Journal of Science and Medicine in Sport 21 (2018) 103–108

Contents lists available at ScienceDirect

Journal of Science and Medicine in Sport

journal homepage: www.elsevier.com/locate/jsams

Original research

Investigating the effects of maximal anaerobic fatigue on dynamic postural control using the Y-Balance Test

William Johnston[a,b,*], Kara Dolan[a,b], Niamh Reid[a,b], Garrett F. Coughlan[c], Brian Caulfield[a,b]

[a] Insight Centre for Data Analytics, University College Dublin, Ireland
[b] School of Public Health, Physiotherapy and Sports Science, University College Dublin, Ireland
[c] Connacht Rugby, The Sportsground, Ireland

ARTICLE INFO

Article history:
Received 20 September 2016
Received in revised form 30 May 2017
Accepted 1 June 2017
Available online 8 June 2017

Keywords:
Dynamic postural control
Dynamic balance
Y-Balance Test
Fatigue

ABSTRACT

Objectives: The Y Balance Test is one of the most commonly used dynamic balance assessments, providing an insight into the integration of the sensorimotor subsystems. In recent times, there has been an increase in interest surrounding it's use in various clinical populations demonstrating alterations in motor function. Therefore, it is important to examine the effect physiological influences such as fatigue play in dynamic postural control, and establish a timeframe for its recovery.
Design: Descriptive laboratory study.
Methods: Twenty male and female (age 23.75 ± 4.79 years, height 174.12 ± 8.45 cm, mass 69.32 ± 8.76 kg) partaking in competitive sport, completed the Y Balance Test protocol at 0, 10 and 20 min, prior to a modified 60 s Wingate fatiguing protocol. Post-fatigue assessments were then completed at 0, 10 and 20 min post-fatiguing intervention.
Results: Intraclass correlation coefficients demonstrated excellent intra-session reliability (0.976–0.982) across the three pre-fatigue YBT tests. Post-hoc paired sample t-tests demonstrated that all three reach directions demonstrated statistically significant differences between pre-fatigue and the first post-fatigue measurement (anterior; $p = 0.019$, posteromedial; $p = 0.019$ & posterolateral; $p = 0.003$). The anterior reach direction returned to pre-fatigue levels within 10 min ($p = 0.632$). The posteromedial reach direction returned to pre-fatigue levels within 20 min ($p = 0.236$), while the posterolateral direction maintained a statistically significant difference at 20 min ($p = 0.023$).
Conclusions: Maximal anaerobic fatigue has a negative effect on normalised Y balance test scores in all three directions. Following the fatiguing protocol, dynamic postural control returns to pre-fatigue levels for the anterior (<10 min), posteromedial (<20 min) and posterolateral (>20 min).

1. Introduction

Postural control can be defined as the maintenance of the body's centre of gravity within the limits of stability, as defined by the base of support.[1] Dynamic postural control involves the maintenance of balance while transitioning from a dynamic to a static state. It is essential for maintaining one's balance during functional tasks such as running, jumping and landing. To date, the Star Excursion Balance Test (SEBT) has been the most commonly used tool for measuring dynamic postural control.[2,3] The SEBT requires that the subject reaches as far as possible in eight directions, while maintaining a state of equilibrium.[2] More recently, research has highlighted the redundancy of five of the eight SEBT reach directions.[4] This has resulted in the development of an instrumented, commercially available assessment, known as the Y-Balance Test (YBT) (functionalmovement.com, Danville, VA). The YBT incorporates the anterior (ANT), posteromedial (PM) and posterolateral (PL) reach directions. Strength, range of motion, proprioception and balance are physiological properties which the YBT challenges, thus closely mimicking the demands of physical activity, and comprehensively challenging the sensorimotor integration of the motor function subsystems.

