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Does biologically categorised training alter the perceived exertion and neuromuscular movement profile of academy soccer players compared to traditional age-group categorisation?

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ABSTRACT

The individual response to load is multifactorial and complicated by transient temporal changes in biological maturation. The period surrounding peak height velocity exposes potentially "fragile" individuals to systematic, age-related increases in training loads. Bio-banding allows practitioners to manage the biological diversity and align training to the individual development needs . This study explores the acute impact of maturation on neuromuscular performance and perceived intensity through comparing both chronological and bio-banded training sessions. 55 male soccer players (mean ± SD; age 13.8 ± 1.4 years) were recruited from an EPPP academy. Following a warm-up and standardised sub-maximal run (30–15^{IFT}), players competed in five bouts of 5-min 6v6 small-sided games (SSGs) before repeating the standardised sub-maximal run. The sessions were repeated on three occasions with chronological SSGs and the same with bio-banded SSGs wearing foot-mounted inertial measurement units (PlayerMaker[TM]) with differential ratings of perceived exertion used to quantify internal loads. Mixed linear modelling indicated maturity-specific pre–post differences in neuromuscular response, stride length and cadence having contrasting responses pre- (reduced) and post-PHV (increased), and larger changes in post sessions stiffness for pre- (~18.6 kN·m^{-1}) and circa-PHV (~12.1 kN·m^{-1}) players. Secondly, there were small to large differences in neuromuscular response (RSI, stride length, stiffness, and contact time) and perceptions of intensity between conditions, with bio-banding generally reducing pre–post changes. Bio-banding may therefore offer a mechanism to prescribe maturity-specific training loads which may help to alleviate the impact of repeated exposure to high-intensity activity, thus reducing injury risk whilst promoting long-term player development.

KEYWORDS
Maturation; training load; bio-banding; injury risk

Highlights

- Utilising a sub-maximal running protocol (30–15^{IFT}) with foot mounted accelerometers can detect maturity specific responses to football specific training activity, which aligns with subjective perceptions of intensity.
- Chronologically derived small-sided games elicit different acute responses between players of varying maturity status, which is somewhat negated when bio-banded small-sided games are used instead.
- Bio-banding training sessions may offer practitioners a practical way of managing maturity-specific trainings load to reduce injury risk and promote long-term players development.

Introduction

The period surrounding peak height velocity (PHV) exposes potentially "fragile" individuals to systematic, age-related increases in training loads (van der Sluis et al., 2015). Temporal changes associated with the rapid growth of both soft and hard tissue observed in this period have been associated with increased injury risk in adolescent footballers, particularly apophyseal and overuse related injuries (McKay et al., 2019; Monasterio et al., 2021). The individual response to load is influenced by several factors such as tissue morphology, cross-sectional area, density, and stiffness properties

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(Kalkhoven et al., 2021) resulting in varied dose-responses amongst pubertal populations. The frequency and intensity of training schedules often limit recovery time between training sessions (i.e. <72 h) with adolescent training loads regularly superimposed on top of academic and recreational activities (Phibbs et al., 2018). Reduced recovery time and additional "stressors" (i.e. exams, academic pressure) can contribute to injury incidence and may predispose athletes to amplified injury risk (Gustafsson et al., 2017). In some academies, often only subjective internal training loads are measured (i.e. ratings of perceived exertion) (Salter et al., 2020b) which can have poor agreement between coach and player rated intensity (Macpherson et al., 2019), and may consequently complicate dose-responses interpretations. Combined, these issues make "managing" adolescent workloads complex in comparison to elite adult environments, where often training prescription is wholly controlled by experienced support staff utilising a combination of internal and external markers of training and recovery (West et al., 2020), with players of a greater anatomical, biological, and physiological stability.

Small-sided games (SSGs) are an efficient and commonly applied method to combine technical proficiency, tactical and spatial awareness, speed, agility whilst offering a conditioning stimulus (Riboli et al., 2020). The composition of SSGs can be altered by manipulating parameters including pitch-size, number of players, duration, rules, and goalkeeper inclusion to suit the objectives of the session and micro-cycle (Riboli et al., 2020). FA Guidelines (Football Association, 2012) stipulate pitch sizes for academy fixtures, with 11-a-side area per player (m^2) ranging from 187 (U13–14) to 292 m^2 (>U16) across the Youth Development Phase (YDP). Naturally, SSGs utilise tighter areas per player, with studies ranging from 52 to 128 m^2 (Fenner et al., 2016; Guard et al., 2021; Riboli et al., 2020), which significantly influences both internal and external markers of load. Typically, smaller area sizes are associated with higher physiological and perceptual responses and a concomitant increase in accelerative and high magnitude decelerative loads, but reduce high velocity running exposure (Guard et al., 2021; Riboli et al., 2020). It is common for SSGs to be performed using multiple bouts (e.g. 4–6) of shorter durations (e.g. 4–5 min) with regular recovery (i.e. 2–3 min) to facilitate the maintenance of the required intensity (Fenner et al., 2016; Guard et al., 2021; Riboli et al., 2020). Standardising the duration, dimensions, rules, and number of players offers practitioners a valid and useful tool to regulate variations in external loads to facilitate quantification of acute changes in neuromuscular performance (Rowell et al., 2018).

Transient temporal modifications in soft and hard tissue during maturation, stimulated by hormonal and anthropometrical development combined with exposure to mechanical load produces an individual stress-response matrix athletes (Salter et al., 2020a; Waugh et al., 2012). Tendon mechanical load-adaptation profiles respond to changes in load, which is also influenced by maturation related changes in body mass and force production capabilities (i.e. muscle mass and motor unit recruitment) (Waugh et al., 2012). Maturational adaptations such as fibre type composition, pennation angle, tendon size and stiffness and co-contraction directly influence the kinetic ability of adolescent athletes (Radnor et al., 2018) which ultimately influences their dynamic control and injury risk. Although the sequential development of these musculo-tendinous properties is known, the timing and tempo of these is inconsistent and therefore may result in individuals competing with peers more (or less) proficient at utilising these properties to produce/absorb forces (Radnor et al., 2018). Naturally, this has implications for talent identification, development, performance, and injury risk and should therefore be monitored and load exposure aligned appropriately.

