PROCRUSTES ANALYSIS APPLIED TO RELATIVE MOTION PLOTS OF LOCOMOTOR PATTERNS IN SPRINT

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INTRODUCTION

A crucial aspect of motion analysis is the ability to quantify and identify movement strategies for a specific task. This is particularly important in human motion, because more than one movement strategy can be used to accomplish the same objective. While the importance of alternate movement techniques has been acknowledged in certain fields (e.g., motor control, ergonomics), quantitative methods for identifying movement strategies have not been developed. Thus, we sought to quantify a methodology that can clearly show us how two performers could use different combinations of segmental movements while producing identical gait features (speed, frequency and amplitude). To accomplish this task, we proposed to use geometric morphometry algorithms (e.g. Procrustes method; Bookstein, 1991) which allow to describe curve shape and shape changes in a mathematical and statistical framework, regardless of time and size factors. We applied the Procrustes method to the shape of gait patterns by using relative motion plots (i.e. fifth metatarsal head trajectory relative to hip trajectory). We utilized the 100-meter event and we compared the motor behaviors adopted by runners with different levels of expertise in order to identify the characteristics of motor performance in high level sprinting. We hypothesized that the difference between novices versus experts would not rely exclusively on the optimization of physical ability. In other words, there will be no continuity, but different levels of organization between these two populations.

METHODS

Fifty-five male sprinters with 12 highly advanced (international level), 19 advanced (national level), 13 intermediate (regional level) and 10 novice athletes participated in the study. They all performed two 80-meter sprints at maximal effort. The three-dimensional kinematics of the lower extremity were collected at 200 Hz along the track between 42- and 54-m marks of a 100-m race using a Vicon™ 612 motion capture system including six high speed cameras (Oxford Metrics, Ltd., Oxford, UK). The 3D coordinate data were smoothed using a zero-lag, fourth-order Butterworth filter. After superimposition of the hip marker positions, the resultant relative trajectory of the fifth metatarsal head was smoothed using a Fast Fourier Transform in order to both reduce errors and eliminate the data disjunction to form a completed cyclogram. Seven gait events were determined by our customized mathematical algorithms. We selected 112 cyclograms from the running sequences and they were superimposed using the Procrustes method (Bookstein, 1991) (Figure 1).

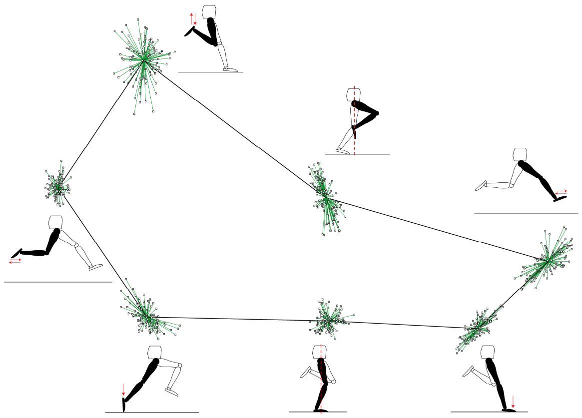

Figure 1. Procrustes superimposition of 112 ankle cyclograms in the sagittal view.

The shape of each cyclogram was defined as "Procrustes residuals", i.e. landmarks deviating from the "consensus" (mean shape) (Rohlf & Slice, 1990). A principal components analysis (PCA) in conjunction with a Hierarchical Ascendant Classification (HAC) was performed on all the Procrustes residuals. A multivariate regression was used in which the dependent variables were the principal component (PC) scores, and the independent variable corresponded to the different sprint expertise-levels. The graphic representations of the cyclograms along the PC are useful to identify atypical patterns. Multivariate regression provides the linear combination (called "vector V") of the most significant PCs to express the changes in conformation associated with expertise (Kraznowski, 1988). A one-way ANOVA with Bonferroni adjustment was performed in order to ensure the statistical validity of the expertise groups.

RESULTS AND DISCUSSION

The analyses (PCA and HAC) revealed the main shape changes of the cyclogram relative to expertise (PC1: novices vs. experts) and the sport speciality (PC2: sprinters vs. athletes non sprinters but "trained" in sports requiring qualities for sprint performance e.g. soccer, rugby). Multivariate regression calculated with the first two PCs was significant: $R^2 = 0.77$; $F = 20.26$; $p < 10^{-6}$. The equation of the V shape vector ($V=0.99\times PC1-0.010\times PC2$) showed that PC1 makes an overwhelming (even almost exclusive) contribution. Although the vector V guarantees the existence of a "continuum" or "gradient" towards expertise ($F= 72.10$, $P<0.001$), it creates a "hurdle to cross" in the progression from the national level to the international level (HSD: $p<0.001$). Moreover, the cyclograms of the sprinters and "trained" athletes are scarcely different regarding the vector V (HSD: $p=0.096$), thus suggesting two distinct "pathways" towards expertise: the first relates to the learning process as an effect of practice and experience; the second is related to the "transfer of the learning" process (e.g., speed skills in soccer transferred in high-speed races).

SUMMARY/CONCLUSIONS

In conclusion, by evaluating the size, shape, and orientation of these relative motion plots, it is possible to examine variation in gait patterns within and among groups. Recourses from morphometry applied in the area of movement analysis provided useful gait indicators to select and correct performances in Track and Field running.

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