Postural control responses to different acute and chronic training load profiles in professional rugby union

ABSTRACT

The current investigation identified the response of postural control measures of single-leg balance and landing to different accumulated training load profiles representing normal, higher, and spiked loads. Twenty-two professional rugby union players performed single-leg balance and landing tests on a 1000Hz force plate on the first training day of 24 weeks across the season following 36 h recovery. Internal (sRPE-TL) and external (total and high-speed running distance) load measures were monitored during all training sessions and matches. Calculations of acute (7-day rolling average), chronic (28-day rolling average), and acute to chronic workload ratio were determined. Three-week load profiles were identified that represented normal, spike, and higher load profiles to determine the effect on postural control, which were analyzed using two-way repeated measures ANOVA. A significant effect of load profile on landing impulse on the dominant (p=0.005) and non-dominant legs (p=0.001) was identified, with significantly greater impulse measures in the spike and higher load profiles (p=0.001-0.041) compared to the normal load profile. Significant load profile x week interactions (p<0.05) were identified for landing peak force on the dominant leg and impulse on both legs suggesting a decrement during the spike load profile and increased impulse in the higher load profile. No effects (p>0.05) were identified for load profile changes in single-leg balance sway velocity or single-leg landing time to stabilization. The respective landing responses may indicate altered movement strategies under spike and higher load profiles resulting from neuromuscular fatigue in response to the accumulated load.

KEYWORDS: single-leg balance, single-leg landing, neuromuscular fatigue, accumulated load

INTRODUCTION

Professional rugby union is a high-intensity sport, requiring repeated bouts of high-intensity running, collisions, and static combative efforts which result in the accumulation of neuromuscular fatigue (NMF) (West et al., 2014). Monitoring NMF in applied sport settings requires tools that are cost effective, time-efficient, non-aversive to players, and that provide immediate feedback to guide decision making (Starling & Lambert, 2018). The responsiveness of NMF measures to the acute and chronic accumulated loads encountered by players across a professional rugby union season are rarely reported yet are often deemed important for performance and injury risk (Cross et al., 2016). For example, Roe and colleagues (Roe et al., 2017) report greater responsiveness of weekly countermovement jump (CMJ) peak and mean power compared to cycle ergometer peak power during a six-week training block. Further, reports of impaired CMJ during periods of overreaching in female rugby sevens players (Gathercole et al., 2015) also highlight that accumulated load may result in changes in measures used to infer the existence of NMF. While such reports suggest the possibility of impaired neuromuscular function in relation to explicit overloading, no studies have reported the effects of differing patterns of load accumulation profiles (ie. normal, spike, or higher loads) on any measures of NMF. In part this may be due to the difficulty of obtaining consistent field-based measures of NMF during such periods of overload and fatigue. Accordingly, some authors have proposed novel tests of postural control (PC) as measures of NMF, however the effects of accumulated load on such tests remain unknown (Clarke et al., 2015; Pau et al., 2016).

While countermovement jump (CMJ) tests are frequently used in applied sport settings as a measure of NMF (Taylor et al., 2012), some have challenged their regular in-season usefulness in collision sports due to the required maximal physical effort and motivation (Austruy, 2016). This maximal nature may in turn compromise athlete compliance and the consistency of data collection to inform NMF in response to accumulated loads (Austruy, 2016). As such, novel postural control (PC) tests of single-leg balance and landing have been proposed for monitoring NMF as they may require less exertion and motivation than maximal CMJ tests (Austruy, 2016; Clarke et al., 2015). Further, PC related tests may also be sensitive to impairment of fine motor control and proprioception, elements not captured in maximal power movements (Austruy, 2016; Clarke et al., 2015). As evidence of their validity for measuring NMF, measures of single-leg balance (Effect Size [ES]=0.76-1.68) and landing (ES=0.33-0.71) demonstrate impairment immediately following a soccer match (Pau et al., 2016; Zemkova, 2009), Canadian gridiron football game simulation (Clarke et al., 2015), and functional fatigue protocols (Brazen, Todd, Ambegaonkar, Wunderlich, & Peterson, 2010). Furthermore, reliability of single-leg balance sway velocity (ICC=.75-.79; CV=9-12%), single-leg landing peak force (ICC=.69-.72; CV=12-13%), impulse (ICC=.64-.68; CV=7-8%), and time to stabilization (ICC=.28-.60; CV=13-21%) measures have been established in a professional rugby union population allowing practitioners to understand thresholds for meaningful change (Troester et al., 2018).