Utilising standardised running activity as part of a training session is growing in prevalence and offers practitioners the ability to assess the status of, or changes in movement profiles of athletes (Leduc et al., 2020). The relative expense of microelectromechanical systems (MEMS) to quantify these changes is often inaccessible for academies who more commonly employ self-reported perceptions of intensity as an integral part of their load monitoring strategy (Salter et al., 2020b). Sessional ratings of perceived exertion (sRPE) are a valid and common way to monitor the psycho-physiological perceptions of intensity within soccer (Fanchini et al., 2016), and widely used in academy settings. More recently applied differentiated-RPE (i.e. breathlessness, leg muscle and cognitive/technical) may help to distinguish between central and peripheral constructs and provide insight into individual responses (Wright et al., 2020). By collating such data, coaches and practitioners can begin to recognise how the composition of training sessions can influence the stress-response and ultimately injury risk.

Bio-banding has been utilised across sport to group individuals based on biological maturation rather than chronological age, primarily for talent identification and development purposes (Cumming et al., 2017). Typically, players falling within established maturity thresholds (e.g. 88–96% of predicted adult height percentage [PAH%]) are periodically grouped together for training sessions and/or competition that supplements the age-specific programme, irrespective of their chronological age. This approach reduces the biological heterogeneity between players and allows individuals that are either pre-, mid-, or post-PHV to compete against similar counterparts, reducing any biological advantages (Cumming et al., 2017). Naturally, reducing the heterogeneity within sessions consequently smooths the inter-individual responses due to players possessing similar biological make up. Therefore, supplementing the chronological programme with bio-banded activities, may offer practitioners a feasible method to better control load exposure by manipulating the composition and frequency of high-intensity actions to preserve "at risk" athletes whilst ensuring appropriate developmental loads for those not at risk (Salter et al., 2021). Therefore, this study has two primary outcomes, (a) to explore the impact of maturity status on acute neuromuscular performance and psycho-physiological perceptions; and (b) to observe the acute effect of chronological versus bio-banded sessions on neuromuscular performance and psycho-physiological perceptions.

Methods

Participants

Fifty-five male soccer players (mean ±SD; age 13.8 ±1.4 years; stature 164.3 ±11.5 cm; body mass 52.7 ±10.3 kg; PAH% 91.3 ±5.3) were recruited from the U12–U16 age-groups of an EPPP academy (Table 1). Percentage of predicted adult height (PAH%) (Khamis & Roche, 1994) was used to determine maturity status, using self-reported parent stature corrected for over-estimation (Epstein et al., 1995). Participants were subsequently categorised as either pre-PHV (<88%; $n = 20$), circa-PHV (88–93%; $n = 19$) or post-PHV (>93%; $n = 16$). Participants were eligible to take part if they were registered with the academy, free from injury and available to take part in full training. Participants typically completed three training sessions (90 mins) and one competitive match each week. Due to the difference in movement profiles, goalkeepers were excluded from the analysis, but were permitted to participate in the sessions alongside outfield players. All participants provided written consent with parents providing written assent following ethical approval from the University of Gloucestershire ethics panel in accordance with the Declaration of Helsinki.

Procedures

Data for each group was collected over a 6-week period during normal training sessions for the academy, separated by 7-days (i.e. once weekly). Following an initial familiarisation session, three consecutive weeks of chronological SSGs were followed by three consecutive weeks of bio-banded SSGs. All data were collected at the same time of day (evening) at the same training venue using natural grass pitches in weather condition between 13 and 21°C.

At the start of each session players completed a standardised FIFA11+ (Stage 1 and 3) warm up. Players were familiar with this as part of their normal warm-up routine, which was standardised to facilitate accurate observation of the SSG intervention. Following this, players performed a standardised sub-maximal run using the audio controlled 30–15^{IFT}, with starting velocity set at 10 km·h^{-1} (Buchheit, 2008). Each 30-second shuttle across the 40 m area was separated by 15-second passive recovery with the velocity increasing by 0.5 km·h^{-1} each shuttle up to and including 12.5 km·h^{-1}. It is acknowledged that from a relative intensity perspective, these speeds are different for U12 and U16 players, however 12.5 km·h^{-1} represents 79–89% maximal aerobic speed (MAS) in these age-groups respectively (Mendez-Villanueva et al., 2012), which results in all players performing sufficiently sub-maximally and at a similar intensity. Participants were instructed to run at a consistent pace throughout and to keep in time with the audio cue. Players then competed in five bouts of 5-min 6v6 (including GK) SSG on a playing area 45×36 m (135m^2 per player), each bout separated by 2-min passive recovery. It is acknowledged that the area per player changes for competitive matches between U12 (187 m^2) and U16 (292 m^2) and that this study deliberately confined play to a tighter relative space (Football Association, 2012). These dimensions align with previous research utilising SSG type-activity (Fenner et al., 2016; Guard et al., 2021; Riboli et al., 2020, 2021) and it was deemed important to fix the area size to investigate the research question, rather than be confined by chronologically informed pitch dimensions. SSGs were supervised by age-group coaches who could verbally coach and encourage throughout. Corners and throw-ins were replaced by short passes by the nearest player and a multi-ball system was employed to keep intensity high. Where there were more than 6 players assigned to a team, these were included as "bounce" players on the periphery for both chronological and bio-banded SSGs, with rolling subs utilised throughout to keep non-playing time minimal. In some cases, there were varying numbers of bounce players (between 1 and 4) which may have influenced the loads experienced by players (i.e. more bounce players result in slightly less playing time per player). Chronological (week 1–3) and bio-banded (week 4–6) teams were selected by coaches

Table 1. Mean ± SD anthropometrical and predicted adult height data for U12–U16 age groups.

