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| ***Title*** | Capturing concussion related changes in dynamic balance using the quantified Y Balance Test - a case series of six elite rugby union players |
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| ***Publication date*** | 2019-03-18 |
| ***Publication information*** | 2019 41st Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC) |
| ***Conference details*** | The 41st International Conference of the IEEE Engineering in Medicine and Biology þÿSociety, Berlin, Germany, 23 27 July 2019 |
| ***Publisher*** | IEEE |
| ***Link to online version*** | https://embc.embs.org/2019/ |
| ***Item record/more information*** | http://hdl.handle.net/10197/11045 |
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| ***Publisher's version (DOI)*** | 10.1109/EMBC.2019.8857628 |

# Capturing concussion related changes in dynamic balance using the Quantified Y Balance Test – a case series of six elite rugby union players

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*Abstract*— **Concussion is one of the most common injuries reported across a myriad of sports. Recent evidence suggests that individuals may possess sensorimotor deficits beyond clinical recovery, predisposing them to further injury. This preliminary prospective case series aimed to determine if an inertial sensor instrumented Y balance test can capture changes in dynamic balance, regardless of apparent 'clinical recovery', in six concussed elite rugby union players. The findings from this case series demonstrate that the inertial sensor-based measures can detect clinically meaningful changes in dynamic balance performance, not captured by the traditional clinical scoring methods, 48-hours post-injury and at the point of 'clinical recovery' (return to play). Further research should investigate the role such instrumented dynamic balance assessments may play in the management of sports-related concussion.**

## I. INTRODUCTION

Concussion is a traumatic brain injury induced by biomechanical forces [1]. It is one of the most common injuries observed across a host of sports [2] and cannot be identified using traditional neuroimaging [1]. Recently, there has been a growing concern about the medium to long-term consequences of concussion, such as an increased risk of sustaining subsequent concussions [3] and musculoskeletal injuries [4], as well as the potential relationship between concussion and chronic traumatic encephalopathy associated neurological conditions [5].

The current model of concussion assessment is centered around a multifactorial clinical assessment. This is designed to assess the different components of cerebral function. These include symptomatology, motor and neurocognitive function, assessed through a multifactorial assessment battery known as the sport concussion assessment tool (SCAT) [6]. Despite its widespread implementation, this clinical battery is not without major limitations. The symptom scores rely on self-reporting, while the cognitive and motor function assessments are not sufficiently challenging [7], have poor-moderate reliability [8], are subject to learning effects [9] and fail to accurately identify concussed and non-concussed individuals [10]. Furthermore, despite clinical recovery typically occurring within 7-10 days, recent evidence suggests that individuals may possess motor function deficits which extend beyond the resolution of clinical symptoms [11, 12], increasing the risk of subsequent musculoskeletal injury [4].

Recent advances in smart-phone and wearable technology has allowed for the development of digital health systems capable of objectively quantifying human movement [13, 14]. Such systems have overcome some of the limitations typically seen with traditional biomechanical measurement tools (force platforms and marker-based motion capture), allowing for the quantification of clinical balance assessments [15]. The Y-balance test (YBT) is one of the most commonly used sports medicine dynamic balance assessments, providing a means to validly and reliably quantify sensorimotor function [16]. However, the traditional clinical scoring method does not allow for the objective quantification of information related to an individual's balance 'stability' or 'strategy'. Recent research has resulted in the development of an inertial sensor quantified YBT (QYBT), demonstrating that it can provide a reliable measure of performance [17], is more sensitive to change than the traditional scoring method [18, 19] and can identify deficits in performance that increase an athletes risk of concussion [20]. To date, despite a call for research, there have been no prospective investigations conducted to determine the capability of an inertial sensor based assessment to quantify motor function following 'clinical recovery' from concussion [7].

The aim of this case series is to carry out a preliminary assessment of the potential for the QYBT to quantify alterations in dynamic balance performance in rugby union players, 48-hours post-concussion and at return to play (RTP). It is hypothesized that the QYBT will provide a more sensitive measure of balance performance than the traditional YBT and modified balance error scoring system (mBESS), capturing changes that extend beyond clinical recovery.

