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The effect of bio-banding on technical and tactical indicators of talent identification in academy soccer players

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ABSTRACT

The aim of this study was to examine the effect of bio-banding on technical and tactical markers of talent identification in 11- to 14-year-old academy soccer players. Using a repeated measures design, 92 players were bio-banded using percentage of estimated adult stature attainment (week 1), maturity-offset (week 2) and a mixed-maturity method (week 3). All players contested five maturity (mis)matched small-sided games with technical and tactical variables measured. Data were analysed using a series of Bayesian hierarchical models, fitted with different response distributions and different random and fixed effect structures. Despite differences during maturity-matched bio-banding for post-peak height velocity players, very few tactical differences were evident during the remaining maturity-matched and mis-matched fixtures for both banding methods. In fact, the results showed no consistent differences across both banding methods for practitioner and video analysis-derived technical performance characteristics during maturity matched and mis-matched fixtures. Both bio-banding methods explained similar levels of variance across the measured variables. Maturity-matched bio-banding had some effect on both technical and tactical characteristics of players during maturity-matched bio-banded formats. That said, this trend remained during maturity mis-matched bio-banded formats which restricts the conclusions that can be made regarding the effectiveness of bio-banding to manipulate technical and tactical measures in academy soccer players.

Keywords: maturation; bio-banding; soccer; talent identification; technical; tactical; positioning

INTRODUCTION

The asynchronous relationship between the rate of child growth and physical fitness development with chronological age can often confound the accurate identification of talented, young soccer players [1 2]. This may result in the over-selection of earlier maturing soccer players for soccer development programmes who display temporary, maturity-related enhancements in anthropometric (typically stature) and physical fitness characteristics [3-5]. This often occurs despite the fact that technical performance is a key consideration for talent selectors [6] and that technical development is influenced by advancing maturity in academy soccer players [7]. One potential consequence of this is the under-selection of 'later'-maturing players (who likely possess the potential to develop equal technical ability) in favour of players who possess transient, maturity-related enhancements in anthropometric characteristics due to their earlier onset of the adolescent growth spurt, [8-11], otherwise known as peak height velocity (PHV [12]). Therefore, there is a need for soccer academies to explore the use of talent identification and development approaches that negate the (un)conscious influence that maturity-related advantages can have on practitioner's assessment of player technical and tactical characteristics.

Advocated by professional soccer policy makers [13] and players [10] alike, a possible solution for maturity-related (un)conscious bias is to categorise players according to their biological maturity status (instead of traditional chronological age), commonly referred to as bio-banding [11 14-19]. Bio-banding within professional soccer academies is typically performed using one of two methods. One method involves determining maturity offset, which represents the estimated number of years players are from undergoing PHV [16-18]. In contrast, the Khamis and Roche [20] method involves estimating the percentage of estimated adult stature attainment (EASA) to bio-band players [10 14 16 17 21]. Using the latter method [20] to bio-band players, Cumming, et al. [10] reported that bio-banding had been positively received by both 'earlier' and 'later'-maturing players during match-play. In addition to this, bio-banding studies [14 17] suggest that such maturity-matched formats may control the physical demands placed on developing players and may expose players to more technically challenging environments [14]. However, although showing promise to control for maturity associated differences in physical demands, these findings have also continued during maturity mis-matched bio-banded formats which may limit the inferences that can be made regarding the effectiveness of bio-banding to manipulate physical outputs [17]. That said, Abbott, et al. [14] demonstrated increases in the number of short passing instances in the post and circa-PHV players, and subsequent reductions in the number of long passes for circa-PHV and late developers during bio-banded full match-play. Although having strong merit, the study by Abbott, et al. [14] only drew on players from one professional soccer academy whose technical performances likely reflected the playing philosophies implemented by the club, which may limit the conclusions we can reach regarding the efficacy of bio-banding to identify technically talented soccer players. In addition to this, it is also currently unknown how bio-banding might influence the tactical behaviours of players, particularly movements and decision making in relation to the match context such as pitch exploration and team centroid (being the geometric centre point between all players within the team) [22]. This is of relevance to practitioners responsible for identifying talented soccer players given that contextual match factors such as larger relative pitch size may permit earlier-maturing players the opportunity to apply tactical superiority due their transient anthropometric, physical fitness and decision-making characteristics [5 3 23 24]. These tactical characteristics are of relevance to soccer practitioners, given the importance they place on soccer players' ability to make tactical adaptations to effectively manage pitch space relative to the position of their team-mates (and opponents) to gain an advantage. This ability likely underpins players concept of tactics and formation decision-making [25], with tactical awareness being considered of equal importance for academy soccer players, regardless of playing position.[6]

Early research suggests bio-banding may exclusively [26] negate the transient maturity-related advantages associated with 'earlier' maturing players and has been shown to offer players a technical and tactical benefit [10 14]. However, little is known about the efficacy of bio-banding as a means to identify technically and tactically gifted players during talent (de)selection processes [14]. Furthermore, although the percentage of EASA [20] has been used for bio-banding players [10 14 17], likely due to its enhanced ability to predict the timing of PHV [27], many practitioners continue to use maturity offset measures as their preferred method to estimate stage of maturation [28], and sole equation to allocate players in to bio-banded groupings [16 18]. Despite such evidence it is seemingly unclear which maturity estimation equation academy practitioners should utilise to bio-band players when assessing players' technical and tactical talent. Given the growing utilisation of bio-banding by league governing bodies [13], studies exploring the efficacy of bio-banded match-play on such characteristics are of relevance to practitioners as it will help inform them of the practical use this strategy might offer when evaluating academy soccer players for (de)selection. Therefore, the primary aim of this study was to examine the effect of maturity-related 'bio-banding' on important technical and tactical actions of players during small-sided game (SSG) match-play which are often utilised as part of players regular training activities and have previously been used during talent identification and bio-banding scenarios [17 29]. In addition, this study sought to examine the effect of using different bio-banding methods (Khamis and Roche [20] and Fransen, et al. [30]) on practitioner and video analysis-derived technical performance characteristics of players during maturity matched and mis-matched fixtures.

METHODS

Study design

Having institutional ethics approval (approval number 1819011) and parental consent, participating players completed a full familiarisation of the testing battery one week prior to the commencement of the main trials. The study was conducted using a three-week, repeated-measured design. Following previously outlined methods [17], in weeks 1 and 2, players were required to compete in a bio-banded, SSG round-robin format using the Khamis and Roche [20] (week 1) or the Fransen, et al. [30] (week 2) maturity estimation equations, with a mixed-maturity banded format applied in week 3. Dependent on study week number, players were assigned to one of 6 teams of four players according to either percentage EASA [20] in week 1, years to/from PHV [30] in week 2 and mixed maturity status in week 3 (6 teams of 'mixed' maturity).