Measurement of dynamic postural control is commonly used in both clinical and research settings. Clinically, dynamic measurement is often used to determine if a player is fit to return to sport following injury,[5,6] as well as an indicator of increased risk of lower

* Corresponding author.
E-mail address: William.Johnston@ucdconnect.ie (W. Johnston).

http://dx.doi.org/10.1016/j.jsams.2017.06.007
1440-2440/

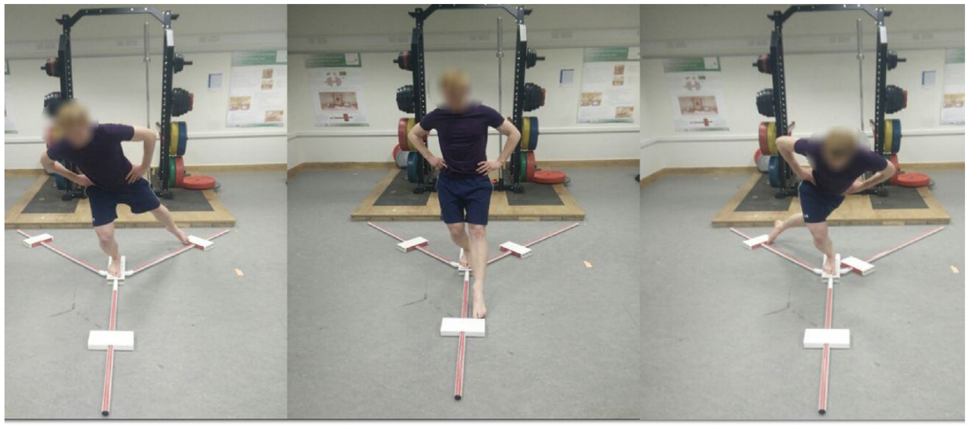

Fig. 1. Participant demonstrating the YBT in the posteromedial (left), anterior (centre) and posterolateral (right) reach directions on their right leg.

limb injury.[7,8] In the research setting, the effects of lower limb injuries such as chronic ankle instability and anterior cruciate ligament injury on dynamic postural control have been established.[3,9] The increasing popularity of the YBT as a balance outcome measure means that it is vital to identify biological factors that may influence its accuracy (Fig. 1).

Muscle fatigue can be defined as exercise induced decreases in maximal voluntary force or power produced by a muscle or group of muscles.[10] Fatigue mechanisms induced during anaerobic exercise include central and peripheral fatigue mechanisms. Peripheral fatigue refers to exercise-induced processes that lead to a reduction in force production occurring at or distal to the neuromuscular junction. Central fatigue refers to more centralised processes and can be defined as a progressive exercise-induced failure of voluntary activation of the muscle.[10] It can be postulated that the combined physiological effects of central and peripheral fatigue can lead to changes in the sensorimotor integration of balance information, resulting in alterations in one's ability to maintain dynamic postural control.

It has been demonstrated that dynamic postural control, as measured by the SEBT, is influenced by different forms of fatigue.[11–13] Whyte and co-workers[5] demonstrated the effects of high intensity intermittent exercise (a combination of peripheral and central fatigue mechanisms) on dynamic postural control using the SEBT. However, to date, the effects of maximal anaerobic fatigue (predominantly central fatigue[14]) on YBT performance has not been established. Investigating the effects of maximal fatigue on YBT performance is of utmost importance, as the alterations in neuromuscular control may result in poorer control of movement, leading to an increased risk of an individual sustaining non-contact lower limb injuries such as an anterior cruciate ligament injuries and lateral ankle sprains.[7,8,15] Additionally, while Whyte and co-workers established the effects of high intensity exercise on dynamic postural control performance, they did not investigate the period of recovery required for an individual to return to their baseline pre-fatigue levels. The importance of developing an understanding of the time-frame for recovery of dynamic balance following fatigue is two-fold; firstly, clinicians and strength and conditioning professionals need to understand the length of time an individual may be at risk of sustaining an injury following fatigue. Secondly, to ensure a reliable and accurate measurement, representative of the individual's baseline, the length of time for balance performance recovery following fatigue is required. Such information may aid clinicians and strength and conditioning coaches in the implementation of injury risk factor screening protocols, and the development of injury prevention programs that consider neuromuscular control training under fatigued conditions.

Therefore, the primary aim of this study was to investigate the effects of maximal anaerobic fatigue on a dynamic postural control test (YBT). A secondary aim was to investigate how long it takes for dynamic postural control (YBT) to return to baseline levels.