## II. METHODS

### A. Participants

One-hundred and nine elite rugby union players were recruited as part of a larger study, as detailed in Johnston et al. [20]. The Institution's Ethical Review Board approved all experimental procedures involving human subjects (LS-15-52-Caulfield), and all participants provided informed consent prior to completion of the testing protocol. Athletes' age, height, weight, leg-length, self-reported concussion history and baseline QYBT performance were obtained. Participants were excluded during baseline screening if they were younger

Research supported by the Science Foundation of Ireland (12/RC/2289).

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than 18 years of age, had a history of a lower limb injury within the last 6 months, and/or possessed any vestibular, visual or balance deficits, and/ or any neurological disease. Of the 109 players who entered the study, 21 sustained a concussion during the following season. Six of these players were located close to the University campus and therefore entered the post-injury pilot QYBT monitoring protocol.

### B. *Experimental Procedure*

A single inertial sensor (Shimmer3, Dublin, Ireland) was mounted at the level of the 4th lumbar vertebrae, in line with the top of the iliac crest, using a custom-made elastic belt. This mounting location was chosen as previous research has indicated that the closest estimate of the body's center of mass lies in the region of L3 - L5 [29, 30]. The inertial sensor was configured to collect tri-axial accelerometer data (± 2 g) and tri-axial gyroscope data (± 500 °/s) at a sampling frequency of 51.2 Hz during each YBT reach excursion. Inertial sensor data were streamed via Bluetooth to an android tablet (Galaxy Tab 2, Samsung), operating a custom-made application.

The YBT requires an individual to place their hands on their hips, transition from a position of bilateral to single leg stance and complete a maximal reach excursion in one of three directions; anterior (ANT); posteromedial (PM); posterolateral (PL) (Fig. 1). The individual is then required to return to the starting position in a controlled manner. A trial is deemed a fail if they remove their hands from their hips, make contact with the ground, weight bear through the slider, raise the stance leg heel or kick the slider forward for extra distance. Participants completed four practice trials prior to completion of three recorded trials in each direction (randomized order), bilaterally [21].

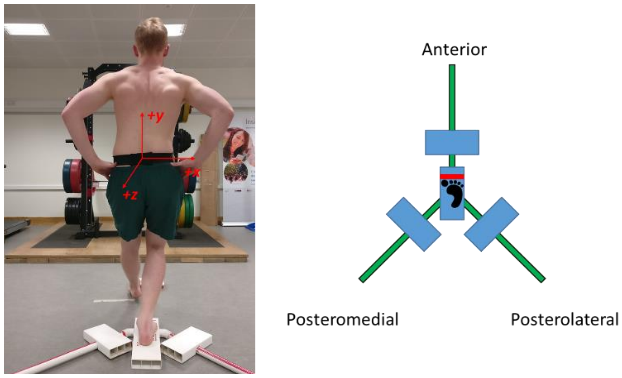

Fig. 1 Illustrates the three reach directions of the YBT and the inertial sensor mounting location and axis orientation.

### C. *Signal processing*

Traditional YBT reach distances were normalized by representing the reach distance as a percentage of leg length [21]. Gyroscope magnitude (GM) was computed using the vector magnitude of gyroscope *x, y* and *z* axis. The following four variables were then derived from the GM signal for all completed reach excursions of the YBT, using MATLAB 2017b (Mathworks, Natwick, USA): root-mean-square (RMS), variance (Var), sample entropy (SEn) and area under the curve (AUC) of the fast-Fourier transform (FFT). The RMS and Var and variables were computed with the standard Matlab 'rms' and 'var' functions, respectively. The SEn was derived using the methods previously outlined by Johnston et al. [20]. AUC FFT was computed for the GM signal by first using the Matlab 'fft' function to derive a power-frequency plot and then using the 'cumsum' function to find the area under the curve FFT power spectrum. These variables provide a means to quantify balance performance through an array of methods commonly used in variability analysis of physiological signals [22].