Using methods outlined by Towlson, et al. [17], players completed a standardised ~15 minute warm up, and contested five, 4 Vs 4 SSGs (18.3 x 23 m pitch), lasting 5 min each (25 min total playing time) on an outdoor 3G surface where individual and team technical and tactical characteristics were monitored. To promote continuous play and afford greater opportunity for players to demonstrate technical and tactical match-play behaviours, the valid and reliable method by [29] was adapted. Each SSG preserved a continuous play by using two (2 m × 1 m) goals, no allocated goalkeepers and shots only being allowed to be taken from within the attacking half of the pitch. As per the study by Fenner, et al. [29] only refereeing decisions and score was provided to players, with verbal feedback relating to the player performance from practitioners being prohibited to remove (un)conscious practitioner bias. Each team received a maximum of 10 and minimum of 5 min practitioner-led, low intensity, active recovery whereby players completed one of three standardised technical drills to preserve match-readiness between games. This SSG structure repeated in one-week intervals, for three consecutive weeks.

Participants

92 academy soccer players (under 13: n =31; under 14: n = 32; under 15: n = 26; under 16: n =3) participated in the study. This allowed for an initial group of 72 participating players and 20 reserve players in the event of player injury and/or absence. The sample size was constrained by a range of external factors: funder-set limits on time and budget and the finite number of players available to recruit from across the three academies involved. With performance outcome measures being selected in collaboration with participating club practitioners. A Bayesian approach was used to produce credible parameter estimates that allows the reader to evaluate the precision of our population estimates; the 95% credible interval for the mean difference between groups provides a 95% chance of capturing the true difference.

As per our previous research [17], we used a convenience sample of 92 academy soccer players (under 13: n = 31; under 14: n = 32; under 15: n = 26; under 16: n = 3) from two English and one Scottish professional soccer academies. As indicated in the acknowledgements, this study was funded by the Union of European Football Associations via a 12-month grant. As such, the sample size was constrained by a range of external factors such as time, financial, and travel constraints afforded to the research team by the conditions of the grant. The sample of twenty four players from each academy (n = 72). The players were categorised according to biological maturity status using either percentage EASA [20] or YPHV [30], and the remaining 20 players were used as reserves (please see Towlson, et al. [17] for full inclusion details).

Anthropometric and Maturity measurements

Using previously published methods, players' anthropometric (stature, body-mass) measures were taken [23]. As per previous studies [10 14 17] the Khamis and Roche [20] method was used (week 1) to estimate percentage EASA from each player's decimal age, stature and body-mass, accompanied by adjusted [31], self-reported mid-parental stature of both biological parents, reporting a measurement error of 2.1% between actual and estimated adult stature in male athletes aged between 4 and 18 years. This method has been validated against criterion skeletal maturity methods [32 33] with an adjusted threshold of 87.0 to 92.0% of final EASA used to 'bio-band' players into their respective 'bio-banded' groupings. We defined our groupings as 'post-PHV' (92.0 to 95.0% estimated adult stature attainment), 'circa-PHV' (87.0 – 92.0% estimated adult stature attainment) and 'pre-PHV' (85.0 to 87.0 % estimated adult stature attainment) to permit standard terms to be used.

Estimated maturity offset (i.e. decimal age in years - predictive APHV = YPHV) were calculated using the Fransen, et al. [30] predictive equation to bio-band players in week two. The Fransen, et al. [30] method uses a predictive algorithm based on a longitudinal sample of 'normative' growth data for Belgian pre-post adolescent (aged 8-17 years) soccer player from various ethnic backgrounds. The method excludes previously criticised [34] sources or measurement error (e.g. estimated leg length) and uses the interactions between somatic components (stature and body-mass) and calendar age to determine the player's predicted APHV and YPHV (See Towlson, et al. [35] for details). Similar to Till, et al. [36] and for the current study, the following modified thresholds were used to define years to PHV categories: 'pre-PHV' (< -1.0 years to PHV), 'circa-PHV' (-1.0 – 0.0 years to PHV) and 'post-PHV' (>0.0 years to PHV). Given the repeated-measures design nature of the study, 8 players changed bio-banding categories between methods (i.e. from Khamis and Roche [20] to Fransen, et al. [30]), with two circa players being reallocated to early, two early players being reallocated to circa, two late players being reallocated to circa, and two circa players being reallocated to the late category.

In week three, players were randomly and independently (i.e., no prior knowledge regarding each player's somatic characteristics) assigned to six mixed-maturity teams to act as a surrogate control measure. To permit pairwise statistical comparison, mixed-maturity teams were aggregated in to three 'mixed' maturity bandings (e.g., team 1A and 1B were aggregated to form group A).

Practitioner derived technical measures

Using the Game Technical Scoring Chart (GTSC) [29], four practitioners (F.A. Level 2 to Level 3 qualified coaches) independently assessed players for evidence of key technical ('cover/support', 'communication', 'decision-making', 'passing', 'first touch', 'control', 'one versus one', 'shooting', 'assists' and 'marking' as defined by Fenner, et al. [29]) performance indicators during each 5 min SSG. Practitioners were randomly assigned players to evaluate using a 5-point scale containing the following criteria: 1 – poor, 2 – below average, 3 – average, 4 – very good and 5 – excellent. Thus, if a player was perceived as being a poor 'passer' of the ball during a given SSG, then they were allocated a score of 1 in the 'passing' element. To permit easy player identification, players wore coloured and numbered bibs (1-4). This process was completed for all trials.

Video analysis derived technical measures

Using a 4K video-camera (SONY Handycam FDR-AX33 4K Ultra HD Camcorder), all matches, across all 3 weeks were video recorded. The camera was mounted on an elevated tripod, at a mean (SD) height of 7.3 (2.9) m and at a distance from the pitch of 13 m. The camera was placed at the halfway line to capture the whole pitch in frame. Each video file was first exported to specialised video analysis software (Sportscode Elite, version 10.3.36, Sportstec Ltd, Geluksburg, South Africa). Following video file import, footage was analysed for player 'passes' ([un]successful) (f), 'turning' (f), 'goals' (f), 'shots' (on/off target) (f), 'ground ball challenge' (f), 'interceptions'(f), and 'dribbling' (f). These events were coded in accordance with operational definitions that were modified from the literature [37] and OPTA event definitions [38] and piloted with academy technical coaches for face validity (Table 1). To ensure video analyses were accurate, intra-analyst reliability metrics for technical key performance indicators were established using a sub-sample of bio-banded (n = 12) and mixed maturity (n = 6) SSGs as coded by the same operator on two occasions, interspaced by 7 days (Table 2). The operator was embedded within a professional soccer academy and inter-coder reliability was systematically performed as part of their normal working practices.

****** Insert table 1 here ******

****** Insert table 2 here ******

Tactical Behaviours

Each player wore a specially designed paediatric fitted neoprene vest that housed a Micro-Electro-Mechanical Sensors (MEMS) device (MEMS; Optmeye X4, Catapult Innovations, Melbourne, Australia) containing a 10 Hz global positioning system (GPS) chip. The neoprene vest ensured that the MEMS device was located between the scapulae for each player. The GPS chip was used to record player latitude and longitude coordinates during match-play to an acceptable satellite signal strength (see Towlson, et al. [17]). The GPS-derived coordinate data were downloaded and exported to Openfield™ (version 1.12.0, Catapult Sports, Melbourne, Australia). The coordinates were then resampled to remove eventual data gaps and converted to meters using the Universal Transverse Mercator coordinate system and smoothed using a 3 Hz Butterworth low pass filter. A rotational matrix was applied to ensure players displacement data and pitch length and width were aligned to the x and y-axis, respectively (for complete guidelines, Folgado, et al. [39]). The previous processing step was carried out using Matlab R2014b (The MathWorks Inc., Natick, Massachusetts, USA). Using a previously outlined method [22], a spatial exploration index (SEI) algorithm was utilised to assess differences in players pitch exploration according to bio-banding format, with higher values being inferred as players who explore more space during each SSG [22]. This was achieved by calculating each players' mean pitch position using the interaction between distance between each positioning time series relative to the mean position and then calculating the mean value from the aggregated distances. In addition, and as per Gonçalves, et al. [22] the coordinate data was used to calculate: (i) the mean distance (m) to nearest team-mate/opponent to provide functional information about how players adapted their positioning behaviour according to team-mates and opponents; (ii) the distance to team and opponent team centroid (the team centroid as measured by the mean position from all team/opponent outfield players) to provide functional information about how players' decision-making (positioning-related) is based on perceived information from their team-mates/opponents. It may also provide functional information about team structures since it reflects the contraction/dispersion of the teams.