Characteristic	U12 ($n = 14$)	U13 ($n = 14$)	U14 ($n = 13$)	U15 ($n = 7$)	U16 ($n = 7$)
Age (years)	12.1 ± 0.3	13.2 ± 0.2	14.0 ± 0.3	15.2 ± 0.3	16.3 ± 0.1
Stature (cm)	153.6 ± 6.8	157.7 ± 6.2	169.2 ± 7.6	175.1 ± 6.5	177.9 ± 8.1
Body Mass (kg)	45.6 ± 7.2	45.6 ± 5.1	54.1 ± 7.4	61.7 ± 5.6	67.7 ± 7.6
Sitting Height (cm)	77.1 ± 3.3	78.8 ± 2.9	84.3 ± 4.1	88.9 ± 3.0	100.7 ± 18.5
PAH (%)	85.6 ± 19.9	88.1 ± 1.9	93.0 ± 2.4	97.2 ± 0.8	99.2 ± 1.2

using data provided by the research team (i.e. PAH%) to ensure that an even distribution of playing positions and quality across the 6-a-side teams. The U15 and U16 squads routinely trained together due to carrying lower numbers of players, therefore this was maintained for the SSGs. Following the SSGs, same sub-maximal running protocol was repeated to measure acute changes in neuromuscular movement patterns.

To examine movement profiles a foot-mounted inertial measurement unit (IMU) housed within custom silicone straps was used (PlayerMaker^{TM}, Tel Aviv, Israel). The device, located on the lateral aspect of the calcanei, includes 1000 Hz IMU microprocessor, and comprises of a triaxial 16 g accelerometer and triaxial gyroscope (MPU-9150, InvenSense, California, USA) (Waldron et al., 2021). The PlayerMaker^{TM} system calculates whole-body accelerometery-based metrics which permits detection of the orientation and translation of the participants limbs during gait cycles and through algorithms can detect heel strike, toe-off, zero-velocity and non-gait patterns (e.g. ball contact). This is then computed through a Kalman filter to provide locomotor specific metrics. Previously, locomotion data has been limited to laboratory-based research through the use of movement analysis or force plate assessments but the contemporary and sophisticated IMU with the PlayerMaker^{TM} device has facilitated much needed applied insights to locomotor movement (Verheul et al., 2020). The efficacy of the time-motion properties associated with PlayerMaker^{TM} compared to more traditional trunk mounted accelerometers has been reported in previous work (Waldron et al., 2021). As a result, mean ground contact time, flight time, stride length and cadence were calculated for the pre–post sub-maximal 30–15^{IFT} and interpreted to examine adaptations in locomotion owing to neuromuscular responses. Data is subsequently synchronised to the manufactures cloud-based software system and exported to Excel (Microsoft, Redmond, USA) for analysis (Waldron et al., 2021). Reactive Strength Index (RSI) was calculated using equation 1 from data derived from PlayerMaker^{TM} units during the sub-maximal 30–15^{IFT}. Additionally, absolute, and relative leg stiffness were then measured from contact times and flight times. Absolute leg stiffness (kN·m^{-1}) was calculated using equation 2 where K_{leg} refers to leg stiffness, M is total body mass, Tc refers to ground contact time and Tf is equal to flight time. To account for the influence of mass on leg stiffness and leg length on mechanical properties of locomotion between participants, absolute values of leg stiffness were divided by body mass and leg length to provide a dimensionless value of relative leg stiffness (De Ste Croix et al., 2017).

$$\mathrm{RSI} = \mathrm{jumpheight\ (m)/\ ground\ contact\ time\ (s)} \quad (1)$$

$$K_{leg} = [M{*}\pi(T_f + T_c)]/T_{c2}[(T_f + T_c/\pi) - (T_c/4)] \quad (2)$$

Psycho-physiological perceptions of intensity were measured using sessional rating of perceived exertion (sRPE) alongside differential rating of perceived exertion (d-RPE) for breathlessness (RPE-B), leg muscle exertion (RPE-L) and cognitive/technical (RPE-T) demands. Players individually provided their rating in arbitrary units (Au) using the centiMax scale (CR100®) (Borg & Borg, 2002) with verbal anchors to provide confidential responses free from conformation bias within 15-mins post-session (Wright et al., 2020).

Data analysis

Baseline data was visually inspected through Q-Q plots of the raw data. All data were approximately normal except for flight time which showed a slight deviation at each tail. To analyse the impact of maturation (model 1) and then chronological age or biologically categorised matches (model 2) mixed linear modelling (SPSS v25 IBM Corp) was used to examine differences between fixed effects (model 1: maturity status; model 2: categorisation), with player identity included as a random effect (intercept; variance components) to account for repeated observations within players. Raw change scores (i.e. post session RSI – pre session RSI) of each variable were computed and used the dependant variable, with mean centred baseline pre-session values used as a covariate to account for individual difference and regression to the mean. Secondly, to determine the differences in psycho-physiological perceptions (i.e. sRPE) of intensity between maturity groups and categorised SSGs a between-groups ANOVA was conducted. Effects were deemed to be statistically significant at a Bonferroni adjusted alpha level of $P < 0.05$ with data presented as means (± SD) with 95% confidence intervals (CI) (Hopkins et al., 2009), alongside Cohens *d* effect sizes (i.e. psycho-physiological perceptions) using standard published thresholds (Cohen, 1992).