### D. *Statistical Methods*

Descriptive statistics (means, standard deviations (SD) and frequencies) were used to describe the population. The average of the three trials for each reach direction was obtained for each right stance leg testing point (baseline, 48-hour and RTP) to ensure measurement reliability [21]. The mean difference between the baseline measurements and two follow-up measurement points were obtained for each of the YBT variables, across each of the six participants. The mean difference was then compared to the minimal detectable change values, derived from a previously published reliability study [17]. This allowed for the individual scores to be dichotomized into 'clinically real change', represented by a '1', and 'non-clinically real change', represented by a '0'. Formal hypothesis testing was not conducted due to the small sample size recruited in this case series and the resultant risk of type one and two errors. The sum of the mBESS errors and the total number of symptoms 48-hours post-injury and the time to RTP was obtained for each participant.

## III. RESULTS

The six concussed participants descriptive statistics (mean ± SD) were as follows: age 21 ± 1.48 years; height 182 ± 6.29cm; weight 91 ± 15.44kg; right leg length 95 ± 4.20cm; left leg length 95 ± 4.22cm. The six individuals presented with a median SCAT3 symptom score of 4.5/22 and mBESS score of 0.5 48-hours post-injury (TABLE I).

TABLE I: Symptom and mBESS total score for the 6 concussed individuals 48-hours post-injury

| Participant | Symptoms | mBESS Total | RTP Duration (Days) |
|---|---|---|---|
| **Participant 1** | 11 | 1 | 21 |
| **Participant 2** | 1 | 0 | 21 |
| **Participant 3** | 0 | 5 | 21 |
| **Participant 4** | 8 | 1 | 21 |
| **Participant 5** | 17 | 0 | 21 |
| **Participant 6** | 0 | 0 | 7 |

Table II presents the descriptive data (means and SD) for the YBT reach distance and inertial sensor variables. Table III presents the dichotomized data for the six participants, across the traditional YBT and QYBT variables. A clinically meaningful change was defined as change larger than the minimal detectable change thresholds derived from the data described by Johnston et al,. [17]. Only one participant (participant 5) demonstrated a clinically real change for the traditional YBT reach distance. Conversely, clinically real changes in balance performance were captured by the inertial sensor based QYBT variables post-concussion.

TABLE II. The mean and SD of the traditional and inertial sensor quantified variables at baseline, 48-hours post-injury and at return to play for the six injured Rugby Union players.

| **Anterior Variables** | | **Baseline** | | **48-hours** | | **RTP** | |
|---|---|---|---|---|---|---|---|
| | | **Mean** | **SD** | **Mean** | **SD** | **Mean** | **SD** |
| ***A*nterior** | **Distance (% leg length)** | 55.94 | 7.95 | 54.10 | 6.84 | 57.97 | 8.71 |
| | **SEn** | 1.24 | 0.24 | 0.90 | 0.22 | 1.10 | 0.26 |
| | **RMS (deg/s)** | 17.48 | 3.26 | 20.43 | 4.75 | 21.69 | 4.94 |
| | **Variance ((deg/s)$^2$)** | 110.51 | 52.21 | 178.91 | 98.84 | 195.27 | 136.81 |
| | **AUC FFT** | 14.64 | 4.39 | 15.19 | 6.26 | 18.65 | 4.59 |
| ***P*osteromedial** | **Distance (% leg length)** | 104.46 | 5.33 | 101.71 | 6.91 | 106.78 | 7.57 |
| | **SEn** | 0.69 | 0.25 | 0.65 | 0.14 | 0.80 | 0.32 |
| | **RMS (m/s)** | 23.47 | 5.39 | 24.72 | 5.01 | 27.00 | 6.23 |
| | **Variance ((m/s)$^2$)** | 234.09 | 99.64 | 248.48 | 118.05 | 285.51 | 192.17 |
| | **AUC FFT** | 14.19 | 4.11 | 15.65 | 5.50 | 18.01 | 5.22 |
| ***P*osterolateral** | **Distance (% leg length)** | 99.92 | 5.91 | 98.91 | 8.51 | 104.78 | 6.46 |
| | **SEn** | 0.79 | 0.33 | 0.62 | 0.17 | 0.66 | 0.27 |
| | **RMS (m/s)** | 21.72 | 9.51 | 25.60 | 8.81 | 29.96 | 8.36 |
| | **Variance ((m/s)$^2$)** | 251.24 | 202.99 | 276.41 | 146.59 | 394.25 | 223.62 |
| | **AUC FFT** | 12.99 | 6.35 | 15.30 | 8.11 | 18.96 | 5.85 |