2. Methods

Participants consisted of 20 male and female (age 23.75 ± 4.79 years, height 174.12 ± 8.45 cm, mass 69.32 ± 8.76 kg) university students engaged in competitive sport, aged between 18 and 40. Participants were excluded if they suffered from chronic ankle instability, vestibular or visual impairment, lower limb musculoskeletal injury in the previous 6 months, cardiovascular disease or previous reports of chest pain, any neurological disease, balance disorder or if they were currently taking medication for balance disorders. Participants were also excluded if they answered yes to any question in the PAR-Q[16] or were not taking part in competitive sport. Ethical approval was obtained for the study from the Human Research Ethics Committee of University College Dublin. All participants read the participant information leaflet and provided written consent prior to testing.

Participants were required to attend one 90-min session in a university performance laboratory. Participants were instructed on how to complete the YBT and completed 4 practice trials in each direction, on their dominant limb as per the guidelines previously outlined by Gribble and co-workers.[2] Leg dominance was attained by asking the participant which leg they would kick a ball with.[17] Following the practice trials, participants completed three recorded YBT's in each direction (randomised order) on the dominant stance limb. This was repeated at time points of 0, 10, and 20 min to provide a pre-fatigue baseline measurement of the individuals dynamic postural control. A 10-min rest period was chosen between YBTs to allow for a standard rest period for the pre- and post-fatigue measurements, and allow for the creation of an intra-session reliability dataset. Following completion of the pre-fatigue YBTs, the subject then completed a modified Wingate maximal anaerobic exercise test. Participant's heart rate (HR) was recorded at baseline, prior to, and immediately post the Wingate test to establish the physiological effects of the Wingate protocol on the participants, and demonstrate the physiological stress exerted by the test. The YBT was immediately assessed following the Wingate test at time intervals of 0, 10 and 20 min.

The YBT utilises three directions derived from the SEBT (ANT, PL and PM). The YBT is a commercially available tool for assessing dynamic postural control, and possesses excellent intra-tester (0.85–0.89) and inter-tester (0.97–1.00) reliability.[4] Its design has addressed the limitations of the traditional SEBT testing methods, allowing for more accurate results, in a less time consuming manner. The YBT testing protocol was conducted in accordance with the guidelines outlined by Gribble and co-workers.[2] The YBT requires participants to maintain their balance on one leg while sliding a block as far as possible in a given direction, with the contralateral limb. Participants then return to bilateral stance, while maintaining their balance. The criteria denoting a failed trial were chosen in line with previously published literature.[4] Measures of the YBT reach distances were normalised for limb length using the formula:

$$\text{Normalise Reach Distance} = \frac{\text{Reach distance (cm)}}{\text{Leg Length (cm)}} \text{x} \frac{100}{1} \quad (1)$$

The overall YBT reach direction score was obtained by averaging the three normalised maximal YBT scores for each direction. Lower limb leg length was obtained by measuring the distance between the anterior-superior iliac spine and the most distal aspect of the medial malleolus.[18] Data collected from each participant's dominant limb was utilised in the data analysis stage.

A modified version of the Wingate anaerobic test was performed on a cycle ergometer. A modified version of the protocol employed by Carey and co-workers[19] was utilised in order to maximally anaerobically fatigue participants. The test required the participant to cycle for 60 s rather than the traditional 30 s. Prior to maximal exercise testing, the subject initially completed a low-resistance warm-up for 5 min. During the warm-up, participants completed 3×5 s sprints. On completion of the warm-up, participants commenced cycling at a cadence of between 50–60 RPM for 30 s. The participants were instructed that the test would commence at the completion of the 30 s and that they should accelerated maximally. Participants were encouraged to maintain maximal effort throughout the 60 s in order to ensure maximal fatigue. Changes in the power generated were monitored over the course of the test to ensure that each individual had maintained a maximal effort throughout the Wingate protocol. In addition, participants HR were assessed directly post-fatigue and compared to the pre-fatigue measurements to establish the physiological stress caused by the Wingate protocol, and confirm maximal effort during the fatigue test. Resistance was set to 0.075 g kg^{-1} based on previously published methods.[20,21] The modified Wingate test concluded following 60 s maximal intensity cycling.

Intraclass correlation coefficients (ICC 3, 1) where calculated across the three baseline measurements in order to determine the repeatability of the normalised YBT scores. Standard error of measurement (SEM) is an absolute index of reliability and was calculated in order to assess the degree of variation between the repeated measures. SEM was calculated using the formula:

$$SEM = SD \times \surd(1 - ICC) \quad (2)$$

Where SD represents the standard deviation of the test score, and the ICC was the reliability coefficient used.

