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Short communication

The effect of the stability threshold on time to stabilization and its reliability following a single leg drop jump landing

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ABSTRACT

We aimed to provide insight in how threshold selection affects time to stabilization (TTS) and its reliability to support selection of methods to determine TTS.

Eighty-two elite youth soccer players performed six single leg drop jump landings. The TTS was calculated based on four processed signals: raw ground reaction force (GRF) signal (RAW), moving root mean square window (RMS), sequential average (SA) or unbounded third order polynomial fit (TOP). For each trial and processing method a wide range of thresholds was applied. Per threshold, reliability of the TTS was assessed through intra-class correlation coefficients (ICC) for the vertical (V), anteroposterior (AP) and mediolateral (ML) direction of force.

Low thresholds resulted in a sharp increase of TTS values and in the percentage of trials in which TTS exceeded trial duration. The TTS and ICC were essentially similar for RAW and RMS in all directions; ICC's were mostly 'insufficient' (<0.4) to 'fair' (0.4–0.6) for the entire range of thresholds. The SA signals resulted in the most stable ICC values across thresholds, being 'substantial' (>0.8) for V, and 'moderate' (0.6–0.8) for AP and ML. The ICC's for TOP were 'substantial' for V, 'moderate' for AP, and 'fair' for ML.

The present findings did not reveal an optimal threshold to assess TTS in elite youth soccer players following a single leg drop jump landing. Irrespective of threshold selection, the SA and TOP methods yielded sufficiently reliable TTS values, while for RAW and RMS the reliability was insufficient to differentiate between players.

1. Introduction

A variety of laboratory and field tests have been applied to characterize different aspects of a soccer player's ability as potential determinants of performance (Svensson and Drust, 2005). Among these aspects dynamic postural stability has received increasing interest (Fransz et al., 2013, Shaw et al., 2008). The most commonly applied dynamic postural stability test is the single leg jump landing, which involves subjects jumping either from a box or to a certain height, landing upon a force plate on one foot, and stabilizing as quickly as possible. The performance on such a test is usually quantified with the ground reaction forces (GRF) from which a variety of outcome measures can be calculated (Fransz et al., 2013).

Time to stabilization (TTS) is a frequently used outcome measure, but widely different calculation methods to establish TTS following a single leg jump landing test have been identified in the literature (Fransz et al., 2015). For instance, these calculation methods differ with regard to the input signal that is used. The GRF's can be assessed in vertical (V), anteroposterior (AP) or mediolateral (ML) direction, resulting in substantially different TTS values, ranging from 1.3 to 6.1 s (Fransz et al., 2015). Secondly, four essentially different signal-processing methods have been employed. The 'RAW' method employed no additional processing (Colby et al., 1999), the 'RMS' method produced a new signal by calculating the root mean square over a time window moving along the time series (Tulloch et al., 2012), the 'SA' method produced a sequential average signal by calculating a new average after each added data point (Colby et al., 1999), and the 'TOP'

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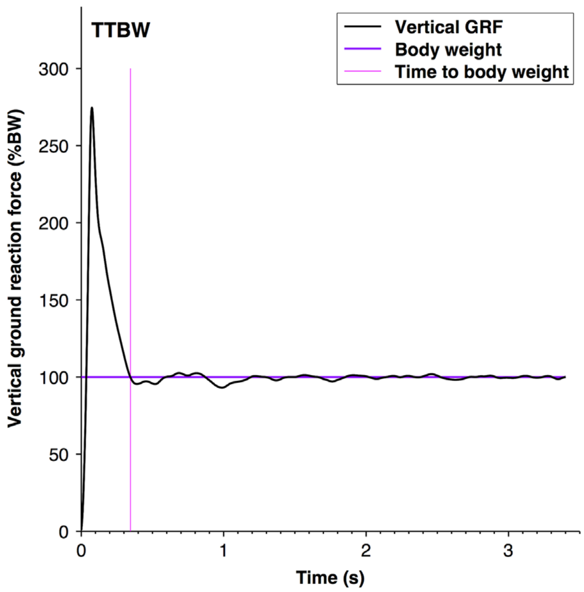

Fig. 1. A typical example of the establishment of 'time to bodyweight' (TTBW). The TTBW is the intersection of the Vertical GRF signal with the body weight (100%) directly following the impact peak.

method produced a new signal by fitting an unbounded third order polynomial to the time series (Ross and Guskiewicz, 2003). These processed signals resulted in a range of mean TTS values differing up to 5.5 s within the same direction (Fransz et al., 2015). Furthermore, a definition of the stable state has to be determined. This is the threshold below which the processed signal is considered stable. The effects of threshold selection have not yet been assessed. This is important as threshold selection may considerably change the resulting TTS values. Even more so, it may have implications for the interpretation of the values, as higher thresholds lead to smaller TTS values (Fransz et al., 2015).

To date it is unknown which processed signal/threshold combination will be most accurate in detecting impairments in sensorimotor function. A prerequisite for accurate detection is reliability and therefore a thorough and systematic examination of the effect of threshold selection in combination with the different processing methods seems warranted. The present study provides an analysis of reliability for a wide range of thresholds in combination with four commonly used signal processing methods and three directions of force.

