

# Use of a GPS-Embedded Accelerometer to Evaluate the Complexity of the Running Gait. Part 2: Effects of Fatiguing Activity

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## Headline

In the companion study, we report a new approach for analyzing gait complexity and the structure of gait variability (12). Previous studies show that the fractal scaling index (FSI) determined using detrended fluctuation analysis (DFA) is reduced by neuromuscular disorders (6) as well as low back pain, fatigue, injury and overtraining (2, 5, 8, 10), indicating a less healthy gait (1). On the other hand, physical training increases DFA (9).

**Aim.** The purpose of this study was to apply the approach described by Williams et al. (12) to evaluate gait complexity associated with fatiguing activity. Specifically, we sought to determine if gait is altered the day following a competitive soccer match.

## Methods

Subjects were 18 female collegiate soccer players participating in a competitive match (165.8 ± 6.5 cm, 61.5 ± 6.0 kg). Prior

to data collection, human use approval and informed consent was obtained. The match was played in the evening. It ended regulation drawn then proceeded through two 10-min extra time periods for a total of 110 min. Afterwards, players were divided into three groups: Starters (n=6), who started the match and played more than 90 min, Substitutes (n=7) who started or entered the match and played for less than 60 min and Reserves did not play at all during the match (n=5).

GPS and accelerometer data were obtained during both the match and during a 40 min pre-match warm up (GPSports<sup>®</sup> SPI HPU). They were analyzed (using TeamAMS<sup>®</sup> software) for total distance, sprint distance, number of sprints, speed exertion, average heart rate (HR) and HR exertion.

Three days prior to the match (following an off day) and the morning after the match, subjects completed a 400m run at ~10 km/hr. During this time, GPS and accelerometer data were collected for gait analyses. The players ran as a group and were instructed to run at a comfortable pace. This run was executed following a short warm up consisting of dynamic stretching, light sprints and jogging. Prior to the warm-up, players were asked to rate their perception of recovery on a 10-point scale with 1 being fully recovered and 10 being very poorly recovered.

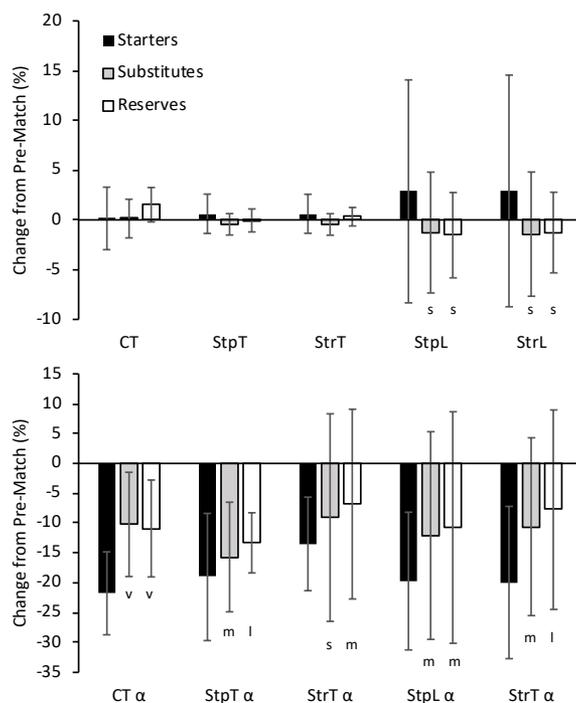
Gait analyses were used as described in the previous paper (12) incorporating Gaussian continuous wavelet transform (CWT) (4) and detrended fluctuation analysis (DFA) (6). Accelerometer and speed data from the 400m run were analyzed via CWT to determine spatiotemporal variables contact time (CT), step time (StpT), stride time (StrT), step length (StpL) and stride length (StrL). From those variables, DFA was used to calculate fractal scaling index (FSI or  $\alpha$ ) values ( $CT\alpha$ ,  $StpT\alpha$ ,  $StrT\alpha$ ,  $StpL\alpha$  and  $StrL\alpha$ ). For all variables,  $x \pm SD$  were computed and effect sizes (ES) were calculated using Cohen's d (small, 0.2; medium, 0.5; large, 0.8; very large, 1.2).