Results

Anthropometric characteristics are provided in Table 1. Sub-group analysis of the chronologically categorised SSGs demonstrates that there are moderate to large increases in absolute stiffness across all maturity groups during the session (Table 2). Additionally, the pre-PHV and Circa-PHV groups experience a small reduction in stride length with Circa-PHV having a simultaneous small reduction in cadence. Both the pre-PHV and Circa-PHV reduce their stride length post session by ~4.3 cm whilst the post-PHV group increase theirs by 0.69 cm, indicating a between-group difference of >5 cm. A similar outcome is observed between Circa-PHV cadence reduction (−3.93 s/m) and post-PHV cadence increase (1.53 s/m), resulting in a between-group difference of 5.4 s/m (Table 2). Additionally, the post-session increases in absolute stiffness for post-PHV (12.16 $kN{\cdot}m^{-1}$) is approximately a third of the pre- and circa-PHV groups (~18.6 $kN{\cdot}m^{-1}$), with relative stiffness reducing in pre-PHV (−1.07 $kN{\cdot}m^{-1}$) but increasing post-PHV (0.83 $kN{\cdot}m^{-1}$).

Table 3 illustrates noteworthy (small to moderate) differences between chronologically and bio-banded SSGs for several neuromuscular variables, including RSI, contact time, absolute stiffness, stride length and cadence. In general (except for cadence and relative stiffness) bio-banded categorisation reduced the magnitude of within-session change in neuromuscular performance. Although effect sizes illustrate small to large differences in several markers of performance, only absolute stiffness, stride length and cadence produced statistically significant differences ($P = <0.05$) (Table 3). Players almost unanimously perceived bio-banded training sessions to be less intense across both sRPE and all dRPE constructs, but only RPE-T (post-PHV) showed a significant statistical difference (Table 4), with all responses being categorised as "Moderate" or "Heavy" on the centiMAX CR100 scale. There were consistently small to moderate reductions in sRPE, RPE-B, RPE-L and RPE-T for the pre-PHV and post-PHV with the circa-PHV group reporting trivial differences or a small increase in RPE-L.

Discussion

This study intended to explore the within-session impact of maturity status on neuromuscular performance and psycho-physiological response, whilst observing the effect of standardising both chronological and bio-banded training sessions. Primary findings indicate that the introduction of bio-banded training sessions does minimise the decrement in neuromuscular and locomotor markers and ratings of perceived intensity for players across the maturation spectrum.

Table 2 indicates that despite being exposed to the same training session, players experience different stress-responses according to their maturity status. For example, all groups experienced a moderate (pre-PHV) or large (mid and post-PHV) within-session increase in absolute stiffness. Yet the post-PHV group saw an increase only two-thirds that of pre- and circa-PHV. The elevated but comparatively smaller pre–post session change in absolute stiffness in post-PHV players is likely explained by tendon stiffness maturity, as tendons reach adult values around PHV (Radnor et al., 2018; Tumkur Anil Kumar et al., 2021) suggesting that post-PHV players may tolerate mechanical loads better than less mature counterparts. These moderate (pre-PHV) to large (circa-PHV) changes in post-session stiffness values support the notion that less mature individuals have limited "energy-saving" mechanisms and therefore experience greater reductions in performance which may heighten injury risk (Tumkur Anil Kumar et al., 2021). Additionally, less mature individuals may not have the ability to create optimal tendon stiffness via appropriate muscle activation or motor unit recruitment, causing the muscle to yield under force (Radnor et al., 2018). Combined, muscle yielding, and elevated levels of lower limb stiffness are speculated to be associated with an higher risk of overuse, bone-related injuries which aligns with injury epidemiology for adolescent athletes (Read et al., 2018). Mechanistically, it is proposed that increased stiffness leads to amplified loading rates and peak forces and subsequently augmented shock to the lower extremity, which ultimately increases the mechanical stress on bony structures and musculotendinous unit, initiating a causal pathway for injury (Kalkhoven et al., 2021). This mechanistic theory links to the work of Ratel (2016) whereby less mature individuals may experience more central fatigue which compromises the neuromuscular system to a greater extent than peripheral fatigue. Although tentative findings, this may offer potential insight into the higher relative prevalence of musculotendinous and apophyseal injuries observed during maturation in academy soccer, particularly in the U12–U14 age-groups (Read et al., 2018). The changes in stiffness outlined above, may also contribute to the post-session stride length reduction for pre- and circa-PHV players (~4.3 cm) and increased (~0.7 cm) for post-PHV

Table 2. Pre–post differences (95% confidence interval) in neuromuscular markers for each maturity group with significance (P) and effect size (*d*).

	Pre-PHV			Circa-PHV			Post-PHV		
Variable	Pre–Post Diff (95% CI)	*P-value*	Cohens *d*	Pre–Post Diff (95% CI)	*P-value*	Cohens *d*	Pre–Post Diff (95% CI)	*P-value*	Cohens *d*
RSI	−0.029 (−0.18–0.12)	0.99	−0.05	−0.087 (−0.29–0.11)	0.99	−0.12	−0.06 (−0.19–0.07)	0.99	−0.13
Contact Time (s)	0.028 (−0.03–0.09)	0.99	0.15	0.001 (−0.07–0.07)	0.99	0.01	0.01 (−0.04–0.06)	0.99	0.06
Flight Time (s)	−0.02 (−0.05–0.01)	0.76	−0.19	0.001 (−0.03–0.03)	0.99	0.01	−0.02 (−0.04–0.01)	0.58	−0.21^{S}
Absolute Stiffness (K_{leg})	18.69 (12.8–24.5)	<0.001	1.01^{L}	18.65 (11.14–26.2)	<0.001	0.78^{M}	12.16 (6.72–17.62)	<0.001	0.71^{M}
Relative Stiffness (R_{leg})	−1.07 (−6.87–4.74)	0.99	−0.06	0.02 (−7.44–7.48)	0.99	0.001	0.83 (−4.57–6.25)	0.99	0.05
Stride Length (cm)	−4.32 (−8.12 to −0.51)	0.01	−0.31^{S}	−4.31 (−8.66–0.05)	0.055	−0.27^{S}	0.69 (−3.88–2.50)	0.99	−0.06
Cadence (s/m)	2.63 (−1.32–6.59)	0.72	0.18	−3.93 (−7.29–1.14)	0.40	−0.20^{S}	1.53 (−1.79–4.85)	0.99	0.12