2. Methods

2.1. Participants

At the youth academy of AFC Ajax, players are regularly tested as part of a program aiming to monitor player performance on a variety of neuromusculoskeletal tasks. The current performance data set was acquired at the start of the 2013–2014 season. We included the data of 82 players between 11 and 18 years old (mean ± SD; age 14.10 ± 1.86 years; height 1.68 ± 0.12 m; body weight 56.70 ± 13.20 kg) for whom six valid trials obtained during one session were available. At the time of measurements, all players were fit to perform at the highest standard of competitive football matches. The local ethics committee approved the research protocol and all players or parents/guardians (depending on the age of the participant) were informed in advance of the procedures involved and provided written informed consent.

2.2. Instrumentation

Ground reaction forces (GRF) in vertical (V), anteroposterior (AP) and mediolateral (ML) directions were recorded at 1000 samples/s, using a 40 × 60 cm AMTI force plate (type BP400600HF, Advanced Medical Technologies Inc., Watertown, MA, USA).

2.3. Procedures

The players were asked to jump from an aerobic step of 20 cm height, which was placed 5 cm posterior to the force plate. Players took off by means of a small jump with two feet, landed on the testing leg on the center of the force plate, and stabilized as quickly as possible. They had to balance for 15 s with their hands on their hips, whilst keeping all other movement to a minimum. If a player exaggerated the jump height or only slid of the aerobic step, he was asked to perform another jump following extra instruction. No specific instructions were given with regard to stabilization, however all players performed the test in a similar fashion. Following landing, the testing leg was flexed about 15° at the knee, the non-testing leg was flexed about 90° at the knee. Before actual testing commenced, all players completed the regular warm-up as accustomed before a training session and performed one practice trial per leg. Both legs were tested thrice without breaks; the left leg was appointed the initial testing leg. All trials were performed without shoes. A trial was considered invalid if a player touched the floor with the contralateral leg or if arm movement was used to regain balance.

2.4. Data processing

A custom MATLAB (The Mathworks, Natick, RI, USA) program was written for data processing. Raw GRF data were cropped from time of impact (vertical GRF > 10 N) to 12 s post-impact and rectified. Data were low pass filtered at 12 Hz with a bidirectional second order Butterworth filter (Huurnink et al., 2013).

2.5. Data analysis

To facilitate consistent data processing in V, AP and ML directions, the mean GRF value over 7 to 12 s was subtracted from the signal for each direction. Subsequently, the signals were rectified. Four processed signals were evaluated: (1) no additional processing (RAW) (Colby et al., 1999), (2) a new signal was produced by calculating the root mean square (RMS) over time windows of 250 ms, moving along the time series with 1 ms per step (Tulloch et al., 2012), (3) a sequential average (SA) signal was established by adding one data point at a time, and calculating a new average after each added point (Colby et al., 1999), and (4) an unbounded third order polynomial fit (TOP), which started at the peak GRF, was obtained by least-squares fitting the following function: $f(x) = a_0 + a_1x + a_2 \times {}^2 + a_3 \times {}^3$, where $a_3 \neq 0$ (Ross and Guskiewicz, 2003).

Furthermore, a wide range of thresholds was applied. The SD over the last 5 s of each trial (7 to 12 s) was used to calculate up to 1600 threshold values, ranging from 0 to 160 SD (with steps of 0.1 SD). The TTS was defined as time between impact and the intersection of the processed signal with the threshold, after which it remained below the threshold for the subsequent 0.5 s (Tulloch et al., 2012). Consequently, TTS was calculated 1600 times for each trial. The effect of threshold level on the TTS and its reliability was assessed for twelve calculation methods (4 processed signals x 3 GRF directions). For some trials the applied threshold did not result in a TTS value, i.e. when the processed signal stayed above the threshold for the duration of the entire trial. Therefore, the percentage of trials with no TSS value was calculated for each threshold per calculation method (% of 492 trials, 82 subjects x 3 trials x 2 legs).

Finally, in order to define the phase that primarily concerns the impact of the landing, we established the mean 'time to bodyweight' (TTBW) (based on 492 trials). This is the intersection of the RAW V signal with the body weight (100%) directly following the impact peak (Fig. 1). In further data processing, we ignored thresholds yielding TTS values shorter than mean TTBW.

2.6. Statistical analysis

The reliability of TTS across the six trials (3 trials x 2 legs) per subject was calculated for each threshold and calculation method. An absolute agreement two-way random model (average measures) was applied to calculate intra-class correlation coefficients (ICC) (de Vet et al., 2006). When one or more trials did not reveal a TTS value, the ICC was discarded. Both limbs were grouped together, assuming that postural stability is predominately an indicator of whole body sensorimotor function (Witchalls et al., 2012). We used the considerations by Shrout (1998): 'insufficient' (< 0.40), 'fair' (0.40–0.60), 'moderate' (0.60–0.80), and substantial (> 0.80) (Shrout, 1998).

3. Results

The mean SDs of the GRF (in %BW) over the last 5 s of each trial (7 to 12 s) were 0.53 for vertical, 0.23 for anteroposterior and 0.27 for mediolateral GRF, respectively. Fig. 2 provides typical examples of the processed signals in relation to three different thresholds (i.e. 10, 30 and 50 SD) for each force direction. In contrast,