Statistical analysis

Differences between the banding categories (pre-PHV, circa-PHV, post-PHV), were determined using a series of Bayesian hierarchical models fitted with different response distributions and different random and fixed effect structures depending on the response variable: ratings, counts, or metric measurements. We used weakly informative priors to provide some regularisation to improve convergence and sampling efficiency, and to constrain the likelihood to plausible values. Prior predictive checks were used to check the priors before including them in models [40]. Coach ratings were modelled using a Bayesian ordinal cumulative model with a probit link function, with differences reported as standard deviations. For the response variables that were frequencies or counts of particular videoed actions, Bayesian zero inflated Poisson regression models were used, with the estimates reported back-transformed from the log scale. Where response variables were genuinely metric, Bayesian models were fitted using a Gaussian response distribution. Delta total (δt) effect size was calculated from posterior distributions for metric measures. A lower bound threshold of 0.4 was set for δt based on the probability of superiority. The effect size for differences in ratings are reported as standard deviations, so provide a similar measure to Cohen's d. The effect size for back-transformed counts from a log scale are reported as the raw differences using back-transformed estimated marginal means. Probability of direction (pd) was calculated for each of the differences and can be interpreted as the probability of an effect in a particular direction - whichever is the more probable. Two techniques were used to determine whether the Fransen, et al. [30] or Khamis and Roche [20] banding equations better explained the data, in terms of out-of-sample prediction: Bayesian R squared [41] and Leave-One-Out cross-validation (LOO;[42]). All analyses were conducted using R (R Core Team, 2020) and with the Bayesian Regression Models in Stan (brms) package [43] which uses Stan [44] to implement a Hamiltonian

Markov Chain Monte Carlo (MCMC) with a No-U-Turn Sampler. All models were checked for convergence ($\hat{r} = 1$), with graphical posterior predictive checks showing how the predicted distribution compared to the observed data [40].

RESULTS

Technical variables

Video analysis

With the exception of ground ball challenges, the largest differences between groups across all technical actions recorded on video are where maturation groups are matched (see Table 3). With the exception of differences in the frequency of turning when circa-PHV played circa-PHV (Khamis and Roche [20] method), all the difference values greater than 1 are for successful passes with a high probability of a difference across matched maturation groups (pd = 93.77% to 100%). When mixed maturity groups played each other, only goals scored produced a difference greater than 1 (pd = 99.50% to 99.58%). Across all the technical actions recorded on video, the Khamis and Roche [20] method produced the single highest individual difference in frequency, with a difference in rate of successful passes of 1.87 when pre-PHV groups played each other (pd=100%). For time spent dribbling the ball, the only standardised differences above our criterion value of 0.4 standard deviations, is when the circa-PHV group played another circa-PHV group (see Table 3). The largest difference in dribbling time is for the Khamis and Roche [20] method (pd = 98.24%), while the Fransen, et al. [30] method produced the second largest standardised difference for dribbling across maturation groups, but this difference is less certain than for Khamis and Roche [20] (pd = 85.62%).

*****Table 3 about here*****

Practitioner rated variables

With the exception of ratings for passing and shooting, the largest differences across variables were found when maturation groups were matched. The only variable where matched groups did not produce differences above our 0.4 criterion effect size value was for ratings of passing (see Table 4). The Khamis and Roche [20] method produced the single highest individual difference across ratings of technical variables between maturation groups, with ratings of communication 0.85 standard deviations different when post-PHV groups played each other (pd=99.24%). Differences generally dissipated in ratings for mixed maturity groups playing each other, with the highest difference of 0.33 standard deviations (pd= 96.25%). However, Fransen, et al. [30] produced the highest number of differences in ratings across maturation groups above the 0.4 criterion effect - 7 differences for post-PHV groups playing each other, 8 differences for circa-PHV groups playing each other, and 5 differences when pre-PHV groups played each other were all above the criterion value. In mismatched groups, only cover, control, shooting, passing and shooting had differences higher than this value (see Table 4).

*****Table 4 about here*****

Tactical variables

As displayed in Table 6, with the exception for spatial exploration index, the only standardised differences above the 0.4 criterion effect across tactical variables for both Khamis and Roche [20] and Fransen, et al., [30] are between post-PHV matched groups (see Figure 1). For spatial exploration index (see Figure 2), the highest values for both Khamis and Roche [20] and Fransen, et al. [30] are when circa-PHV groups played each other with a high probability of a difference (pd=97.17% and 92.90% respectively). The only differences above our 0.4 effect for mixed maturity groups playing each other was for SEI (0.45; pd= 96.15%). The Fransen, et al. [30] method produced the largest standardised difference across tactical variables for distance to the nearest team-mate when post-PHV groups played each other. This difference also had a high probability (pd= 99.52%) of a difference. The second largest standardised difference was for the same variable with the Khamis and Roche [20] method (pd= 99.17%). Fransen, et al. [30] produced the next largest standardised difference for distance to centroid with a high probability (pd=97.62%), again for matched post-PHV groups.

*****Table 5 about here*****

Variance explained and out-of-sample prediction

Fransen, et al. [30] produced the highest percentage of variance explained (R^2*100), across all the variables in the total technical score, where the model explained 67% of the variance in practitioner ratings. Nonetheless, in terms of variance explained across all tactical and technical variables, Fransen, et al. [30] and Khamis and Roche [20] performed similarly in terms of the highest R^2 values. Out-of-sample prediction (LOOIC) values are considered a better measure for this purpose and [30] produced the best (lowest) LOOIC values for 19 out the 25 variables (see Table 6).

*****Table 6 about here*****

*****Figure 1 about here*****

*****Figure 2 about here*****

DISCUSSION

The aim of the study was to examine the effect of maturity status bio-banding on important technical and tactical actions of academy players during SSGs. In addition, this study also sought to examine the effect of using different bio-banding methods (Khamis and Roche [20] and Fransen, et al. [30]) on practitioner and video analysis-derived technical performance characteristics of players during maturity matched and mis-matched fixtures. The main findings of our study were that (1) despite differences during maturity-matched bio-banding for post-PHV SSGs, very few tactical differences manifest during the remaining maturity-matched and mis-matched fixtures for both banding methods, (2) there were no consistent differences across both banding methods for practitioner and video analysis-derived technical performance characteristics of players during maturity matched and mis-matched fixtures, and (3) the Fransen, et al. [30] and Khamis and Roche [20] methods explained similar levels of variance across the measured variables (using R^2), but the Fransen, et al. [30] method produced the best fitting model (19 out of 25) when applying LOOIC.