In order to investigate the effect of maximal anaerobic fatigue on dynamic postural control, a repeated measures ANOVA with a Greenhouse-Geisser correction (violation of the sphericity assumption) was conducted using the final pre-fatigue measurement, and the three post-fatigue measurements. Post-hoc paired sampled t-tests were subsequently conducted in order to determine the effect time (recovery) had on dynamic postural control, as measured by the YBT.

3. Results

ICC values ranged from 0.976–0.982 for the three normalised YBT reach directions, demonstrating excellent reliability across the baseline pre-fatigue scores. The SEM for the baseline pre-fatigue measurements ranged from 0.97–1.195. A repeated measures ANOVA with a Greenhouse-Geisser correction determined that the mean reach distances for the anterior ($F = 3.818$, $p = 0.025$) and posterolateral ($F = 6.503$, $P = 0.0004$) reach directions were statistically significantly different between time points. The posteromedial reach direction was approaching significance ($F = 2.215$, $p = 0.059$). Due to the excellent ICC scores observed in the reliability analysis of the 3 pre-fatigue measures, the final pre-fatigue measure (pre03) was taken as been representative of the pre-fatigue state, and therefore was used as the basis of comparison between pre-fatigue and post-fatigue in the subsequent post-hoc analysis.

The mean HR for all participants was 69 ± 10 BPM at baseline, 80 ± 12 BPM directly pre-fatigue and 184 ± 9 directly post fatigue. The average decrease in normalised reach distance between the final pre-fatigue and the first post-fatigue measure was 2.57 ± 4.91 (ANT), 2.63 ± 3.06 (PM) and 3.34 ± 4.26 (PL). The percentage change between the final pre-fatigue score and the first post-fatigue score was 4.16% (ANT), 2.58% (PM) and 3.19% (PL). Post-hoc paired sample t-tests demonstrated statistically significant differences ($p < 0.05$) between the final pre-fatigue YBT measurement, and the first post-fatigue YBT measurement in all reach directions (Table 1). In the ANT reach direction, there were no significant differences between the final pre-fatigue measurement, and the second and third post-fatigue measurements. In the PM direction, significant differences were seen only in the first and second post-fatigue measurement, and not in the third measurement. In the PL reach direction, a significant difference remained between the final pre-fatigue measure, and each of the first, second and third post-fatigue measures (Fig. 2).

4. Discussion

The results presented in this study demonstrate that dynamic postural control, as measured by the YBT, is affected by maximal anaerobic fatigue. This immediate degradation in postural control subsequently returns to baseline levels over the course of 20 min for two of the three reach directions.

The ICC scores presented in this study demonstrate that the YBT possesses excellent intra-session reliability. The high levels of reliability presented across the repeated baseline measurements ensure that the scores obtained were a true resting baseline. Additionally, across all three reach directions, the decline in normalised reach distances between the final pre-fatigue and the first post-fatigue measure were greater than the SEM. This indicates that the fatigue intervention resulted in an initial reduction in YBT scores, greater than the intra-session variability. The SEM, in combination with the ICC allows us to be sure that any deviation from that baseline is as a result of the fatiguing intervention, and not a consequence of natural biological variation.

The results presented in this study demonstrate that the modified Wingate protocol employed in this study physiologically stressed the participants with heart rates of 184 ± 9, similar to those reported by Whyte and co-workers.[11] The extended Wingate protocol was utilised as it provided a means to ensure that participants were maximally fatigued.[14] The post-hoc t-test analysis results suggest that the anaerobic fatigue intervention had a significant impact on postural control when reaching in all three reach directions (Table 1).

The traditional Wingate test produces both central and peripheral fatigue, with central fatigue being suggested as the primary mechanism.[14] Previous research has determined that central fatigue mechanisms tend to manifest during the final stages of cycling to exhaustion, thus it was decided that an extended Wingate protocol would be employed in an effort to more comprehensively stress the central and peripheral fatigue mechanisms. Fatigue processes such as reduced motor drive, as a result of centrally induced inhibition of lower motor neurons at the spinal level, and peripherally induced increases in central fatigue mechanisms may

Table 1
Comparison of ICC results, SEM and post-hoc paired-samples t-tests.

