A chaos-inspired biomechanical biomarker of ankle instability

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Introduction

A lateral ankle sprain (LAS) is one of the most common injuries in sports, and particularly in females who take part in indoor court sports, with 40% of cases developing into chronic ankle instability (CAI) [1]. CAI describes a predisposition for recurrent sprains, persistent pain, limited range of motion, weakness and frequently feeling the ankle is 'giving way'. Currently CAI is diagnosed through patient reported outcome measures, such as the Cumberland ankle instability tool (CAIT), manual testing and imaging. There is no standard method for diagnosis, and none based on function. Insufficient methods to quantify CAI result in people returning to sport without adequate treatment, further damage to the ankle or retirement from sport altogether. Applying chaos theory to ankle kinematics, this study develops and assesses a novel biomechanical biomarker of ankle instability.

Methods

Hypothesising that netballers would have a different history of LAS than runners, female recreational runners (n = 12) and netballers (n = 10) were recruited. All self-identified as free of musculoskeletal injury. After completing a CAIT questionnaire, participants walked and ran on a treadmill for 2 minutes at fixed velocities of 1, 2 and 3 $m.s^{-1}$ and, additionally, at similar self-selected velocities. Trials were repeated. Ankles were classified as unstable if the average of the left and right-sided CAIT scores ≤ 25, and stable otherwise [2]. The PlugInGait marker set was used from which the phase space of the ankle was defined by the three joint angles, each normalised to a mean of zero and standard deviation of 1, and time-normalised to the gait cycle. Inspired by the calculation of largest Lyapunov exponents from experimental time series [3], we propose the following measure:

$$\lambda_p = \frac{1}{N}\sum_{i=1}^{N} \ln\left(\frac{\left\|r_{j+1,p} - r_{i+1,p}\right\|_2}{\left\|r_{j,p} - r_{i,p}\right\|_2}\right)$$

where $r_{i,p}$ is the joint position in phase space of the i^{th} gait cycle ($i = 1..N$) at the p^{th} percentile of the gait cycle (p = 0..100%). $r_{j,p}$ is the "nearest neighbour" to $r_{i,p}$, defined by $r_{j,p} = \min_k \left\|r_{k,p} - r_{i,p}\right\|_2$ where $i \neq k, k = 1..N$. λ_p can be further averaged over the gait cycle to give, λ, a biomechanical biomarker representing the average one-cycle deviation of the trajectory of the ankle joint from its nearest neighbour trajectory. A positive λ indicates trajectory divergence and chaotic behaviour. The effects of the experimental variables on λ was determined by ANOVA.

Results and Discussion

Consistent with the recruitment hypothesis, netballers reported functionally worse ankles than runners (25.5 ± 3.8 vs 28.3 ± 2.7, respectively, p = 0.055). λ varied with velocity ($p < 0.001$) with walking being less chaotic than running. λ also varied with side of the body, and with CAIT classification (both $p < 0.001$, Figure 1). λ was not dependent on whether the treadmill velocity was fixed or self-selected or with trial. With λ decreasing with decreasing CAIT score this suggests either netballers run differently to recreational runners, or that those who report lower CAIT scores run less chaotically, perhaps deliberately and subconsciously imposing less variability in their ankle joint. In other words, pathological ankles may be less chaotic than un-injured ankles, akin to heart rate variability being less chaotic in pathological conditions [4].

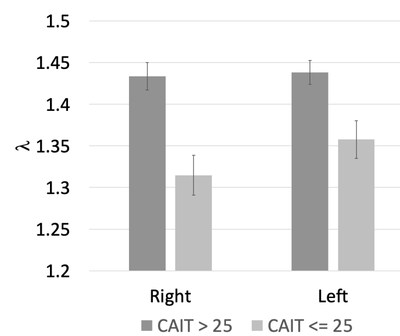

Figure 1: Variation of λ with CAIT classification and side during walking (mean ± S.E)

Conclusion

A new, functionally meaningful, biomechanical biomarker of joint instability has been proposed which seems to be rigorous yet potentially sensitive to functional ankle pathologies. Results support applying this novel biomarker to a better-controlled clinical population.

References

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