstance (48-75% of stance phase, p = 0.007) in runner of Cluster 3 compared to Cluster 1 (Figure 1c).
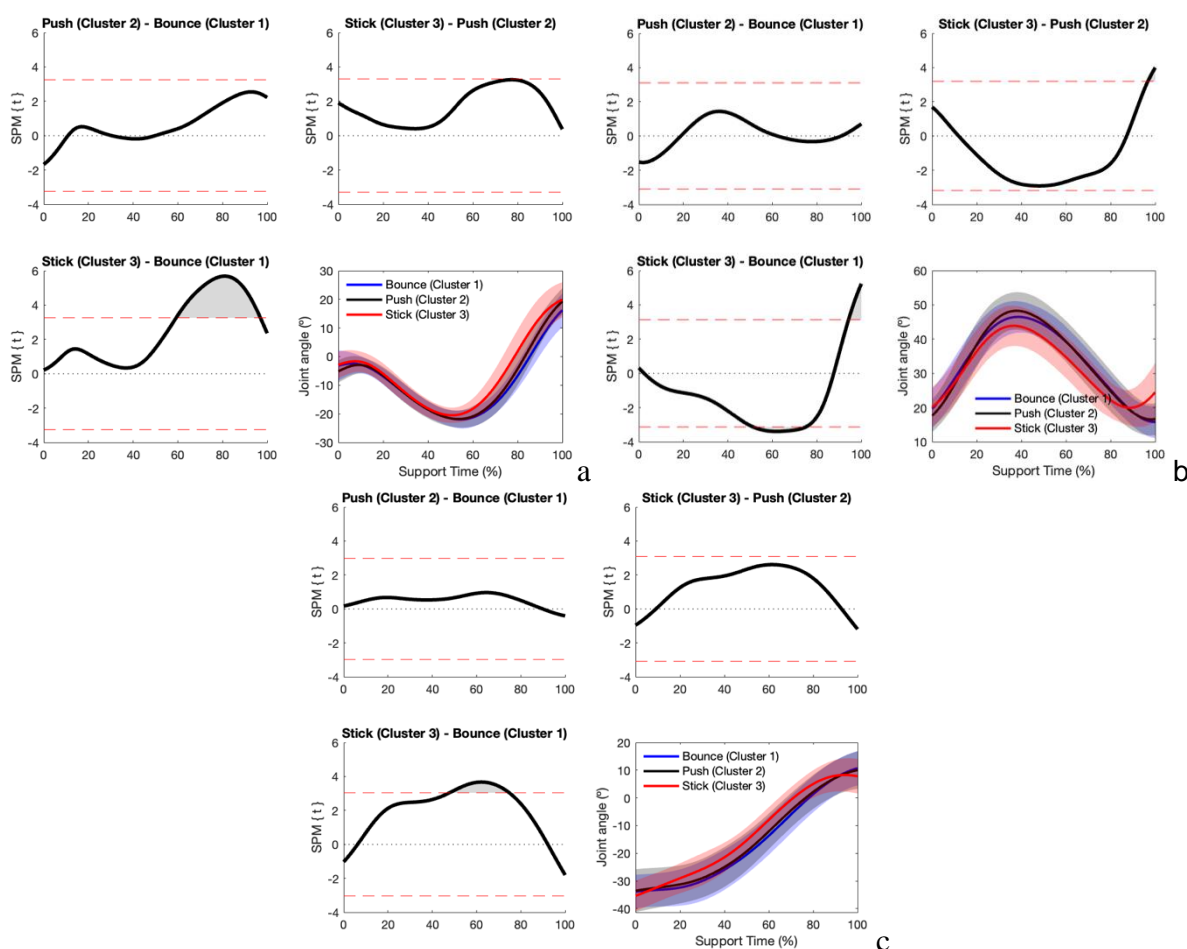

Figure 1: Post-hoc runner clusters comparisons during stance phase for sagittal plane of ankle (a), knee (b), and hip (c) angles.

DISCUSSION: The spatiotemporal variables that differed between the runner clusters were flight time, duty factor, and stride cadence, although the direction of these differences was not always the same. Cluster runners 2 showed the lowest cadence of the three groups. The lower cadence, rather than a lower stride length (extended flight and stance times), could explain the significantly slower speed of cluster 2. Cluster runners 1 achieved a higher cadence by lowering the duty factor despite achieving a higher flight time. While the Cluster runners 3 increased their cadence, they reduced the flight time despite reaching a higher duty factor. In accordance with the dual framework proposal of van Oeveren et al. (2021), the three identified clusters could be named as Bounce (Cluster 1), Push (Cluster 2), and Stick (Cluster 3). Kinematic differences were only found when Stick and Bounce runners were compared. These results suggest that for the same running speed, stride cadence and stance time must increase

to find differences in joint kinematics. Previous studies have analysed the influence of stride cadence on joint kinematics, suggesting a reduction in the range of motion during stance phase (Anderson et al., 2022). Less ankle dorsiflexion and knee flexion were observed during midstance when Stick runners was compared to Bounce runners. On the contrary, no kinematics differences were found in the rest of the pairwise comparisons despite differences in cadence stride. This discrepancy could be related to the circumstance that cadence and contact time increased simultaneously while other spatiotemporal combinations do not cause sagittal kinematics differences. Temporal shifts in sagittal movement hip rather than differences in range of motion were observed between Stick and Bounce runners. These results contrast with those reported in the literature, which associate a higher stride cadence (Heiderscheit et al., 2011) and a stance time (Patoz et al., 2020) with a greater range of movement of the hip in the sagittal plane. This discrepancy can be attributed to differences in the experimental approaches used. In the present study, the differences between groups who self-selected speed were analysed, while previous studies instructed participants to alter their spatiotemporal characteristics of the running cycle to analyse the effect produced

CONCLUSION: In summary, this study has shown that the combination of several spatial-temporal parameters of the running cycle should be considered when analysing the movement pattern of the lower limb. Differences in joint kinematics between runners were observed when they were clustered in relation to their stride cadence and Duty Factor. Only a combination of high cadence and prolonged support times showed differences in sagittal joint kinematics.

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