Reach direction	Reliability analysis		Level of significance (p values)		
	Pre01, Pre02 & Pre03		for Post-hoc Paired t-tests		
	ICC	SEM	Pre03 vs Post01	Pre03 vs Post02	Pre03 vs Post 03
Anterior	0.978	0.970	0.019*	0.632	0.943
Posteromedial	0.982	1.195	0.004*	0.046*	0.236
Posterolateral	0.976	1.104	0.003*	0.012*	0.023*

The level of significance was set to $p < 0.05$ and differences that reached the level of significance are denoted by an *.

have a negative effect on cortical motor drive, resulting in inhibition of lower motor neurons as the spinal level.[10] Peripheral aspects that may inhibit descending central commands include changes in calcium release from the sarcoplasmic reticulum, increased concentrations of inorganic phosphate and adenosine diphosphate.[22,23] Additionally, it may lead to decreases in muscle fibre conduction velocity as a result of intracellular acidosis.[24,25] The mixture of the central and peripheral fatigue mechanisms outlined above may result in an alteration of a muscles contraction efficacy in the extrafusal muscle fibres. As a consequence, this may lead to decreases in afferent sensorimotor inputs from the muscle spindle, resulting in changes in neuromuscular control and ultimately dynamic postural control.[2,11,12,26]

The findings of this study support previous research demonstrating that dynamic postural control is heavily influenced by fatiguing protocols such as isolated muscle fatigue,[12,13] lower limb fatiguing exercises,[12] treadmill running[27] and high intensity intermittent exercise.[11] Whyte and co-workers reported that a high intensity intermittent exercise protocol had detrimental effects on dynamic postural control as measured by the SEBT. The percentage reduction in normalised reach distance in this study were comparable to those presented by Whyte and co-workers for the ANT reach direction, but were found to be marginally lower for the PM and PL reach direction in our study. Importantly, these observations must be viewed with caution as previous work comparing the YBT and SEBT has found that YBT reach distances in the ANT direction are significantly less than the SEBT, but that there is no difference between PM and PL.[28] Additionally, the two studies employed different fatiguing interventions, potentially effecting the sensorimotor system to different extensts. Conversely, Wright and co-workers also demonstrated that a cycling intervention does not appear to have influences on dynamic postural control as measured by the Biodex Balance System,[27] however the incremental cycle ergometer test may result in different fatigue mechanisms to those observed in our study. Additionally, the method of assessment utilised in our study offers a more dynamic movement than the Biodex Balance System, which may serve to more comprehensively challenge the sensorimotor system post-fatigue.

An important component of this study was the investigation of the recovery time required for one's dynamic postural control to return to baseline levels. Previous research has been carried out investigating the time required for static postural control to return to baseline levels following fatigue,[29] however minimal research has investigated this in dynamic postural control. The results in our study demonstrated that post-fatigue dynamic postural control, as measured by the YBT, returned to baseline levels within 10 min for the ANT reach direction, and 20 min for the PM reach direction. The PL reach direction did not return to pre-fatigue levels by the 20th minute, however it was approaching pre-fatigue levels (Fig. 2). The varying recovery times demonstrated by the reach directions may be explained by the differing movement strategies required to complete each task. The ANT reach direction requires a predominantly single-planar movement, while the PM and PL directions require more complex multi-planar movements, which shift ones centre of gravity further outside of the base of support.[30] Despite the return of the ANT and PM reach distances to baseline levels by the 20th minute, the PL reach distances remained statistically significantly different to the baseline scores. While both the PM and PL reach directions require complex multiplanar movements, the PL reach direction requires a greater degree of pelvic contralateral rotation, knee adduction, pelvic contralateral rotation, pelvic ipsilateral upward obliquity and ankle internal rotation.[30] This increased complexity of the PL reach direction may pose a greater challenge to the sensorimotor systems than the PM reach direction, resulting in the persistence of a balance deficit. Our study is not alone in demonstrating the persistence of PL reach deficits despite normal ANT and PM reach distances. Doherty and co-workers[31] previously demonstrated that individuals with chronic ankle instability possess PL reach deficits despite normal ANT and PM distances. Wright and co-workers[27] investigated the time taken for dynamic postural control, as measured by the Biodex Balance System, to return to pre-fatigue levels after treadmill and cycle ergometer fatiguing interventions. It was found that dynamic postural control returned to baseline levels in 9 min (incremental treadmill test) and 12 min (incremental cycle test). A possible explanation for the differing results reported by Wright and co-workers to those presented in our study is due to the less challenging method of assessment (Biodex Balance System), and the differing fatiguing protocol utilised (incremental cycle test).