^{S}, small effect size; ^{M}, moderate effect size, ^{L}, large effect size.

players. Higher levels of stiffness are associated with a more efficient stretch-reflex, which can lead to shorter contact times and better force production capabilities (Radnor et al., 2018). This may explain why post-PHV players slightly increased stride length, whilst pre- and circa-PHV reduced theirs, likely owing to a greater post-session decrement in force production capacity. The trivial changes in contact and flight times for all groups limit this notion to speculation, with further exploration required to confidently support claims.

Bio-banded training sessions produced significant differences in pre–post response for absolute stiffness, stride length and cadence, whilst offering small to large changes in RSI and contact time (Table 3). The only marker to offer greater change (trivial) in the bio-banded condition was relative stiffness, which considers both limb length and body mass within the calculation, thus catering for maturation to some extent (De Ste Croix et al., 2017). From a load management point of view, these relatively smaller pre–post changes offer promising early indications that bio-banding may help to stabilise the negative stress-response for players across maturity groups. Of all markers, the impact on absolute stiffness was most notable, which may have indirectly (positively) impacted contact time, RSI, and stride length to stimulate less "shock" to the athletes and therefore ultimately moderating injury risk. Not only do these changes indicate that acute changes in neuromuscular performance are stabilised, but they also surmise that reduced pre–post change performance requires less recovery time ahead of the next session (Kellmann et al., 2018). Theoretically, these differences could be attributable to the changes in technical demands during bio-banded activity (Abbott et al., 2019; Lüdin et al., 2021), whereby players were more evenly matched physically and therefore able to express themselves technically without the large biological diversity apparent in chronological SSGs. Evidence indicates that bio-banded activity involves less long-range passing (particularly for pre- and circa-PHV) and dribbling, and more shots on goal with limited differences in external load profiles between chronological and bio-banded games (Abbott et al., 2019; Lüdin et al., 2021). This may result in less emphasis on physical attributes and offer a reduced dose–response, which may be advantageous in some, but not all sessions as exposure to match-specific loads are important for injury prevention. Although these findings are novel, and therefore conscious of overstating findings, but this could potentially reduce the likelihood of accumulative fatigue, which is associated with the high prevalence of gradual onset overuse type injury within the adolescent soccer population (Williams et al., 2017). Thus, the inclusion of bio-banded training sessions may offer coaches a useful tool to help moderate the stress-response of players in varying stages of maturation simultaneously.

Table 3. Within participant pre–post change values (Mean ± SD) for chronological and bio-banded training sessions with mean difference presented with 95% confidence intervals and effect size (d) for neuromuscular markers.

Variable	Chronological SSG	Bio-banded SSG	Mean Difference*(95% CI)*	*P*-value	Cohens *d*
RSI	−0.54 ± 0.30	−0.43 ± 0.23	−0.11 *(−0.10–0.79)*	0.818	0.39^{S}
Contact Time (s)	0.17 ± 0.11	−0.02 ± 0.33	*0.02 (−0.01–0.05)*	0.189	0.88^{L}
Flight Time (s)	−0.00 ± 0.08	−0.00 ± 0.05	*−0.00 (−0.02 to −0.02)*	0.677	0.01
Absolute Stiffness (K_{leg})	14.41 ± 19.72	−1.66 ± 4.86	*16.07 (10.94–21.21)*	0.000*	1.01^{L}
Relative Stiffness (R_{leg})	−0.26 ± 21.4	−2.29 ± 7.46	2.03 (−3.65–7.71)	0.481	0.11
Stride Length (cm)	−2.69 ± 7.97	1.96 ± 14.57	−4.66 (−7.93 to −1.39)	0.005*	0.43^{M}
Cadence (s/m)	0.69 ± 8.41	−2.84 ± 7.02	3.54 (1.03–6.05)	0.006*	0.44^{M}

^{S}, small effect size; ^{M}, moderate effect size, ^{L}, large effect size.

Table 4. Ratings of perceived exertion (Au) for chronological and bio-banded SSG sessions with mean difference and 95% confidence intervals (95% CI) and effect size (d).