Although post-PHV players possess transient, maturity-related enhancements in stature and body-mass[5 23], maturity matched bio-banding had no meaningful effect on the tactical outputs of players during circa-PHV and pre-PHV maturity matched SSGs. Similar trends emerged for maturity mis-matched (circa-PHV vs post-PHV, circa-PHV vs pre-PHV and post-PHV vs late-PHV) SSGs. However, modest differences in distance to nearest opponent and distance to centroid were observed in the maturity-matched fixtures for post-PHV players in both the Khamis-Roche[20] and Fransen[30] banding methods. The mechanisms underpinning these differences are unclear, however, players were matched for stage of maturation and therefore the assumed maturity-related variance in anthropometric, physical fitness, and decision-making differences were accounted for [3 5 23 24]. All match actions emerge out of the relationships between the players who move in a particular environment and perform a particular task. During the dynamics of play, these relationships open and close windows of opportunity that encourage certain types of movements and actions and discourage others [45]. That said, the individual constraint of advanced lower limb strength of 'earlier' maturing players [46], (developed with specific strength and athletic development programmes spanning PHV [47]) likely enhances post-PHV players ability to play longer passes due to their enhanced strength and power to propel the ball longer distances and offering a plausible explanation for the increased distances between team-mates and opposition. However, at this stage we are unable to establish cause and effect. That is, the higher strength of post-PHV players might allow them to try longer passes more often even if the receiving player isn't in an advanced position, as opposed to attacking players moving further up the pitch in anticipation of a longer pass.

Despite the present study using SSGs (i.e. same pitch-size, player number and rules) previously used for both talent identification [29] and maturity status bio-banding [17] the short duration (5 min) and small relative pitch size (52.6 m^2 per player) may well have thwarted anticipated tactical (dis)advantages afforded to post-PHV players during maturity mis-matched bio-banded SSGs being displayed. This is likely due to tactical behaviours of players on a small pitch eliciting a higher density of players per square meter, in comparison to using a relatively larger pitch size [48]. For instance, the distance between players when using larger pitch dimensions are increased and likely affords 'earlier'-maturing players the opportunity to take advantage of the increased pitch space [48], by applying tactical superiority as a composite of their advanced anthropometric, physical fitness and decision-making characteristics [5 3 23 24]. The limitations imposed by restricted pitch size in the present study is of relevance, given that advanced maturity status has been shown to enhance young soccer players ability to detect task-relevant signals during the decision making process in comparison to their less mature counterparts [24]. This may allow these players to respond more quickly and accurately to situational challenges thereby enhancing their tactical behaviours during match-play [24]. However, exploring the effect of relative pitch size on tactical behaviours during maturity bio-banded match-play was not within the scope of the present study. Nevertheless, it seems relevant to understand from this study that restricted pitch size might be an interesting strategy to attenuate maturity differences between players, when expressed in terms of tactical performance. In this sense, it will be more difficult for post-PHV players to rely on their physical-related actions for their decision-making process and, as a naturally imposed constraint, other sources of information will be integrated in the process generating different opportunities for action. Further research is required to fully understand the influence of relative pitch size on bio-banded match-play and its implications for associated talent identification processes.

Similar to Abbott et al 2020 [14], the present study observed that maturity-matched bio-banding had a limited effect on technical variables across both the Khamis-Roche[20] and Fransen[30] bio-banding methods. This suggests that any maturity-related differences in technical ability were negated for when players were matched according to maturity status. However, reflecting our previous bio-banding work [17], there were few differences in technical performance variables within the most extreme condition where the difference in maturation was at its greatest (i.e. pre-PHV players played post-PHV players). This trend was also consistent for practitioner derived assessments of technical attributes for both bio-banding methods. Despite it being advocated in previous talent identification work [29], the maturity related differences in technical output may have been thwarted by the small relative pitch size (40-50 m^2) which has been shown to constrain the type of technical actions performed by players as a function of advancing age and pitch size [49]. This finding contradicts previous claims made about the effectiveness of maturity status bio-banding to manipulate technical outcomes during SSG match-play. This is of obvious relevance, given that the technical ability of players is considered important by practitioners when selecting and allocating players for different positional roles across age groups associated with the timing of PHV[6 50]. As such, this is likely to confound the accurate identification of technically gifted players during the talent identification process.

In line with previous bio-banding work [17], the present study observed uncertainty in determining which bio-banding method explained more of the variance (i.e. R^2) for technical and tactical performance measures. However, it is worth noting that higher R^2 values do not always indicate a better fit and can indicate overfitting [51] and leave one out cross validation is a better model comparison method for determining out-of-sample performance. In the present study, the Fransen, et al. [30] method produced the best out-of-sample performance approximation for 76% (19 out the 25) of the measured variables (see Table 6). Nevertheless, this does not mean that the Fransen, et al. [30] equation is a 'better' method for establishing maturity status. Our findings merely suggest that in cases where LOOIC is lower, this method may be better for out-of-sample generalisation and capturing the data generating process. As we have previously stated [17 35], although both methods provide a non-invasive, cost- and time effective alternative to estimate biological maturity status, the limitations associated with both methods used to bio-band players must be considered (see Towlson, et al. [35] for full discussion). Despite the inherent limitations within both maturity estimation equations [35 52], there is an emerging body of soccer-based evidence that suggests the Khamis and Roche [20] method has greater maturity prediction qualities (assuming that appropriate anthropometric measures have been collected according to best practice guidelines) than maturity offset-based methods when thresholds are aligned with the timing of PHV [27]. However, given the situational flux (e.g. staffing, expertise, equipment) that soccer academy practitioners face [28], we suggest that soccer academy practitioners should carefully consider which bio-banding method and game format (i.e. maturity matched or maturity mis-matched) will likely afford their players with the best playing environment for them to showcase attributes which are considered important by talent selectors [6]

Although the sample size of the present study surpasses all previous bio-banding match-play studies [14 16 18], we recognise that the precision of such differences is perhaps compromised (evidenced by broad credible intervals of 0.0 to 1.49). This is likely exacerbated by the combination of measurement error within the MEMs devices which collected the geodetic coordinate data [53], in addition to the match-to-match variability of players tactical behaviours [54]. Collectively, these sources of error might render such differences as a statistical artifact. Therefore, inferences relating to the effectiveness of bio-banding to manipulate tactical outputs of academy soccer players should be interpreted with caution. This issue of sample size is an important one in sport and exercise science [55] and one for future bio-banding studies that needs to be addressed. We would suggest that larger league-wide collaborative studies as used in other contexts [56] is required, and that governing bodies have an important role to play in helping researchers obtain a large enough sample to allow robust statistical inferences to be obtained.

Conclusion

The present study suggests that maturity-matched bio-banding had limited effect on both technical and tactical characteristics of players during maturity-matched bio-banded formats. That said, this trend remained during maturity mis-matched bio-banded formats which restricts the conclusions that can be made regarding the effectiveness of bio-banding to manipulate technical and tactical performance of academy soccer players during SSGs. Although not an initial intention of the study, data here provides some early evidence to suggest that restricted relative pitch size may provide a playing environment that restricts maturity related technical and tactical actions from manifesting during SSGs contested by players of differing maturity status. However, further research in this line of enquiry is needed to enhance knowledge about the effectiveness of maturity-related bio-banding on talent identification processes of professional soccer academies.