The presented research has implications for both the clinical and research application of dynamic postural control assessments such as the YBT, and the understanding of the physiological effect of fatigue on the sensorimotor systems. The findings of this study indicate that fatigue has a detrimental effect on dynamic postural control through the potential mechanisms outlined above. Dynamic postural control requires the integration and coordination of the sensorimotor subsystems to ensure adequate processing and reaction to the changing environment. Previous research has demonstrated the negative effects that fatigue has on joint proprioception[32] as a result of decreased muscle-spindle activity and increased joint laxity.[33] Additionally, it has previously been shown that fatigue delays the onset of muscle contraction, and reduces activation.[34] The combination of these findings suggest that dynamic postural control may be negatively affected by the reduction in the efficiency of the integration of the sensorimotor subsystems. The findings observed in our study support previous research which has indicated that athletes are at increased risk of injury when fatigued,[35,36] and suggest that this may in part be a result of dynamic postural control deficits.[7,8] Sports such as rugby and soccer frequently require short bursts of maximal intensity exercise, potentially fatiguing an individual and subsequently increasing their risk of injury. Furthermore, as the level of fatigue required to induce an alteration in neuromuscular control is currently not known, the authors would advise that if clinicians or researchers are utilising the YBT or SEBT assessments, it is imperative that they consider the possible effects of fatigue, and allow an adequate recovery period of approximately 20–30 min. Clinicians and researchers should consider conducting the YBT protocol under fatigued and non-fatigued states, as this has the potential to