Variable	Maturity group	Chronological SSG (Mean ± SD)	Bio-banded SSG (Mean ± SD)	Mean difference [AU]*(95% CI)*	*P*-value	Cohens *d*
sRPE	Pre-PHV	47.1 ± 12.3	40.5 ± 10.3	6.6 *(−0.7–13.6)*	0.139	0.56[M]
	Circa-PHV	44.1 ± 16.1	40.7 ± 10.5	3.4 *(−5.3–11.9)*	0.993	0.23[S]
	Post-PHV	50.9 ± 12.2	46.9 ± 11.2	3.95 *(−3.4–11.3)*	0.863	0.33[S]
RPE-B	Pre-PHV	43.5 ± 13.7	37.5 ± 12.5	5.9 *(−1.5–13.4)*	0.292	0.45[S]
	Circa-PHV	37.5 ± 15	37.6 ± 14.2	−0.1 *(−9.1–8.9)*	0.999	0.01
	Post-PHV	46.1 ± 11.1	43.1 ± 11.6	2.84 *(−4.7–10.4)*	0.994	0.26[S]
RPE-L	Pre-PHV	45.4 ± 15.4	38.3 ± 11.7	7.1 *(−0.2–14.2)*	0.078	0.51[M]
	Circa-PHV	39.8 ± 10.9	43.1 ± 10.9	−3.2 *(−11.9–5.44)*	0.993	0.30[S]
	Post-PHV	47.6 ± 10.1	44.4 ± 11.2	3.1 *(−4.2–10.6)*	0.975	0.31[S]
RPE-T	Pre-PHV	39.3 ± 11.9	35.3 ± 14.5	4.1 *(−3.3–11.3)*	0.826	0.31[S]
	Circa-PHV	37.6 ± 12.5	36.7 ± 14.8	0.9 *(−7.8–9.7)*	0.999	0.07
	Post-PHV	43.8 ± 11.5	35.2 ± 13.4	8.6 *(1.14–16.1)*	0.016*	0.71[M]

SD, standard deviation; 90% CI, 90% confidence intervals; PHV, peak height velocity; sRPE, sessional rating of perceived exertion; RPE-B, breathlessness; RPE-L, leg muscle exertion; RPE-T, technical/cognitive exertion.
*Denotes significance $p < 0.05$; [S], small effect size; [M], moderate effect size.

RPE was generally lower during bio-banded training sessions (Table 4), which opposes previous work (Abbott et al., 2019; Lüdin et al., 2021). Pre- and post-PHV players rated all components of differential RPE less intense (small or moderate) when bio-banded SSGs were used, versus chronologically aged where perceptions of intensity were less homogenic. Circa-PHV players showed a similar trend for sRPE and RPE-T, but rated RPE-L more intense (small) in bio-banded sessions. These differences are likely influenced by the reduced biological diversity within these sessions resulting in perceived lower relative intensities. For example, the pre-PHV group rated every RPE construct lower in bio-banded sessions, likely because this approach eases the emphasis on physical characteristics and offers opportunity for individuals to flourish technically and tactically (Abbott et al., 2019; Cumming et al., 2017; Lüdin et al., 2021). Similarly, the post-PHV group rated the bio-banded sessions relatively lower intensity than chronologically categorised sessions, but comparatively higher than both the pre- and circa-PHV groups for all constructs. Therefore, although grouping the most mature players together reduces perceived intensity, players still consistently rate these sessions higher than pre- circa-PHV players. Again, from a load management perspective these data illustrate that using bio-banded training sessions can reduce the perceived stress-response for players of all maturities and offer a mechanism by which coaches can modify training stimulus, which may be a useful to manage chronic training loads. Importantly, these self-reported markers of internal load concur with more objective data provided by the PlayerMaker™ IMUs, in that locomotor and neuromuscular responses align with perceptions of intensity. This is important based on the limited availability of these IMU devices to academy settings due to cost and resource implications and thus offer insightful additions to the research which needs to be explored further using similar contemporary methods.

Due to the contemporary nature of the technology used, there is a need to validate PlayerMaker™ within adolescent populations in future research. However, previous evidence supports the use of triaxial accelerometery to assess whole body loads such as stiffness to infer neuromuscular fatigue and/or performance (Verheul et al., 2020) with the time-motion efficacy of PlayerMakerTM devices supported through early research (Waldron et al., 2021). All players were from the same soccer academy which limit the generalisation of these findings to the wider soccer network, particularly those with a differing socio-economic and ethnic diversity. The research design (multiple repetitions of each condition) was intended to accommodate some missed sessions; however, these were slightly more prevalent than envisaged (i.e. injury, absence, covid-19) which may have limited the outcomes of the study. Unfortunately, this is one of the primary barriers to applied adolescent research and therefore these conclusions should be considered exploratory findings, with follow-up work on this line required. Practically, it was occasionally difficult to maintain the 135 m^2 area per player specified in the methodology. Due to the number of players at each session, coaching needs, and logistics this did vary slightly on occasions but not deemed to have significant impact on the outcomes explained. Finally, it is acknowledged that the use of natural turf instead of artificial pitches may have influenced ground contact quality in variable weather conditions and therefore neuromuscular metrics. Whilst increasing ecological validity, we accept that subtle changes in ground condition may impact reliability of neuromuscular values and impact self-reported perceptions of intensity. However, all changes reported reflect pre–post session changes in performance and would have been completed on the same ground condition each day.

Practical applications

Current chronologically categorised development pathways permit significant within-session biological diversity, which harvests complexity around the management of individual stress-responses. Based on the high relative prevalence of non-contact, growth-related injuries within this population, it is important that technical, medical and support staff adopt a proactive approach to load management for all players. Although tentative based on study limitations, this study illustrates the potential positive impact that bio-banded training may have on load management for players. Bio-banded sessions elicit a smaller pre–post decrement in neuromuscular performance, particularly on metrics associated with injury risk with similar reduced ratings of perceived exertion. Findings also identify that there were small to moderate differences in the way in which maturity groups responded to the sessions, which advocates a maturity-specific approach to load exposure. Based on this, practitioners should actively seek opportunities to integrate bio-banded training activity alongside chronologically categorised sessions within their training schedules. Bio-banding may alleviate the consistent stress placed on less mature players as part of age-derived sessions without compromising the development of those more mature and able to tolerate greater workloads. In doing so, coaches can up- or down-regulate bio-banded session composition and intensities as desired to help ease the turbulent period through maturation for talented young soccer players.