## Results

Table 1 shows the physical demands and physiological responses experienced during the match. Match loads for the Starters were generally greater than the Substitutes and the Substitutes generally greater than the Reserves. ES between groups are also shown in table 1 and ranged from small to very large (designated by superscripts).

Recovery scores for the pre- and post-match days were markedly increased for the Starters and Substitutes from  $2.5 \pm 0.5$  to  $7.5 \pm 0.5^v$  and  $2.4 \pm 0.5$  to  $6.3 \pm 0.6^v$  (ES indicated by superscripts). Smaller increases were seen for the Reserves, from  $2.5 \pm 0.6$  to  $3.0 \pm 0.5^l$ .

Pre- and post-match values for the spatiotemporal variables are shown in Table 2. For the Starters and Substitutes, ES between trials for StpL and StrL were trivial. All other between trial comparisons were small. Table 2 also shows pre- and post-match FSI values for all variables. In the Starter



**Fig. 1.** Changes in spatiotemporal variables and DFA variables from pre- to post-match. ES designations represent differences between Substitutes and Reserves versus Starters.

**Table 1. Match load variables in Starters, Substitutes and Reserves.**

Variable	Starters <sup>1</sup>	Substitutes <sup>2</sup>	Reserves
Min Played	108.1 ± 15.3 <sup>v,v</sup>	48 ± 18. <sup>2v</sup>	0 ± 0
Total Dist (m)	14523.1 ± 1515.3 <sup>v,v</sup>	8852.6 ± 2383 <sup>v</sup>	2769.3 ± 423.6
Sprints (n)	114.3 ± 49.5 <sup>l,v</sup>	93.7 ± 27 <sup>v</sup>	32.8 ± 15.5
Sprint Dist (m)	1389.5 ± 729.9 <sup>s,v</sup>	1204.1 ± 358.4 <sup>v</sup>	296.3 ± 129.9
Speed Exert (au)	12313.2 ± 86 <sup>s,v</sup>	12285.6 ± 87 <sup>v</sup>	12093 ± 8.8
Avg HR (bpm)	161.1 ± 10 <sup>l,v</sup>	145.3 ± 10.7 <sup>v</sup>	106.9 ± 14.5
HR Exert (au)	866.9 ± 201.6 <sup>l,v</sup>	678.9 ± 194.4 <sup>v</sup>	128.1 ± 117.4

<sup>1</sup>ES for Starters vs Substitutes, Reserves. <sup>2</sup>ES for Substitutes vs Reserves

**Table 2. Match load variables in Starters, Substitutes and Reserves.**

Variable	Starters		Substitutes		Reserves	
	Pre	Post	Pre	Post	Pre	Post
CT (ms)	263.30 ± 11.06	265.35 ± 10.94	264.65 ± 3.07	264.38 ± 5.87	254.55 ± 4.42	254.8 ± 8.5
StpT (ms)	345.18 ± 12.71	346.37 ± 10.51	346.65 ± 4.44	345.82 ± 7.63	335.3 ± 9.7	335.35 ± 11.04
StrT (ms)	690.38 ± 25.35	691.47 ± 23.56	693.25 ± 8.86	691.55 ± 15.31	668.35 ± 12.02	670.63 ± 22.11
StpL (m)	0.97 ± 0.05	0.99 ± 0.05 <sup>s</sup>	1.00 ± 0.11	0.99 ± 0.02 <sup>s</sup>	0.96 ± 0.05	0.95 ± 0.04
StrL (m)	1.93 ± 0.09	1.98 ± 0.11 <sup>s</sup>	2.01 ± 0.20	1.97 ± 0.05 <sup>s</sup>	1.91 ± 0.06	1.92 ± 0.06
CT $\alpha$	0.780 ± 0.069	0.703 ± 0.089 <sup>v</sup>	0.735 ± 0.151	0.685 ± 0.073 <sup>s</sup>	0.732 ± 0.106	0.747 ± 0.162
StpT $\alpha$	0.769 ± 0.087	0.721 ± 0.069 <sup>m</sup>	0.769 ± 0.140	0.718 ± 0.099 <sup>s</sup>	0.793 ± 0.167	0.76 ± 0.129 <sup>s</sup>
StrT $\alpha$	0.940 ± 0.070	0.888 ± 0.070 <sup>m</sup>	0.994 ± 0.102	0.944 ± 0.088 <sup>m</sup>	0.846 ± 0.170	0.887 ± 0.176
StpL $\alpha$	1.205 ± 0.112	1.102 ± 0.192 <sup>l</sup>	1.328 ± 0.162	1.256 ± 0.199 <sup>s</sup>	1.252 ± 0.169	1.205 ± 0.162 <sup>s</sup>
StrL $\alpha$	1.363 ± 0.108	1.285 ± 0.11 <sup>l</sup>	1.387 ± 0.171	1.281 ± 0.17 <sup>l</sup>	1.184 ± 0.130	1.209 ± 0.123 <sup>s</sup>

