Maintenance of dynamic single-legged stability with delayed peroneal reaction time in collegiate footballers during a prolonged football simulation

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The purpose of this study was to examine the change of peroneal reaction time and dynamic single-legged stability during a prolonged football match simulation. 12 collegiate footballers participated a Loughborough intermittent shuttle run protocol, within which peroneal reaction time and dynamic single-legged stability were measured to record the change. Results showed that during a prolonged fatiguing protocol, the peroneal reaction time increased significantly, whereas two indicators of the dynamic single-legged stability, root mean square of the mediolateral ground reaction force in 0.4 second of landing and late dynamic mediolateral ground reaction force, remained unchanged. The outcome indicated that the body might adopt different mechanism to maintain sensorimotor control in fatigue state.

KEYWORDS: *ankle sprain, sensorimotor control, fatigue*.

INTRODUCTION: Lateral ankle sprain (LAS) is one of the most common lower body musculoskeletal injuries in all performance level of football(Hawkins and Fuller, 1999; Ekstrand *et al.*, 2019) with injury rate as high as 4.4 incidences per 1000 hours match exposure(Waldén, Hägglund and Ekstrand, 2013). Mismanagement of the centre of mass and the position of the ankle joint while landing, sprinting and turning were the primary scenes for non-contact LAS(Fong *et al.*, 2009). It was speculated that football-specific fatigue might played an important role in the mechanisms of the LAS(Fousekis, Tsepis and Vagenas, 2012). The impairment of the ankle sensorimotor control due to fatigue was associated with increased risks of LAS and re-occurrence of LAS(Greig and McNaughton, 2014; Fransz *et al.*, 2018). Compromised ankle sensorimotor control, such as delayed peroneal muscles reaction time(Hoch and McKeon, 2014), inferior single leg balance(Fransz *et al.*, 2014), impaired ground reaction force management during single-legged landing(Fransz *et al.*, 2016, 2018) could increase the risk of ankle injury, especially LAS.

Peroneal reaction time has been recognised as an indicator of the involuntary ankle sensorimotor control in unexpected ankle inversion(Hoch and McKeon, 2014). The reaction of peroneal muscles during a rapid and forceful ankle inversion was proposed to serve as a kinetic defence of the lateral tissue of the joint from impairment(Fong *et al.*, 2009). Thus, elongated or delayed peroneal reaction time would postpone the reaction of the peroneal muscles, and leading to augmented the vulnerability of the ankle joint to injury(Fong *et al.*, 2009).

On the other hand, dynamic single-legged stability after landing was recognised as an important voluntary ankle sensorimotor control, as well as a representation of the whole-body sensorimotor function in football performance(Witchalls *et al.*, 2013). The instability in the mediolateral side of the ankle while landing in single leg would increase the likelihood of excessive inversion and, subsequently, chances of LAS. Previous literature proposed two validated risk factor of LAS in high performance level football players based on GRF derivatives: higher root mean square of mediolateral ground reaction force in first 0.4s (RMS ML 0.4) and higher mean mediolateral ground reaction force in the late stage (3-5s after landing, late dynamic MLGRF) after single-legged landing(Fransz *et al.*, 2016, 2018).

However, the change of the sensorimotor control of the ankle joint due to fatigue elicited during a football match has yet to be explored. The aims are to explore the change of key sensorimotor functions during a simulated football match protocol in order to provide stakeholders in high performance football with valuable information regarding the susceptibility of LAS during football match participation.

METHODS: 12 healthy collegiate footballers (11 males and 1 female, mean ± standard deviation: age 23.0 ± 2.5 years; height 168.0±6.0 cm; weight 67.8±8.2 kg, training age 6.3±4.3 years) with regular football participation (minimum of once a week in recent three months) voluntarily participated into the study. All participants finished Health Screen Questionnaire and were clear for the study. Potential risks of the experiment had been verbally and formally explained to the participants and informed consent was signed by every participant before partaking the study. The study was approved by the Loughborough University ethics committee [ethical approval number: R19-P080].

Participants were asked to complete a modified Loughborough Intermittent Shuttle Test Protocol (LIST)(Nicholas, Nuttall and Williams, 2000), in order to simulate football specific fatigue. A set of tests of peroneal muscles reaction and postural stability, including 2 trials of single-legged drop-jump landing (SLDJ) per foot and 2 trials of ankle trapdoor simulation per foot, was conducted at prior to, every 15-minute interval of the LIST and immediately after the LIST. Peroneal longus muscle belly was identified by palpation during ankle eversion. The participants were asked to perform single-legged drop-jump landing test by jumping from an aerobic step to a force plate (Sampling rate at 2000Hz, Model 9287CA, Kistler Instruments Ltd, UK). The participants were instructed to stand on an aerobic step and remained still before being given instruction to jump on 2 feet and to land on the testing foot on the force plate and remain the single-legged stance for 6 seconds(Fransz *et al.*, 2016, 2018). No specific jump height was required.