Although our study is the largest to examine the effect of bio-banding on tactical and technical measures (n = 92), the degree of measurement uncertainty (evidenced by the broad highest-density intervals and effect sizes) for both technical and tactical measures reported in the present study means our results need to be interpreted considering this large uncertainty. This again raises a pertinent point for discussion about the need for practitioners, researchers, and governing bodies alike to take a coordinated approach when considering research design in order to effectively pool resources, expertise and enhance sample size to provide more insightful inferences and conclusions.

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The authors report no conflict of interest.

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Table 1. Summary table of operational definitions used by the video analyst when coding the small-sided games.

Variable	Operational definition
Ground challenge	*When the ball is competed for when it is on the ground.*
Interception	*The ball is won due to interrupting the oppositions possession of the ball whilst keeping the ball in play. Interception can occur recovering the ball from a ground or an aerial challenge but not through the gaining of the ball through the oppositions breaki the rules or the ball leaving the pitch. Interception is defined as winning the ball whilst game play continues and not through a event that causes a re-start of play.*
Shot on target	*When a player aims the ball towards the goal that results in a goal or a save from the opposition.*
Shot off target	*When a player aims the ball towards the goal that results in missing the goal or re-bounding off the goal posts.*
Successful pass	*When the ball is transferred from one player to another successfully without the ball being intercepted or going out of play.*
Unsuccessful pass	*When the ball is unsuccessfully transferred from one player to another i.e., the ball is intercepted or goes out of play.*
Dribbling	*When a player maintains possession of the ball and guides the ball in a certain direction using their feet.*
Turning	*A change of direction when the player has the ball in their possession.*

Table 2. Summary table of reliability metrics for technical key performance indicators performed by 72 academy soccer players during bio-banded (n = 12) and mixed maturity (n = 6) small-sided games as coded by the same operator on two occasions, interspaced by 7 days.

Variable	Trial 1 Mean (±SD)	Trial 2 Mean (± SD)	Mean difference (± SD)	ICC (95% CI)	Typical error (95% CI)	%CV (95% CI)	Smallest reliable difference (95% CI)
Ground challenges (*f*)	1.2 ± 1.2	1.2 ± 1.2	0.0 ± 1.1	-0.02 (-0.29 – 0.26)	0.77 (0.66 – 0.93)	1.15 (0.83 – 1.61)	1.08 (0.95 – 1.12)
Goals (*f*)	0.4 ± 0.6	0.4 ± 0.6	0.0 ± 0.2	-0.02 (-0.10 – 0.06)	0.15 (0.12 – 0.17)	1.00 (1.00 – 1.00)	1.06 (1.02 – 1.09)
Interceptions (*f*)	0.1 ± 0.6	0.1 ± 0.3	0.0 ± 0.3	-0.07 (-0.27 – 0.13)	0.24 (0.20 – 0.28)	0.63 (0.23 – 1.70)	1.08 (0.90 – 1.16)
Shots on target (*f*)	0.8 ± 0.9	0.8 ± 0.8	0.0 ± 0.5	0.02 (-0.12 – 0.15)	0.32 (0.28 – 0.39)	1.00 (0.79 – 1.26)	1.06 (0.96 – 1.10)
Shots off target (*f*)	0.7 ± 1.0	0.7 ± 0.9	0.0 ± 0.3	0.01 (-0.05 – 0.08)	0.19 (0.16 – 0.22)	1.00 (0.73 – 1.36)	1.08 (0.95 – 1.12)
Successful passes (*f*)	6.2 ± 2.9	6.2 ± 2.7	0.0 ± 0.8	0.01 (-0.06 – 0.08)	0.56 (0.48 – 0.67)	1.01 (0.97 – 1.06)	1.11 (1.09 – 1.13)
Unsuccessful passes (*f*)	1.6 ± 1.4	1.6 ± 1.4	0.0 ± 0.7	0.01 (-0.12 – 0.14)	0.49 (0.42 – 0.58)	0.94 (0.79 – 1.11)	1.10 (1.04 – 1.14)
Turning (*f*)	0.1 ± 0.6	0.1 ± 0.3	0.0 ± 0.3	-0.07 (-0.27 – 0.13)	0.24 (0.20 – 0.27)	0.63 (0.23 – 1.70)	1.08 (0.90 – 1.16)
Dribbling (*f*)	5.3 ± 6.0	6.4 ± 6.2	1.2 ± 2.1	0.20 (0.11 – 0.29)	1.51 (1.30 – 1.80)	1.21 (0.98 – 1.50)	1.13 (1.05 – 1.18)

Key: SD – Standard deviation; CI – Confidence interval; *f* – Frequency; ICC – Intraclass correlation; %CV – Percentage of coefficient of variation

Table 3. Estimated frequencies and smallest reliable difference for between groups for videoed for technical variables according to Fransen et al. (2018) and Khamis & Roche (1994) bio-banding methods.