<sup>1</sup>ES for Starters vs Substitutes, Reserves. <sup>2</sup>ES for Substitutes vs Reserves

group, post-match values were reduced compared to pre-match (medium to very large ES). For the Substitutes, pre- to post-match differences were present but the ES ranged from small to large. For the Reserves, ES between pre- and post-match measurements were trivial to small.

Pre- to post-match changes (%) in spatiotemporal and DFA variables are shown in Figure 1. The top panel shows small ES in SptL and SrtL for the Substitutes and Reserves vs Starters. The lower panel shows decreased FSI for all groups. Small to very large ES were found between Substitutes and Reserves vs Starters.

## Discussion

This investigation establishes the feasibility of the analytic procedure described in the companion paper (12). The results indicate fatiguing activity encountered during a competitive soccer match decreases the structure of gait variability. Changes that are evident less than 24 hrs post-match. Further, these changes in complexity occur without marked changes in the magnitude spatiotemporal characteristics.

Healthy individuals generally possess a gait structure whose step to step or stride to stride variability is dependent on prior steps. This dependency exhibits long-range correlations that decays over time (6). Thus, there is a self-similarity or fractal-like pattern in gait that can be quantified by DFA and the FSI (6). Decker et al. (1) suggest that reductions in FSI indicate a loss of structured variability and progression towards an “unhealthy” gait. For example, Huntington’s and Parkinson’s disease patients show FSI values close to 0.5 compared to healthy counterparts who display values are generally greater than 0.8 (see ref 5). This indicates greater random variability of step and stride cadence in those patients as opposed to structured variability (1, 5). In short, random variability indicates a lack of control and adaptability of the gait (1, 5).

Prior studies show that short- and long-term fatigue leads to reductions in FSI (2, 8). Our work supports these findings.

At present, it is not clear how fatigue affects gait variability. Fatigue is complex involving the central and peripheral nervous systems and the muscle fiber. Gates and Dingwell (3) suggest that the mechanisms regulating gait variability likely lie with the central nervous system. In our study, perceptual recovery scores were markedly reduced in the Starters and Substitutes group, suggesting that central fatigue may have played a role. Accordingly, delayed onset muscle soreness alters gait biomechanics (11) which could manifest as reduced FSI (10). It is also possible that muscle fatigue alters motor unit recruitment patterns (7) which could cause changes in gait control. Clearly, additional work is needed before such a conclusion can be firmly drawn.

## Practical Applications

This study demonstrates the applicability of using CWT and DFA to examine the complexity of the running gait. The structure of gait variability (FSI) decreases the day following a competitive soccer match. This suggests that our approach (12) may be useful to coaches, trainers and medical personnel in identifying fatigue. It may also be useful in identifying alterations in gait that may be indicative of injury or overtraining. (2, 8). Clearly additional research is needed to determine if such is the case.

## Limitations

- Pre-match training, post-match nutritional status, strength of the opponent and weather was not controlled. The nature of the pre-match warm up as well as individual playing time was not controlled.
- Players in the Starters group were mostly defenders and defensive midfielders. Those in the Substitute group were generally attacking players.
- Gait analyses were limited to a single type of exercise, running at a comfortable pace.

## Dataset

Dataset available on SportPerfSci.com

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