The impaired responses of PC tests to high acute loads as representative of NMF is well reported following functional and sport-specific fatigue protocols (Augustsson et al., 2006; Clarke et al., 2015; Madigan & Pidcoe, 2003; Pau et al., 2016; Zemkova, 2009). However, the responsiveness of PC tests to varying accumulated loads present in most successful athlete training programs is lacking. While there are reports of impaired CMJ measures (representing NMF) as a result of accumulated load following periods of overreaching in rugby league, AFL, rugby union, and endurance sports (Cormack, Newton, McGuigan, & Cormie, 2008; Coutts, Reaburn, Piva, & Rowsell, 2007; Coutts, Slattery, & Wallace, 2007; Gathercole et al., 2015), no such evidence exists for PC measures. Understanding the responsiveness of

NMF measures to varying load profiles is important given the recent focus on athlete monitoring and accumulated load (Gabbett, 2016). Thus, an ecologically valid athlete monitoring tool must account for the influence of acute and chronic load as well as the profile of the load accumulation to aid interpretation. While the previously mentioned studies provide some insight into the acute response of PC measures to fatigue (Clarke et al., 2015; Pau et al., 2016; Zemkova, 2009), the effects of acute, chronic, and spiked loads on PC measures are unknown. Therefore, the purpose of this investigation was to evaluate the response of single-leg balance and landing performance to accumulated load profiles representing normal loads, high chronic loads, and spikes in acute load. Such a determination may inform practitioners of the suitability of such tests for monitoring impaired PC and accumulated NMF to guide the planning of training.

METHODS

Experimental Approach to the Problem

Single-leg balance and landing tests were performed on the morning of the first training day of each week following at least 36 h rest (48.6 ± 12.3 h; range = 36 – 60) for 24 weeks throughout a professional rugby union season. Concurrently, internal load was measured using session rating of perceived exertion (sRPE) and external loads were measured using wearable global positioning satellite (GPS) units for all training and matches. As outlined later in the methods, normal, spike, and higher load profiles were retrospectively identified over respective 3-week periods for the purpose of investigating PC responses to these accumulated load profiles. A within-subject repeated measures design was used to compare PC performance between load profiles as well as between weeks within each load profile to determine the response of PC to accumulated load.

Subjects

Twenty-two male professional rugby union players (8 backs, 14 forwards, age: 26 ± 3 y, height: 190 ± 8 cm, mass: 107 ± 18 kg, Super Rugby experience: 57 ± 32 games) participated in this study. All participants were free from injury and participating in full training which generally consisted of 3 strength sessions, 3 team rugby sessions, one position-specific skill session, and one match per week, though some small variation occurred due to alterations in the competition schedule. All data collection methods were part of normal monitoring practices at the club and participants had at least 3 weeks of prior familiarity before commencement of the study. Participants were informed of the risks and benefits of the study prior to any data collection and then signed the institutionally approved informed consent document (UTS HREC REF NO. ETH16-0626).

Procedures

Training Load

Internal load was measured for all training sessions using the sRPE method in which participants provide a subjective CR-10 scale RPE 15-30 min post-training/match (Borg, Hassmen, & Lagerstrom, 1987). RPE was then multiplied by session duration to quantify sRPE training load (sRPE-TL) in arbitrary units (AU) and loads from all on and off-field sessions were added each day, resulting in cumulative daily load (Foster et al., 2001). External load was measured for all on-field training sessions using individual GPS units (SPI-HPU – 15 Hz) (GPSports, Canberra, Australia) worn in manufacturer-provided vests (Vickery et al., 2014). GPS units were turned on 10 min prior to ensure satellite connection and each athlete wore the same allocated unit for each session. Data were downloaded and analyzed using Team AMS software (GPSports, Canberra, Australia). Measures of total distance (m) (TD) and high-speed running distance (>5.5 $m \cdot s^{-1}$) (m) (HSR) were collected for all on-field training sessions, resulting in cumulative daily TD and HSR. Such devices have demonstrated acceptable reliability (Vickery et al., 2014) and measures of TD and HSR are most commonly used to measure and describe movement loads in Rugby union (Bradley et al., 2015).