Variable	Banding	***Post*-PHV vs *Post*-PHV**	(95% HDI)	***Circa*-PHV vs *Circa*-PHV**	(95% HDI)	***Pre*-PHV vs *Pre*-PHV**	(95% HDI)	***Circa*-PHV vs *Post*-PHV**	(95% HDI)	***Pre*-PHV vs *Circa*-PHV**	(95% HDI)	***Pre*-PHV Vs *Post*-PHV**
Successful pass (*f*)	Fransen et al	4.67 to 5.71	(4.72 to 6.84)	5.12 to 6.64	(4.19 to 7.87)	6.07 to 7.34	(4.98 to 8.73)	5.45 to 6.09	(4.86 to 6.73)	5.94 to 6.08	(5.32 to 6.73)	5.94 to 5.59
		1.04		1.52		1.27		0.64		0.86		0.35
	Khamis & Roche	4.94 to 6.23	(4.07 to 7.42)	5.12 to 7.83	(4.15 to 6.21)	5.76 to 7.63	(4.69 to 9.03)	5.62 to 5.74	4.97 to 6.34)	6.28 to 5.66	(5.02 to 6.93)	5.25 to 6.19
		1.27				1.87		-0.12		0.62		0.94
Unsuccessful pass (*f*)	Fransen et al	1.83 to 2.02	(1.24 to 2.64)	1.78 to 1.97	(1.26 to 2.60)	1.77 to 1.97	(1.21 to 2.61)	2.21 to 1.86	(1.66 to 2.33)	1.98 to 1.99	(1.64 to 2.35)	2.26 to 1.93
		0.19		0.19		0.20		0.35		0.01		0.33
	Khamis & Roche	1.83 to 2.53	(1.16 to 2.61)	1.78 to 1.97	(1.24 to 2.41)	1.78 to 1.97	(1.34 to 2.97)	2.21 to 1.86	(1.53 to 2.57)	1.99 to 1.99	(1.65 to 2.34)	2.26 to 1.92
		0.70		0.19		0.19		0.35		0.00		0.34
Turning (*f*)	Fransen et al	0.89 to 1.14	(0.14 to 2.30)	0.97 to 1.29	(0.44 to 2.13)	1.11 to 1.88	(0.41 to 3.65)	1.41 to 1.56	(1.04 to 1.95)	1.29 to 1.34	(0.91 to 1.71)	1.21 to 1.48
		0.25		0.32		0.77		0.15		0.05		0.27
	Khamis & Roche	0.92 to 1.34	(0.231 to 3.19)	1.90 to 0.89	(0.20 to 3.64)	0.91 to 1.54	(0.19 to 2.68)	1.09 to 1.11	(0.43 to 1.96)	1.15 to 1.04	(0.69 to 1.71)	1.20 to 1.09
		0.42		1.01		0.63		0.02		0.11		0.11
Goals (*f*)	Fransen et al	1.09 to 1.14	(0.45 to 1.95)	0.97 to 1.46	(0.48 to 2.45)	1.21 to 1.33	(0.47 to 2.43)	1.36 to 1.60	(1.00 to 2.01)	1.14 to 1.27	(0.75 to 1.66)	1.23 to 1.48
		0.05		0.49		0.12		0.24		0.13		0.25
	Khamis & Roche	0.92 to 1.12	(0.58 to 1.72)	0.97 to 1.29	(0.23 to 1.88)	1.11 to 1.88	(0.41 to 2.05)	1.41 to 1.56	(1.04 to 1.95)	1.29 to 1.34	(0.91 to 1.71)	1.21 to 1.48
		0.20		0.32		0.11		0.15		0.05		0.27
Shots on target (*f*)	Fransen et al	1.51 to 1.64	(0.91 to 2.31)	1.50 to 1.73	(0.95 to 2.52)	1.48 to 1.74	(0.96 to 2.63)	1.58 to 1.94	(1.24 to 2.31)	1.49 to 1.64	(1.17 to 1.97)	1.46 to 1.72
		0.13		0.23		0.26		0.36		0.15		0.26
	Khamis & Roche	1.46 to 1.95	(0.92 to 2.95)	1.53 to 1.81	(0.95 to 2.50)	1.15 to 1.87	(0.59 to 2.72)	1.64 to 1.84	(1.33 to 2.16)	1.54 to 1.74	(1.24 to 2.08)	1.42 to 1.93
		0.49		0.28		0.72		0.20		0.10		0.51
Shots off target (*f*)	Fransen et al	1.27 to 1.32	(0.96 to 1.59)	1.16 to 1.30	(0.57 to 2.10)	1.24 to 1.25	(0.66 to 2.04)	1.50 to 1.27	(0.96 to 1.92)	1.38 to 1.10	(0.80 to 1.73)	1.26 to 1.31
		0.05		0.14		0.01		0.23		0.28		0.05
	Khamis & Roche	1.29 to 1.37	(0.66 to 2.16)	0.93 to 1.62	(0.21 to 2.55)	1.07 to 1.15	(0.47 to 1.89)	1.29 to 1.31	(0.92 to 1.67)	1.38 to 1.45	(0.99 to 1.82)	1.38 1.41
		0.08		0.69		0.08		0.02		0.07		0.03

Aerial challenge (*f*)	Fransen et al	0.68 to 0.70	(0.00 to 3.15	0.00 to 0.85	(0.00 to 2.54)	0.69 to 0.87	(0.00 to 3.26)	0.82 to 0.94	(0.03 to 2.45)	0.92 to 1.41	(0.26 to 2.53)	0.92 to o.92
		0.02		0.85		0.18		0.12		0.49		0.00
	Khamis & Roche	0.67 to 0.81	(0.00 to 3.02)	0.85 to 0.89	(0.04 to 2.38)	0.00 to 0.00	(0.00 to 0.00)	0.68 to 0.92	(0.00 to 3.18)	0.92 to 0.92	(0.19 to 1.88)	0.91 to 0.93
		0.14		0.04		0.00		0.24		0.00		0.02
Ground ball challenge (*f*)	Fransen et al	1.69 to 1.85	(1.15 to 2.56)	1.53 to 1.96	(0.88 to 2.66)	2.17 to 2.25	(1.47 to 2.97)	2.31 to 1.81	(1.92 to 2.74)	2.02 to 1.69	(1.36 to 2.43)	2.19 to 1.90
		0.16		0.43		0.08		0.50		0.33		0.29
	Khamis & Roche	1.79 to 2.28	(1.26 to 3.03)	1.55 to 2.02	0.90 to 2.83)	1.99 to 2.25	(1.35 to 2.93)	1.89 to 1.92	(1.50 to 2.27)	1.95 to 1.81	(1.48 to 2.27)	2.16 to 2.09
		0.49		0.47		0.26		0.03		0.14		0.07
Interception (*f*)	Fransen et al	1.82 to 1.90	(1.16 to 2.60)	1.60 to 1.96	(1.00 to 2.82)	1.40 to 1.50	(0.83 to 2.86)	1.54 to 1.53	(1.24 to 1.88)	1.64 to 1.67	(1.30 to 1.98)	1.63 to 1.91
		0.08		0.36		0.10		0.01		0.03		0.28
	Khamis & Roche	1.68 to 1.73	(1.12 to 2.35)	1.63 to 1.79	(0.89 to 2.55)	1.48 to 1.64	(0.98 to 2.13)	1.64 to 1.59	(1.30 to 1.98)	1.74 to 1.73	(1.40 to 2.13)	1.70 to 1.90
		0.05		0.16		0.16		0.05		0.01		0.20
Dribbling (s)	Fransen et al	4.91 to 6.02	(2.49 to 8.33)	6.37 to 8.12	(3.86 to 10.42)	7.44 to 8.68	(5.12 to 10.83)	6.54 to 7.05	(5.20 to 8.30)	8.11 to 7.23	(5.97 to 9.34)	7.63 to 6.45
effect size		0.25	(-0.45 to 0.96)	0.40	(-0.34 to 1.14)	0.28	(-0.41 to 0.98)	0.11	(-0.28 to 0.51)	0.20	(-0.17 to 0.58)	0.27
Dribbling (s)	Khamis & Roche	5.48 to 6.45	(3.21 to 8.60)	7.21 to 10.59	(4.62 to 12.89)	7.84 to 8.84	(5.38 to 11.00)	6.91 to 6.68	(5.36 to 8.22)	8.49 to 7.81	(6.55 to 9.73)	7.21 to 6.14
effect size		0.23	(-0.50 to 0.95)	0.81	(0.04 to 1.57)	0.24	(-0.50 to 0.98)	0.05	(-0.34 to 0.45)	0.16	(-0.23 to 0.56)	0.25

Key: Peak height velocity (PHV); Highest Density Interval (HDI)

Table 4. Estimated differences between groups for ratings of tactical and technical variables according to Fransen et al. (2018) and Khamis & Roche (1994) bio-banding methods.