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References

Abbott, W., Williams, S., Brickley, G., & Smeeton, N. J. (2019). Effects of Bio-banding upon physical and technical performance during soccer competition: A preliminary analysis. *Sports*, *7*(8), 193. https://doi.org/10.3390/sports7080193

Borg, E., & Borg, G. (2002). A comparison of AME and CR100 for scaling perceived exertion. *Acta Psychologica*, *109*(2), 157–175. https://doi.org/10.1016/S0001-6918(01)00055-5

Buchheit, M. (2008). The 30-15 intermittent fitness test: Accuracy for individualizing interval training of young intermittent sport players. *Journal of Strength and Conditioning Research*, *22*(2), 365–374. https://doi.org/10.1519/JSC.0b013e3181635b2e

Cohen, J. (1992). Statistical power analysis. *Current Directions in Psychological Science*, *1*(3), 98–101. https://doi.org/10.1111/1467-8721.ep10768783

Cumming, S. P., Lloyd, R. S., Oliver, J. L., Eisenmann, J. C., & Malina, R. M. (2017). Bio-banding in sport: Applications to competition, talent identification, and strength and conditioning of youth athletes. *Strength and Conditioning Journal*, *39*(2), 34–47. https://doi.org/10.1519/SSC.0000000000000281

De Ste Croix, M. B. A., Hughes, J. D., Lloyd, R. S., Oliver, J. L., & Read, P. (2017). Leg stiffness in female soccer players: Intersession reliability and the fatiguing effects of soccer-specific exercise. *Journal of Strength and Conditioning Research*, *31*(11), 3052–3058. https://doi.org/10.1519/JSC.0000000000001715

Epstein, L. H., Valoski, A. M., Kalarchian, M. A., & McCurley, J. (1995). Do children lose and maintain weight easier than adults: A comparison of child and parent weight changes from Six months to Ten years. *Obesity Research*, *3*(5), 411–417. https://doi.org/10.1002/j.1550-8528.1995.tb00170.x

Fanchini, M., Ferraresi, I., Modena, R., Schena, F., Coutts, A. J., & Impellizzeri, F. M. (2016). Use of the CR100 scale for session rating of perceived exertion in soccer and Its interchangeability With the CR10. *International Journal of Sports Physiology and Performance*, *11*(3), 388–392. https://doi.org/10.1123/ijspp.2015-0273

Fenner, J. S. J., Iga, J., & Unnithan, V. (2016). The evaluation of small-sided games as a talent identification tool in highly trained prepubertal soccer players. *Journal of Sports Sciences*, *34*(20), 1983–1990. https://doi.org/10.1080/02640414.2016.1149602

Guard, A. N., McMillan, K., & MacFarlane, N. G. (2021). The influence of relative playing area and player numerical imbalance on physical and perceptual demands in soccer small-sided game formats. *Science and Medicine in Football*, *6*(2), 221–227. https://doi.org/10.1080/24733938.2021.1939408

Gustafsson, H., Sagar, S. S., & Stenling, A. (2017). Fear of failure, psychological stress, and burnout among adolescent athletes competing in high level sport. *Scandinavian Journal of Medicine & Science in Sports*, *27*(12), 2091–2102. https://doi.org/10.1111/sms.12797

Hopkins, W., Marshall, S. W., Batterham, A. M., & Hanin, J. (2009). Progressive statistics for studies in sports medicine and exercise science, Medicine & Science in Sports & Exercise, *41*(1), 3–13. https://doi.org/10.1249/MSS.0b013e31818cb278

Kalkhoven, J. T., Watsford, M. L., Coutts, A. J., Edwards, W. B., & Impellizzeri, F. M. (2021). Training load and injury: Causal pathways and future directions. *Sports Medicine*, *51*(6), 1137–1150. https://doi.org/10.1007/s40279-020-01413-6

Kellmann, M., Bertollo, M., Bosquet, L., Brink, M., Coutts, A. J., Duffield, R., Erlacher, D., Halson, S. L., Hecksteden, A., Heidari, J., Kallus, K. W., Meeusen, R., Mujika, I., Robazza, C., Skorski, S., Venter, R., & Beckmann, J. (2018). Recovery and performance in sport: Consensus statement. *International Journal of Sports Physiology and Performance*, *13*(2), 240–245. https://doi.org/10.1123/ijspp.2017-0759

Khamis, H. J., & Roche, A. F. (1994). Predicting adult stature without using skeletal Age: The khamis-roche method. *Pediatrics*, *94*(4), 504–507.

Leduc, C., Lacome, M., & Buchheit, M. (2020). *The use of standardised runs (and associated data analysis) to monitor neuromuscular status in team sports players: A call to action*. 5.

Lüdin, D., Donath, L., Cobley, S., & Romann, M. (2021). Effect of bio-banding on physiological and technical-tactical key performance indicators in youth elite soccer. *European Journal of Sport Science*. Available online at https://doi.org/10.1080/17461391.2021.1974100

Macpherson, T. W., McLaren, S. J., Gregson, W., Lolli, L., Drust, B., & Weston, M. (2019). Using differential ratings of perceived exertion to assess agreement between coach and player perceptions of soccer training intensity: An exploratory investigation. *Journal of Sports Sciences*, *37*(24), 2783–2788. https://doi.org/10.1080/02640414.2019.1653423

McKay, C. D., Cumming, S. P., & Blake, T. (2019). Youth sport: Friend or foe? *Best Practice & Research Clinical Rheumatology*, *33*(1), 141–157. https://doi.org/10.1016/j.berh.2019.01.017

Mendez-Villanueva, A., Buchheit, M., Simpson, B., & Bourdon, P. (2012). Match play intensity distribution in youth soccer. *International Journal of Sports Medicine*, *34*(02), 101–110. https://doi.org/10.1055/s-0032-1306323