The ankle trapdoor test was conducted immediately after the SLDJ. A customised trapdoor device was adopted to elicit the peroneal muscles reaction(Ha, Fong and Chan, 2015). Participants were asked to stand on the trapdoor device and maintain fully relax. Randomly one side of a pair of tilting doors would drop, creating a sudden ankle inversion perturbation. The movement of the trapdoors was recorded by capturing using Vicon MXT T20s (2MP) and T40s (4MP) camera (Sampling rate at 250 HZ, Vicon Motion System Ltd, UK). Peroneal muscle reaction was measured by a pair of surface EMG units (Sampling rate at 2000Hz, The Trigno Wireless System, Delsys, USA) attached to the skin surface of peroneal longus muscle belly(Hoch and McKeon, 2014). The signals of EMG units, force plate and Vicon motion system were synchronised through Nexus 2 Motion Capture Software (Vicon Motion System Ltd, UK). The temporal interval between the onset of the movement of the trapdoor to the onset of EMG activity was recognised as the peroneal reaction time(Ha, Fong and Chan, 2015). The onset of peroneal longus muscle reaction was defined as when the EMG signal suddenly increases and exceeds 3 times of the standard deviation of the baseline EMG signal(Silva *et al.*, 2006). Raw GRF data was trimmed from the point of impact (defined by the first vertical GRF > 10N) to 6 seconds after the impact. In order to offset the influence of the body mass, GRF data was related to the mean vertical GRF from the last 2 seconds(Fransz *et al.*, 2018). RMS ML 0.4 was calculated by the square root of the mean square of the first 0.4s (800 frames) of data. late dynamic MLGRF was obtained by calculating the mean GRF in mediolateral direction from the third to fifth seconds after impact.

Repeated measures one-way multivariate analysis of variance (MANOVA) was conducted over the dependent variables over time points and leg dominance. Should a significant time effect be found, post-hoc Bonferroni test was then performed in order to examine whether the dependent variables at each time point significantly differentiated from that at start (time=0). Should a significant leg dominance effect be found, repeated measures one-way ANOVA was conducted in order to differentiate the difference between dominant and non-dominant effect. Statistical significance was set at $p < 0.05$ level.

RESULTS: The change of peroneal reaction time, RMS ML 0.4 and late stage dynamic MLGRF in different time points were shown in the Table 1. Repeated measures MANOVA suggested significant time effect (Pillai Trace = 0.953, $F = 5.124$, $p < 0.001$) and leg dominance difference (Pillai Trace = 0.819, $F = 13.571$, $p < 0.001$) over the peroneal reaction time, RMS ML 0.4 and late dynamic MLGRF. Post hoc Bonferroni test suggested that the peroneal reaction time for both the dominant and non-dominant leg at 30 minutes, 60 minutes, 75 minutes, 90 minutes and 105 minutes of the protocol were significantly longer than that at the start (time = 0), respectively. The test also suggested that the late dynamic MLGRF of non-dominant leg at 90 minutes of the protocol significantly lower than that at the start. Repeated measures one-way ANOVA showed significant difference effect between dominant and non-dominant leg over RMS ML 0.4 ($F(1,95) = 42.899$, $p < 0.01$) and late stage dynamic MLGRF ($F(1,95) = 21.585$, $p < 0.01$). Time trends of the results was shown in Figure 5.

Table 1. The peroneal reaction time, ground reaction force variables in dominant and non-dominant legs at different time points.

	Peroneal reaction time (ms)				RMS ML 0.4 (% of body weight)				Late stage dynamic MLGRF (% of body weight)			
Time(min)	Dominant	Sig	Non-dominant	Sig	Dominant	Sig	Non-dominant	Sig	Dominant	Sig	Non-dominant	Sig
0	53±5	-	54±3	-	5.64±1.75	-	4.44±1.60	-	2.00±1.82	-	1.93±1.67	-
15	55±4	0.141	56±3	0.455	5.41±1.29	1.000	4.22±1.89	1.000	1.26±1.02	1.000	1.37±1.20	1.000
30	56±3	0.763	56±2	0.345	5.07±1.25	1.000	4.42±1.89	1.000	1.18±1.04	1.000	1.51±0.74	1.000
45	58±2	0.004*	59±3	0.046*	5.99±2.15	1.000	3.84±1.97	1.000	1.14±0.65	1.000	1.49±0.55	0.967
60	58±2	0.241	58±3	0.076	5.54±2.19	1.000	3.99±2.23	1.000	1.33±0.94	1.000	1.62±0.75	1.000
75	60±3	0.000*	61±2	0.020*	5.75±1.49	1.000	4.43±1.88	1.000	0.91±0.68	1.000	1.40±0.63	0.222
90	61±3	0.000*	62±3	0.006*	4.99±1.05	1.000	3.88±1.37	1.000	0.62±0.45	0.447	1.02±0.47	0.025*
105	64±4	0.000*	64±3	0.001*	5.25±1.15	1.000	4.54±2.23	1.000	0.95±0.58	0.203	0.92±0.51	0.304