The distribution of accumulated training load was assessed by defining the acute load as the mean daily load across the previous seven days prior to the PC tests, while the chronic load was defined as the mean daily load over the previous 28 days. The acute to chronic workload ratio (ACWR) was defined as the acute load (7-day average) divided by the chronic load (28-day average) (Gabbett, 2016). Despite recent debate of the validity of ACWR as related to injury causation or association, here it is merely used as a quantification of an abrupt increase in load. Thus no suggestion of the usefulness of ACWR for association or prediction of injury is inherent in this study given its current state of debate in the literature (Hulin & Gabbett, 2019). Individual load measures were collated and weekly mean and weekly z-score (current week's mean – season weekly mean / SD of season weekly mean) were calculated. Group mean and z-score for load measures were mapped across the season and the initial three weeks were removed for athlete familiarization and training adaptation. The highest consecutive three weeks were identified as a higher load profile. Three consecutive weeks with the least week to week change and z-scores nearest to 0 were identified as a normal load profile. Three consecutive weeks with the largest week-to-week increases were identified as the spike load profile.

Postural Control

Postural control measures of single-leg balance and landing were collected on a 1000 Hz (9260AA6, Kistler Instruments, Winterthur, Switzerland) force plate and data were processed using commercially available software (SpartaTrac, Menlo Park, USA). Data collection occurred between 8:00-10:00am on the first training day of the week with no prior activity. Testing was performed in a secluded corner of the training facility and athletes wore team-provided training apparel with shoes removed. Data were coded for dominant (D) and non-dominant (ND) leg, based on preferred kicking leg.

Single-leg balance was assessed while participants stood on one leg with eyes closed and hands on hips. Two 20s trials were performed on each leg in alternating fashion, starting with the right leg. Trials were discarded and repeated where participants lost balance, removed hands from hips, or touched the non-stance leg off the force plate. Measures of sway velocity (SV) were calculated by dividing total displacement (cm) of the center of pressure (COP) by the duration of the trial (s). The mean of two trials on each leg yielded measures of sway velocity ($cm \cdot s^{-1}$) on the dominant (SV-D) and non-dominant (SV-ND) legs. The reliability of single-leg balance methods has been previously reported for SV-ND (CV=12%) and SV-D (CV=9%) (Troester et al., 2018).

Single-leg landing was assessed following a double leg jump from 1m from the center of the force plate. Participants were instructed to jump as high as possible and stick and hold the landing on one leg. Three trials were performed on each leg in alternating fashion, starting with the right leg. Trials were discarded and repeated if the landing foot moved after contact with the force plate or if the opposite foot touched down. Measures were produced for relative peak landing force ($N \cdot kg^{-1}$), relative landing impulse ($N \cdot s \cdot kg^{-1}$) across 200ms post-contact (Madigan & Pidcoe, 2003), and time to stabilization (s) (force equalized within 5% of baseline) (Colby, Hintermeister, Torry, & Steadman, 1999). The mean of three trials on dominant and non-dominant legs yielded measures of peak force (PF-D, PF-ND), impulse (IMP-D, IMP-ND), and time to stabilization (TTS-D, TTS-ND). The reliability of single-leg landing methods has been previously reported for PF-ND (CV=14%), PF-D (CV=12%), IMP-ND (CV=8%), IMP-D (CV=7%), TTS-ND (CV=13%), and TTS-D (CV= 21%) (Troester et al., 2018).

Statistical Analyses

To determine the differences in PC measures within and between accumulated load profiles, general linear models were used with post-hoc tests to differentiate when load differed between weeks. Differences in training load and PC measures were compared between profiles using a 2-way (profile x time) ANOVA with repeated measures. The Shapiro-Wilk test and Mauchly's test of sphericity were used to check data for normality and where the Mauchly's test was significant (p <0.05) epsilon values <0.75 dictated the use of a Greenhouse-Geisser correction while values >0.75 dictated the use of the Huynh-Feldt correction. Where significant effects were detected, a Bonferroni's post hoc test was used to detect differences between load profiles while one-way ANOVA were used to determine differences between weeks within load profiles with Cohen's *d* ES and 95% confidence intervals (CI) used to express magnitude of difference. Descriptive data is expressed as mean ± SD and analysis was performed using SPSS statistics software version 22 (Chicago, IL) with significance set at $p < 0.05$. Significance was set at p < 0.05.