SEn Sample entropy; RMS Root mean square; AUC FFT Area under the fast-Fourier transform; SD Standard Deviation. The Distance variable is a traditional measure of YBT performance, while the SEn, RMS, Variance and AUC FFT are inertial sensor quantified measures of YBT performance.

## IV. DISCUSSION

The primary aim of this case series was to conduct a preliminary prospective investigation to determine if the QYBT can capture clinically real changes in dynamic balance performance in six elite rugby union players, 48-hours post-concussion, and at the point of apparent 'clinical recovery'.

Across the six concussed athletes, it was observed that two athletes were symptom free 48-hours post-injury (participant 3 and participant 6), while four demonstrated at least one symptom 48-hours post-injury (TABLE I). Three players demonstrated no deficit during the mBESS, with only one individual (participant 3) possessing more than one error during the mBESS. All participants were symptom free within the first 7 days, with one player (participant 6) completing the graduated RTP process within the minimum advised time of 7 days, in line with the World Rugby guidelines for professional athletes [23]. The remaining five players underwent a 14-day rest period post-concussion, followed by the graduated RTP process, in line with the Irish Rugby Football Union guidelines for players who do not fall under the professional remit [24]. The resolution of symptoms and lack of balance deficits on standard test protocols is typical following sports related concussion, as clinical recovery typically occurs within the first 7-10 days post-injury [1].

When considering the YBT reach distances, only one individual (participant 5) demonstrated clinically real alterations in performance, persisting up to and including RTP (TABLE III: column 10, row 1). The remaining five participants did not possess any clinically real reach distance deficits (TABLE III: row 1). Conversely, three of the four QYBT variables (*SEn, Var* and *RMS*) captured clinically real changes in balance, across the concussed athletes (TABLE III).

The most valuable QYBT variable across the ANT reach direction was *GM Var* (TABLE III: row 4), detecting changes in balance in three participants 48-hours post-injury and at RTP. Similarly, *GM Var* (TABLE III: row 9) appeared to be the most sensitive to change for the PM reach direction, detecting alterations in two participants 48-hours post-injury, and four participants at RTP. Conversely, *GM RMS* (TABLE III: row 13) was the most sensitive variable post-injury in the PL reach direction, with two participants demonstrating alterations at 48-hours, increasing to three at RTP. Despite not demonstrating deficits in the YBT reach distances, participant 2 demonstrated alterations in the greatest number of QYBT variables. Conversely, participant 4 demonstrated the least number of deficits for the ANT and PL directions. Participant 5, the only athlete who manifested clinically real changes in the YBT reach distances, also possessed changes in ANT *GM SEn* 48 hours post-injury. These changes were further manifested at the point of RTP in the ANT/ PM *GM Var* and PL *GM RMS* variables. While this paper presents a case series of six athletes and should be interpreted with caution, the findings mirror those of previously published case-control studies which have shown that inertial sensor data captured during the mBESS can discriminate concussed and healthy cohorts, with greater sensitivity than the traditional mBESS clinical scores [25].

While it may be expected that participants might possess alterations in balance 48-hours post injury, the deficits at RTP are significant, as they indicate that despite the players undergoing a period of rest and graduated return to activity following the resolution of clinical symptoms, they may continue to possess subtle sensorimotor deficits. For example, when considering the *GM Var* variable, it is seen that 3/6 (ANT) and 4/6 (PM) participants demonstrated clinically real reductions in balance at the point of RTP.