Monasterio, X., Gil, S. M., Bidaurrazaga-Letona, I., Lekue, J. A., Santisteban, J. M., Diaz-Beitia, G., … Larruskain, J. (2021). The burden of injuries according to maturity status and timing: A two-decade study with 110 growth curves in an elite football academy. *European Journal of Sport Science*, *13*(1-11), 1–21. https://doi.org/10.1080/17461391.2021.2006316

Phibbs, P. J., Jones, B., Roe, G., Read, D., Darrall-Jones, J., Weakley, J., Rock, A., & Till, K. (2018). The organised chaos of English adolescent rugby union: Influence of weekly match frequency on the variability of match and training loads. *European Journal of Sport Science*, *18*(3), 341–348. https://doi.org/10.1080/17461391.2017.1418026

Radnor, J. M., Oliver, J. L., Waugh, C. M., Myer, G., Moore, I. S., & Lloyd, R. S. (2018). The influence of growth and maturation on stretch-shortening cycle function in youth. *Sports Medicine*, *48*(1), 57–71. https://doi.org/10.1007/s40279-017-0785-0

Ratel, S. (2016). Neuromuscular physiology and youth. *Pediatric Exercise Science*, *28*(1), 40–43. https://doi.org/10.1123/pes.2016-0012

Read, P., Oliver, J. L., De Ste Croix, M. B. A., Myer, G., & Lloyd, R. S. (2018). An audit of injuries in six English professional soccer academies. *Journal of Sports Sciences*, *36*(13), 1542–1548. https://doi.org/10.1080/02640414.2017.1402535

Riboli, A., Coratella, G., Rampichini, S., Cè, E., & Esposito, F. (2020). Area per player in small-sided games to replicate the external load and estimated physiological match demands in elite soccer players. *PLoS ONE*, *15*(1). https://doi.org/10.1371/journal.pone.0229194

Riboli, A., Olthof, S. B. H., Esposito, F., & Coratella, G. (2021). Training elite youth soccer players: Area per player in small-sided games to replicate the match demands. *Biology of Sport*, *39*(3), 579–598. https://doi.org/10.5114/biolsport.2022.106388

Rowell, A. E., Aughey, R. J., Clubb, J., & Cormack, S. J. (2018). A standardized small sided game Can Be used to monitor neuromuscular fatigue in professional A-league football players. *Frontiers in Physiology*, *9*, 1011. https://doi.org/10.3389/fphys.2018.01011

Salter, J., De Ste Croix, M. B. A., & Hughes, J. D. (2020a). The moderating impact of maturation on acute neuromuscular and psycho-physiological responses to simulated soccer activity in academy soccer players. *European Journal of Sport Science*, *21*(12). https://doi.org/10.1080/17461391.2020.1851775

Salter, J., De Ste Croix, M. B. A., Hughes, J. D., Weston, M., & Towlson, C. (2020b). Monitoring practices of training load and biological maturity in UK soccer academies. *International Journal of Sports Physiology and Performance*, *16*(3), 395–406. https://doi.org/10.1123/ijspp.2019.0624

Salter, J., Johnson, D., & Towlson, C. (2021). A stitch in time saves nine: The importance of biological maturation for talented athlete development. *The Sport and Exercise Scientist, Autumn*, (69), 20–21.

The Football Association. (2012). *The FA Guide to Pitch and Goalpost Dimensions*. The Football Association. www.thefa.com/my-football

Tumkur Anil Kumar, N., Oliver, J. L., Lloyd, R. S., Pedley, J. S., & Radnor, J. M. (2021). The influence of growth, maturation and resistance training on muscle-tendon and neuromuscular adaptations: A narrative review. *Sports*, *9*(5), 59. https://doi.org/10.3390/sports9050059

van der Sluis, A., Elferink-Gemser, M., Brink, M., & Visscher, C. (2015). Importance of peak height velocity timing in terms of injuries in talented soccer players. *International Journal of Sports Medicine*, *36*(04), 327–332. https://doi.org/10.1055/s-0034-1385879

Verheul, J., Nedergaard, N. J., Vanrenterghem, J., & Robinson, M. A. (2020). Measuring biomechanical loads in team sports – From lab to field. *Science and Medicine in Football*, *4*(3), 246–252. https://doi.org/10.1080/24733938.2019.1709654

Waldron, M., Harding, J., Gray, A., & Barrett, S. (2021). A new foot-mounted inertial measurement system in soccer: Reliability and comparison to global positioning systems for velocity measurements during team sport actions. *Journal of Human Kinetics*, *77*, 37–50. https://doi.org/10.2478/hukin-2021-0010

Waugh, C. M., Blazevich, A. J., Fath, F., & Korff, T. (2012). Age-related changes in mechanical properties of the achilles tendon. *Journal of Anatomy*, *220*(2), 144–155. https://doi.org/10.1111/j.1469-7580.2011.01461.x

West, S. W., Clubb, J., Torres-Ronda, L., Howells, D., Leng, E., Vescovi, J. D., … Windt, J. (2020). More than a metric: How training load is used in elite sport for athlete management. *International Journal of Sports Medicine*, *42*(4), 300–306. https://doi.org/10.1055/a-1268-8791

Williams, C., Winsley, R. J., Pinho, G., De Ste Croix, M. B. A., Lloyd, R. S., & Oliver, J. L. (2017). Prevalence of non-functional over-reaching in elite male and female youth academy football players. *Science and Medicine in Football*, *1*(3), 222–228. https://doi.org/10.1080/24733938.2017.1336282

Wright, M., Songane, F., Emmonds, S., Chesterton, P., Weston, M., & Mclaren, S. J. (2020). Differential ratings of perceived match and training exertion in girls' soccer. *International Journal of Sports Physiology and Performance*, *1*(aop), 1–9. https://doi.org/10.1123/ijspp.2019-0595