RESULTS

Training Load

Training load measures across the three weeks of the three different load profiles are presented in Figure 1. Two-way repeated measures ANOVA revealed significant effects for load profile and weeks (p = 0.001 – 0.035; η^2 = 0.10 – 0.78) for all load measures, as well as significant interactions between load profile and weeks (p = 0.001-0.018; η^2 = 0.11 – 0.60) for all measures except 28 Day TD (p = 0.16; η^2 = 0.05). Further analysis revealed that acute loads (7-days) were greater in the higher load profile than the normal load profile for sRPE-TL (p = 0.001; ES = 0.73±0.22), TD (p = 0.001; ES = 0.89±0.24), and HSR (p = 0.001; ES = 0.96±0.26). In the spike load profile, acute load increased across all weeks for sRPE-TL and TD (p = 0.001; ES = 0.76-1.27) and in week 3 for HSR (p = 0.001; ES = 1.63±0.32).

Insert Figure 1 Near here

Chronic loads (28 days) in the higher load profile were significantly greater than normal and spike profiles for sRPE-TL, TD, and HSR (p = 0.001; ES = 1.03±0.25) while chronic TD in the normal load profile was greater than the spike profile (p = 0.04; ES= 0.68±0.21). Chronic loads were not significantly different across weeks within load profiles ($p > 0.05$) except for an increase in sRPE-TL in week 2 in the higher load profile (p = 0.001; ES = 0.54±0.28) and in week 3 for the spike load profile (p = 0.001; ES = 0.61±0.26).

ACWR for sRPE-TL, TD, and HSR were significantly greater in the spike load profile than normal and higher load profiles (p = 0.001-0.013; ES = 1.24-1.66) with significant increases across all weeks for sRPE-TL and TD (p = 0.001-0.022; ES = 0.68-1.53) and a significant increase in week 3 for HSR (p = 0.001; ES = 1.42±0.36).

Postural Control

Mean and SD for PC measures for three different load profiles across three weeks are presented in Figure 2. Significant effects of load profile on IMP-ND (p = .005; η^2 = .33) and IMP-D (p = .001; η^2 = .31) were evident, with significantly lower values for IMP-ND and IMP-D under normal load profiles than spike (p = 0.004; ES = 0.21±0.12 and p = 0.041; ES = 0.28±0.23, respectively) and higher (p = 0.006; ES = 0.26±0.14 and p = 0.001; ES = 0.20±0.10, respectively) profiles. Significant load profile x week interactions were identified for PF-ND (p = .004; η^2 = .11), IMP-ND (p = .001; η^2 = .23), and IMP-D (p = .01; η^2 = .10). Post-hoc analysis revealed that for all three measures, values decreased across weeks in the spike load profile, while increased across weeks in the higher load profile and were not significantly changed in the normal load profile (p > 0.05). Of note, no significant effects or interactions were observed for SL balance SV (p > 0.05) for within or between profile changes.

Insert Figure 2 Near Here

DISCUSSION

During a professional rugby union season, three distinct load profiles representing normal, spike, and higher accumulated loads were identified. These differing profiles resulted in increased single-leg landing measures of IMP and PF in higher and spike load profiles, but no significant effects for stability measures of single-leg balance SV or single-leg landing TTS. While speculative, the significant load profile by week interactions for impulse may indicate the development of divergent landing strategies during the higher and spiked load profiles. In particular, decreased impulse across weeks in the spike load profile may represent a symptom of maladaptation to this load profile, while increased impulse measures in the higher load profile may represent tolerance of the higher chronic loads.