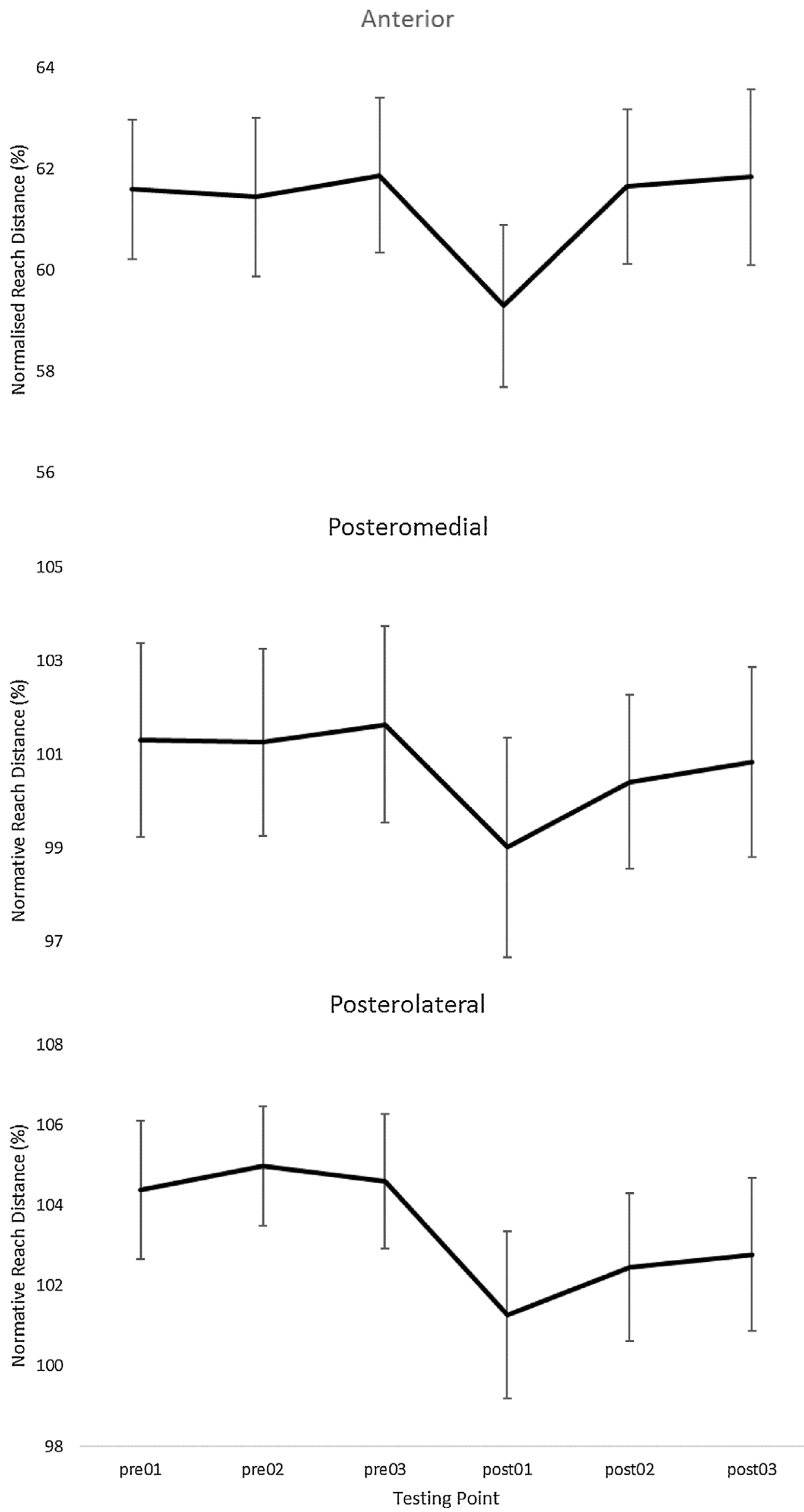

Fig. 2. YBT reach distances for anterior, posteromedial and posterolateral reach directions. Each error bar represents the standard error of the mean. Each point represents the group mean for the different testing points.

highlight neuromuscular control deficits that may not be uncovered when using the YBT under non-fatigued conditions only. Such information may provide clinicians with information pertaining to how an individual's sensorimotor system responds to fatigue, and if they subsequently have an increased risk of a non-contact lower-limb injury. As such, clinicians may use this information to develop injury prevention programs that incorporate neuromuscular control training programs under fatigued conditions. However, further research is required to establish if such methodologies can provide clinically relevant information that may aid clinicians.

A number of limitations to this study exist. Firstly, we only monitored dynamic postural control for 20 min post fatiguing intervention. While this allowed us to establish a timeframe for recovery in the ANT and PM reach direction, it was not sufficiently long to capture the return to baseline levels in the PL direction. Further research should be conducted to investigate the time required for all three reach directions to return to baseline levels. Secondly, participants in this study came from various different sports backgrounds and thus would have been effected differently by the Wingate fatiguing intervention. Thirdly, the challenging nature of the dynamic movements utilised in the YBT may have slowed the recovery of the participants. If an individual rested directly after exercise it may be found that their dynamic postural control returns to baseline levels in less time.

5. Conclusion

The results from this study indicate that maximal anaerobic fatigue has a detrimental effect on dynamic postural control as measured by the YBT. Dynamic postural control returns to baseline levels in <10 min (ANT), <20 (PM) and >20 min (PL). Given the increasing use of such objective dynamic postural control assessments, it is imperative that clinicians and researchers allow an adequate window for recovery following fatiguing exercise. Additionally, clinicians and researchers may consider conducting the YBT under normal and fatigued conditions to establish how an athlete's sensorimotor system responds to an acute bout of fatigue. However, further research is required to establish if this approach can provide clinically useful information

Practical implications

- Maximal fatigue negatively influence dynamic postural control as measured by the YBT.
- Alterations in dynamic postural control do not return to baseline levels immediately, but require a recovery period (approximately 20–30 min) following maximal fatigue.
- Clinicians should allow at least 20–30 min between exercise and Y Balance Test assessment to ensure adequate balance recovery.
- Maximal fatigue may increase an individual's risk of injury due to degradations in neuromuscular control.
- The YBT has the potential to be used as a biomarker to capture an individual's response to fatigue, and how long it takes for them to recover.
- Clinicians should consider conducting the YBT under fatigued and non-fatigued conditions to establish how an athlete's sensorimotor system responds to fatigue.

Acknowledgment

This research was funded by the Science Foundation of Ireland (12/RC/2289).

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