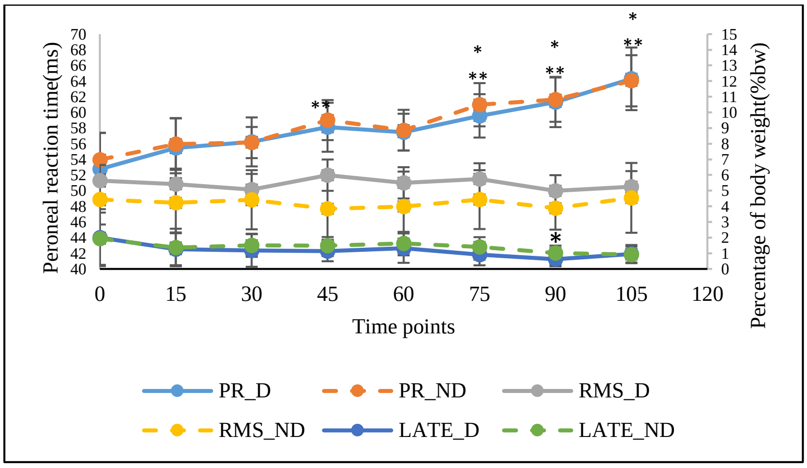

Figure 1: The change of the peroneal reaction time, RMS ML 0.4 and late stage dynamic MLGRF at different time point throughout the protocol. PR = peroneal reaction time; RMS = RMS ML 0.4; LATE = late stage dynamic MLGRF; D = dominant leg; ND = Non-dominant leg; * = *p* < 0.05; ** = *p* < 0.001

DISCUSSION: The main findings of this study are 1) the peroneal muscle reaction time increased significantly for both legs during the protocol, 2) the RMS ML 0.4 and late dynamic MLGRF did not increase significantly during the protocol and 3) the dominant legs displayed higher results in the RMS ML 0.4 and late dynamic MLGRF during the progression the protocol.

The results confirmed the first hypothesis that during a 90-minute prolonged football match simulation protocol the reaction time of the peroneal longus muscle significantly increased in this group of collegiate footballers. The reaction time of peroneal muscles started from 48-58ms and increased during the protocol to 60-68ms at the end of the protocol. Even though a significant increase was observed, the peroneal reaction time still within the normal range in healthy people, which summarised to be 55-85ms based on the previous studies(Ty Hopkins, McLoda and McCaw, 2007). Nonetheless, the trend indicated the neuromuscular fatigue had been built up progressively during the prolonged protocol(Greig and McNaughton, 2014).

However, the change of two voluntary dynamic sensorimotor control variables defied the second hypothesis and the speculation above. No significant change was shown during the prolonged protocol and even for the non-dominant leg, the late dynamic mediolateral balance decreased significantly compared to that at the beginning. Even though previous research identified the higher RMS ML 0.4 and late dynamic MLGRF as two risk factors of LAS, since they represented the inferior management of horizontal GRF perturbation immediately after landing(Fransz *et al.*, 2016, 2018), the result of this study indicated that the management of mediolateral GRF during single-legged landing perturbation would not be impaired during the prolonged football match simulation. This interesting finding raised the question that whether the higher incidence of LAS in the latter stage of the football match was induced by the impaired dynamic sensorimotor control, or by some other factors. It has been suggested that the body would alter the landing strategy during fatigue state(Tamura *et al.*, 2016; Xia *et al.*, 2017). Under this circumstance, the change of the neuromuscular function could act as an optimisation toward the landing strategy(Eils and Rosenbaum, 2001). It would be reasonable to speculate that the temporal similarity between high incidence of LAS and the build-up of neuromuscular fatigue during prolonged football match might be mediated not by the change of sensorimotor control, but some other factor. One of the reasons that the role of sensorimotor control played in the temporal relationship between fatigue and high incidence of LAS in the latter stage of a football match could not be determined might be there is no standardised sensorimotor measurement that could act as the “golden standard”.

CONCLUSION: In this study, the first hypothesis was proven but the second hypothesis was rejected. Delayed peroneal reaction time was found in both leg towards the end of the protocol and reduced late dynamic MLGRF was found in non-dominant leg at 90-minute time points. RMS ML 0.4 for both leg and late dynamic MLGRF in dominant leg were unchanged throughout the protocol. The results indicated that a more holistic approach should be adopted to study the injury mechanism and injury prevention of LAS, as well as future study should focus on finding more sensitive and compelling measurement of dynamic sensorimotor control of the ankle joint.

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