Despite previous evidence of acute post-exercise impairment of single-leg landing IMP and PF (Brazen et al., 2010; Madigan & Pidcoe, 2003; Pau et al., 2016), such studies lack description of ongoing accumulated load profiles evident in ecologically valid training programs in applied sport settings (Cross et al., 2016). In our study, we found IMP on both legs was greater in the spike and higher load profiles compared to the normal load profile with a progressive decrease in IMP with spikes in accumulated load and progressively increasing IMP in the higher load profile. Reports of lag time in anticipatory muscle activation and altered landing strategy that utilizes greater relative contribution of the hip and trunk to absorb landing forces under fatigue could explain the decreasing trend of landing IMP in the spike load profile (Coventry, O'Connor, Hart, Earl, & Ebersole, 2006). Conversely, increasing IMP in the higher load profile may indicate increased stiffness (James, Scheuermann, & Smith, 2010) resulting from adaptation to high acute and chronic loads across repeated weeks of exposure (Spurrs, Murphy, & Watsford, 2003). This may be supported by reports of adaptation to accumulated plyometric loads as evidenced by improved running economy and increased musculotendinous stiffness following 6 weeks of plyometric training (Spurrs et al., 2003). Consequently, the increase of IMP in the higher load profile could represent a stiffer landing strategy, while the decreasing trend in the spike load profile could represent a negative adaptation to load, representative of accumulated NMF (Gabbett, 2016). Given the interest in the role of accumulated load on fatigue and preparation (16), this study provides insight into altered landing strategies employed with different 3-weekly accumulated load profiles (Coventry et al., 2006).

Similar to landing, there is evidence of the acute post-exercise response of balance measures to indicate fatigue (Clarke et al., 2015; Pau, Ibba, & Attene, 2014), but no evidence for the responsiveness of balance measures to different accumulated load profiles. The current results suggest that SV was not responsive to different accumulated load profiles. Previous research demonstrates the response of balance measures to various types and magnitudes of load including small to moderate (ES = 0.25-0.75) impairment of SV immediately following a soccer match, Canadian football game simulation, and treadmill running protocols (Clarke et al., 2015; Pau et al., 2016; Steib, Hentschke, Welsch, Pfeifer, &

Zech, 2013). The lack of differences revealed in the current investigation, alongside previous evidence for the relatively short recovery time (3min – 36h) (Clarke et al., 2015; Fox, Mihalik, Blackburn, Battaglini, & Guskiewicz, 2008) may mean that single-leg balance may not respond to accumulated load. While the dynamic landing tasks in the current investigation showed responsiveness to different load profiles, static balance tasks may not be dynamic and complex enough PC tasks to differentiate varying accumulated load profiles (Zemkova, 2009).

Despite the novel findings regarding landing and balance PC responses to differing load profiles, several limitations of the current study must be considered. Data are the result of weekly monitoring in a competitive team setting and while distinct load profiles were identified, training and recovery were focused on optimizing athlete fitness, and performance and deliberate periods of overreaching were not assessed. Further, numerous mediating factors such as aerobic fitness and injury history that affect tolerance to accumulated load are highly individual (Windt, Zumbo, & Sporer, 2017). While this study investigated group fluctuations in PC under different load profiles, the individual response and potential mediating factors of tolerance to accumulated load require further investigation.

PRACTICAL APPLICATIONS

Single-leg landing measures of impulse may differ under spike and higher load profiles when compared to normal load profiles and may represent altered landing strategies in response to such accumulated load profiles. Alterations in landing strategy may relate to maladaptation or increased tolerance to high ACWR and high accumulated loads respectively. Single-leg balance measures did not demonstrate significant differences suggesting that more dynamic and complex PC tasks may be more sensitive to accumulated load**.** Understanding the responsiveness of PC measures to accumulates load profiles provides practitioners with necessary insight into the potential application of such measures for ongoing fatigue monitoring in applied sport settings.

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ACKNOWLEDGEMENTS

The authors would like to thank the athletes who participated in this study. No funding was obtained for the present study, and results do not constitute endorsement of any product by the authors or the NSCA.

Figure 1. Mean ± SD for acute sRPE-TL, TD, HSR (A,B,C), chronic sRPE-TL, TD, HSR (D,E,F) and acute to chronic workload ratios (ACWR) for sRPE-TL, TD, HSR ratio (G,H,I) under normal, spike, and higher load profiles.

† denotes significant effect compared to spike load profile ($p < 0.05$)

# denotes significant effect compared to higher load profile ($p < 0.05$)

* denotes significant difference between weeks within spike load profile ($p < 0.05$)

ϟ denotes significant difference between weeks within higher load profile ($p < 0.05$)

Figure 2. Mean ± SD for postural control measures on the non-dominant (ND) and dominant (D) legs for single-leg balance sway velocity (SV) (A), single-leg landing relative peak force (PF) (B), relative impulse (IMP) (C) and time to stabilization (TTS) (D) under normal, spike, and higher load profiles.

† denotes significant effect compared to normal load profile ($p < 0.05$)

$ denotes significant load profile by weeks interaction ($p < 0.05$)