TABLE III: Presents the dichotomised balance performance data for each participant, for the traditional YBT and QYBT variables. A clinically meaningful change is denoted by a '1' and highlighted in light blue, and a non-clinically meaningful change is denoted by a '0'.

| **Variables** | | **Participant 1** | | **Participant 2** | | **Participant 3** | | **Participant 4** | | **Participant 5** | | **Participant 6** | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **48hr** | **RTP** | **48hr** | **RTP** | **48hr** | **RTP** | **48hr** | **RTP** | **48hr** | **RTP** | **48hr** | **RTP** |
| **Anterior** | **Distance** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 |
| | **SEn** | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 |
| | **RMS** | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| | **Var** | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 |
| | **AUC FFT** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Posteromedial** | **Distance** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | **SEn** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| | **RMS** | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 |
| | **Var** | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 0 |
| | **AUC FFT** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Posterolateral** | **Distance** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | **SEn** | 0 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| | **RMS** | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 |
| | **Var** | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | **AUC FFT** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

SEn Sample entropy; RMS Root mean square; AUC FFT Area under the fast-Fourier transform; SD Standard Deviation. The 'Distance' variable is a traditional measure of YBT performance, while the SEn, RMS, Variance and AUC FFT are inertial sensor quantified measures of YBT performance.

Importantly, participant 6 demonstrated that they had returned to pre-injury levels of performance at the point of RTP, across all three reach directions and all variables. Furthermore, it was observed that for several injured athletes, balance alterations only manifested at the point of RTP. While the reason for these changes is not clear, it may be hypothesized that the protracted rest and recovery period of 21-days leveraged for participants 1-5, may have result in a period of detraining, leading to a reduction in sensorimotor capabilities. While this is merely a hypothesis, these findings are consistent with emerging research in the field, demonstrating that motor function deficits may manifest post-concussion, beyond resolution of clinical symptoms [11, 12]. Furthermore, a notable observation from this investigation is that not all participants presented with consistent QYBT balance deficits post-injury. This is to be expected, as it is well acknowledged that concussion is a multifactorial injury, with a variable presentation [1]. As such, it should not be assumed that all athletes will present with or develop balance deficits during recovery. However, this case series demonstrates that the QYBT may have value in athlete stratification, ensuring that those who possess such deficits are identified, facilitating the implementation of targeted physiotherapy interventions, designed to ensure an optimal return to sport.

While the sample recruited as part of this case series is small, this is the first prospective case series to demonstrate that the QYBT can capture alterations in dynamic balance performance, despite apparent 'clinical recovery' from concussion. This may indicate that inertial sensor data could provide a more sensitive measure of sensorimotor function than the current measure of static (mBESS) and dynamic (YBT reach distances) balance. This is of importance as previous research has identified that athletes are at a greater risk of sustaining a time-loss injury following concussion [4], with laboratory-based evidence showing that individuals can possess sensorimotor deficits, beyond clinical recovery [11, 12].

There are several key limitations related to this case series which should be acknowledged. Firstly, this preliminary case series only obtained post-concussion QYBT data from six individuals, reducing the conclusions that can be drawn. However, the authors leveraged the minimal detectable change scores derived from Johnston et al [17], ensuring that all changes could be considered 'real', reducing the chance of a type one error. Secondly, due to the sample size recruited in this case series, it was not feasible to investigate the correlates between QYBT performance, symptom recovery, RTP duration and/or future injury incidence. However, further research is currently underway investigating the clinical utility of the QYBT in larger, more-representative cohorts.

## V. CONCLUSION

This case series sought to preliminarily investigate the role the QYBT assessment may play in concussion management. The findings presented in this paper demonstrate that in a case series of six elite Rugby Union players, select QYBT variables are capable of capturing 'clinically real' alterations in dynamic balance performance, despite apparent 'clinical recovery'. As such, this pilot evaluation highlights that the QYBT may provide a means to sufficiently challenge the sensorimotor subsystems, exposing deficits in some athletes that are not detected by traditional management protocols. Further high-quality prospective research is required to investigate the role instrumented dynamic assessments may play in capturing sensorimotor function alterations in larger, more representative cohorts, across a host of patient populations, and determine the 'clinical relevance' of any detected persistent deficits.

## ACKNOWLEDGMENT

This research was funded by the Science Foundation of Ireland (12/RC/2289). The authors would like to thank the participants and medical teams involved in this study for their support.

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