Variable	**Banding**	***Post*-PHV vs *Post*-PHV**	(95% HDI)	***Circa*-PHV vs *Circa*-PHV**	(95% HDI)	***Pre*-PHV vs *Pre*-PHV**	(95% HDI)	***Circa*-PHV vs *Post*-PHV**	(95% HDI)	***Pre*-PHV vs *Circa*-PHV**	(95% HDI)	***Pre*-PHV Vs *Post*-PHV**	(95% HDI)
Cover (AU)	Fransen et al	0.08	(-0.62 to 0.77)	0.66	(-0.04 to 1.37)	0.32	(-1.04 to 1.02)	0.16	(-0.25 to 0.57)	0.11	(-0.30 to 0.52)	0.48	(0.08 to 0.88)
	Khamis & Roche	0.12	(-0.58 to 0.80)	0.40	(-0.26 to 1.07)	0.53	(-0.18 to 1.27)	0.11	(-0.28 to 0.49)	0.09	(-0.31 to 0.49)	0.37	(0.04 to 0.77)
Communication (AU)	Fransen et al	0.65	(-0.05 to 1.38)	0.13	(-0.56 to 0.83)	0.14	(-0.18 to 1.27)	0.14	(-0.25 to 0.57)	0.18	(-0.22 to 0.58)	0.03	(-0.36 to 0.43)
	Khamis & Roche	0.85	(-0.05 to 1.38)	0.26	(-0.42 to 0.94)	0.28	(-0.41 to 0.97)	0.16	(-0.23 to 0.56)	0.20	(-0.22 to 0.58)	0.12	(-0.26 to 0.52)
Decision making (AU)	Fransen et al	0.02	(-0.65 to 0.70)	0.42	(-0.27 to 1.11)	0.13	(-0.55 to 0.82)	0.07	(-0.33 to 0.47)	0.31	(-0.08 to 0.70)	0.11	(-0.29 to 0.51)
	Khamis & Roche	0.04	(-0.65 to 0.70)	0.28	(-0.39 to 0.94)	0.40	(-0.29 to 1.11)	0.12	(-0.25 to 0.47)	0.07	(-0.31 to 0.44)	0.11	(-0.28 to 0.49)
Passing (AU)	Fransen et al	0.07	(-0.63 to 0.78)	0.13	(-0.56 to 0.84)	0.06	(-0.64 to 0.78)	0.40	(-0.00 to 0.80)	0.04	(-0.36 to 0.45)	0.46	(0.07 to 0.87)
	Khamis & Roche	0.18	(-0.51 to 0.88)	0.18	(-0.50 to 0.86)	0.21	(-0.50 to 0.92)	0.10	(-0.29 to 0.48)	0.15	(-0.26 to 0.54)	0.11	(-0.27 to 0.49)
First touch (AU)	Fransen et al	0.35	(-0.65 to 0.70)	0.02	(-0.67 to 0.71)	0.25	(-0.42 to 0.92)	0.20	(-0.20 to 0.60)	0.08	(-0.31 to 0.48)	0.36	(-0.05 to 0.74)
	Khamis & Roche	0.55	(-0.12 to 1.23)	0.22	(-0.45 to 0.88)	0.25	(-0.47 to 0.96)	0.01	(-0.37 to 0.40)	0.28	(-0.11 to 0.68)	0.22	(-0.17 to 0.61)
Control (AU)	Fransen et al	0.54	(-0.24 to 1.30)	0.12	(-0.63 to 0.84)	0.13	(-0.61 to 0.86)	0.11	(-0.31 to 0.52)	0.35	(-0.06 to 0.77)	0.39	(-0.02 to 0.82)
	Khamis & Roche	0.08	(-0.61 to 0.78)	0.41	(-0.33 to 1.14)	0.18	(-0.59 to 0.94)	0.41	(-0.33 to 1.14)	0.37	(-0.05 to 0.79)	0.13	(-0.28 to 0.53)
One v One (AU)	Fransen et al	0.23	(-0.46 to 0.91)	0.47	(-0.24 to 1.17)	0.35	(-0.35 to 1.08)	0.12	(-0.28 to 0.51)	0.00	(-0.40 to 0.41)	0.07	(-0.32 to 0.46)
	Khamis & Roche	0.11	(-0.57 to 0.82)	0.24	(-0.46 to 0.92)	0.27	(-0.44 to 0.97)	0.11	(-0.28 to 0.50)	0.10	(-0.40 to 0.41)	0.07	(-0.31 to 0.45)
Shooting (AU)	Fransen et al	0.11	(-0.62 to 0.85)	0.20	(-0.74 to 1.16)	0.16	(-0.67 to 1.00)	0.03	(-0.50 to 0.56)	0.53	(0.02 to 1.04)	0.26	(-0.24 to 0.75)
	Khamis & Roche	0.50	(0.38 to 1.38)	0.09	(-0.86 to 1.05)	0.12	(-0.76 to 0.97)	0.02	(-0.42 to 0.45)	0.02	(-0.43 to 0.46)	0.07	(-0.39 to 0.53)
Assist (AU)	Fransen et al	0.24	(-0.84 to 1.31)	0.04	(-1.24 to 1.37)	0.79	(-0.39 to 1.97)	0.29	(-0.33 to 0.90)	0.03	(-0.61 to 0.67)	0.15	(-0.49 to 0.80)
	Khamis & Roche	0.33	(-0.84 to 1.51)	0.57	(-0.90 to 2.07)	0.74	(-1.02 to 2.61)	0.15	(-0.45 to 0.78)	0.22	(0.41 to 0.88)	0.14	(-0.53 to 0.81)
Marking (AU)	Fransen et al	0.45	(-0.29 to 1.17)	0.78	(0.38 to 0.05)	0.45	(-0.29 to 1.18)	0.23	(-0.21 to 0.66)	0.11	(-0.31 to 0.52)	0.18	(-0.23 to 0.59)
	Khamis & Roche	0.65	(-0.06 to 1.30)	0.41	(-0.31 to 1.13)	0.15	(-0.60 to 0.91)	0.05	(-0.36 to 0.46)	0.07	(-0.33 to 0.47)	0.13	(-0.26 to 0.53)

Key: Peak height velocity (PHV); Highest Density Interval (HDI)

Table 5. Estimated marginal means and standardised differences between groups for tactical variables according to Fransen et al. (2018) and Khamis & Roche (1994) bio-banding methods with 95% HDI

Variable	Banding	***Post*-PHV Vs *Post*-PHV**	(95% HDI)	***Circa*-PHV vs *Circa*-PHV**	(95% HDI)	***Pre*-PHV vs *Pre*-PHV**	(95% HDI)	***Circa*-PHV vs *Post*-PHV**	(95% HDI)	***Pre*-PHV vs *Circa*-PHV**	(95% HDI)	***Pre*-PHV Vs *Post*-PHV**	(95% HDI)
SEI (AU)	Fransen et al	6.18 to 6.22	(5.72 to 6.70)	5.46 to 5.93	(4.93 to 6.49)	5.91 to 6.11	(5.44 to 6.61)	5.96 to 6.06	(5.61 to 6.42)	6.15 to 5.86	(5.49 to 6.49)	6.21 to 5.57	(5.21 to 6.54)
		0.05	(-0.67 to 0.77)	0.58	(-0.22 to 1.37)	0.33	(-0.31 to 0.97)	0.18	(-0.33 to 0.68)	0.08	(-0.37 to 0.52)	0.43	(-0.03 to 0.84)
	Khamis & Roche	5.94 to 6.14	(5.48 to 6.60)	5.57 to 6.20	(5.06 to 6.71)	5.91 to 6.11	(5.44 to 6.61)	5.83 to 5.80	(5.42 to 6.17)	6.30 to 5.82	(5.47 to 6.18)	5.81 to 5.73	(5.37 to 6.14)
		0.22	(-0.44 to 0.87)	0.69	(-0.03 to 1.41	0.22	(-0.47 to 0.91)	0.03	(-0.40 to 0.65)	0.09	(-0.33 to 0.51)	0.06	(-0.33 to 0.46)
Nearest teammate (m)	Fransen et al	5.79 to 8.82	(4.10 to 10.43)	6.52 to 6.62	(4.61 to 8.54)	6.71 to 7.10	(5.15 to 8.60)	6.72 to 7.68	(5.46 to 9.07)	6.70 to 6.73	(5.44 to 7.97)	6.78 to 7.26	(5.54 to 8.63)
		0.93	(0.21 to 1.65)	0.02	(-0.77 to 0.81)	0.13	(-0.51 to 0.77)	0.24	(-0.27 to 0.74)	0.08	(-0.36 to 0.53)	0.05	(-0.36 to 0.45)
	Khamis & Roche	5.95 to 8.28	(4.41 to 9.49)	6.64 to 6.84	(5.17 to 8.28)	6.72 to 6.88	(5.25 to 8.35)	6.72 to 7.72	(5.33 to 9.03)	6.68 to 6.73	(5.37 to 8.01)	6.72 to 7.32	(5.59 to 8.36)
		0.83	(0.17 to 1.49)	0.06	(-0.66 to 0.78)	0.03	(-0.70 to 0.77)	0.22	(-0.21 to 0.65)	0.10	(19.3 to 24.9)	0.09	(-0.30 to 0.49)
Dist to opponent centroid (m)	Fransen et al	6.66 to 9.50	(4.27 to 11.66)	6.67 to 6.82	(4.27 to 9.28)	7.78 to 8.36	(5.76 to 10.30)	6.99 to 8.36	(5.43 to 9.87)	7.74 to 6.79	(5.29 to 9.06)	7.62 to 7.85	(5.43 to 9.20)
		0.66	(-0.06 to 1.38)	0.04	(-0.75 to 0.83)	0.14	(-0.50 to 0.78)	0.32	(-0.18 to 0.82)	0.21	(-0.23 to 0.65)	0.05	(-0.35 to 0.45)
	Khamis & Roche	6.56 to 9.21	(4.74 to 10.87)	7.17 to 7.93	(5.75 to 9.80)	7.71 to 7.93	(5.75 to 9.80)	7.31 to 8.00	(6.07 to 9.02)	7.67 to 7.22	(5.94 to 8.83)	7.59 to 7.49	(6.30 to 8.77)
		0.69	(0.03 to 1.34)	0.03	(-0.69 to 0.75)	0.05	(-0.64 to 0.74)	0.18	(-0.24 to 0.61)	0.12	(-0.31 to 0.54)	0.03	(-0.37 to 0.43)
Nearest opponent (m)	Fransen et al	4.26 to 6.55	(1.99 to 8.65)	4.46 to 4.47	(1.98 to 6.72)	5.13 to 5.40	(3.26 to 7.30)	4.63 to 5.74	(3.05 to 7.13)	4.63 to 4.97	(3.25 to 6.20)	4.92 to 5.30	(3.73 to 6.53)
		0.59	(-0.13 to 1.31)	0.01	(-0.78 to 0.80)	0.07	(-0.57 to 0.71)	0.27	(-0.23 to 0.78)	0.09	(-0.35 to 0.54	0.09	(-0.31 to 0.49)
	Khamis & Roche	4.35 to 6.26	(2.37 to 7.84)	4.72 to 4.77	(2.92 to 6.66)	4.99 to 5.15	(3.22 to 6.97)	4.68 to 5.56	(3.62 to 6.72)	4.75 to 4.99	(3.67 to 6.13)	4.89 to 5.15	(3.77 to 6.30)
		0.69	(-0.12 to 1.49)	0.01	(-0.88 to 0.89)	0.05	(-0.80 to 0.90)	0.28	(-0.24 to 0.81)	0.08	(-0.44 to 0.60)	0.08	(-0.41 to 0.57)
Dist to centroid (m)	Fransen et al	5.37 to 8.02	(3.27 to 9.82)	5.87 to 5.88	(3.79 to 7.94)	6.11 to 6.83	(4.43 to 8.45)	6.07 to 6.75	(4.73 to 7.99)	6.39 to 6.02	(4.84 to 7.50)	6.39 to 6.78	(5.33 to 7.91)
		0.75	(0.03 to 1.47)	0.00	(-0.79 to 0.79)	0.20	(-0.83 to 0.44)	0.18	(-0.32 to 0.68)	0.10	(-0.35 to 0.54)	0.11	(-0.29 to 0.51)
	Khamis & Roche	5.47 to 7.68	(3.86 to 9.20)	6.03 to 6.20	(4.40 to 7.74)	6.22 to 6.41	(4.64 to 8.03)	6.12 to 6.76	(5.14 to 7.74)	6.44 to 6.17	(5.11 to 7.14)	6.32 to 6.79	(5.42 to 7.80)
		0.69	(0.03 to 1.34)	0.03	(-0.69 to 0.75)	0.05	(-0.64 to 0.74)	0.18	(-0.24 to 0.61)	0.12	(-0.31 to 0.54)	0.03	(-0.37 to 0.43)

Key: Spatial exploration index (SEI); Distance (Dist); Peak height velocity (PHV); Highest Density Interval (HDI)

Table 6. Estimated differences between groups for ratings of tactical and technical variables according to Fransen et al. and Khamis & Roche (1994) bio-banding methods.

Variable	Fransen, et al.			Khamis and Roche		
	R^2	(95% HDI)	**LOOIC**	**R^2**	(95% HDI)	**LOOIC**
Communication	0.54	(0.51 to 0.58)	1417.30	0.46	(0.41 to 0.50)	1459.10
Cover	0.23	(0.08 to 0.37)	2213.00	0.13	(0.04 to 0.27)	2227.20
Decision making	0.44	(0.39 to 0.48)	1427.20	0.36	(0.31 to 0.41)	1518.50
Passing	0.55	(0.51 to 0.59)	1372.90	0.45	(0.40 to 0.49)	1438.60
Marking	0.56	(0.52 to 0.60)	1248.70	0.43	(0.38 to 0.47)	1359.90
First Touch	0.53	(0.49 to 0.57)	1446.50	0.45	(0.40 to 0.49)	1478.90
Control	0.52	(0.48 to 0.56)	1326.30	0.41	(0.36 to 0.46)	1374.40
One v One	0.48	(0.44 to 0.52)	1419.80	0.48	(0.43 to 0.52)	1425.30
Shooting	0.34	(0.27 0.41)	958.00	0.18	(0.10 to 0.25)	1032.00
Assist	0.18	(0.07 to 0.28)	494.20	0.19	0.08 to 0.29)	487.70
Total Technical Score	0.67	(0.64 to 0.69)	4421.50	0.58	(0.54 to 0.61)	4472.00
Successful Passes	0.26	(0.20 to 0.32)	3175.10	0.30	(0.24 to 0.35)	3215.60
Unsuccessful Passes	0.07	(0.02 to 0.14)	1641.50	0.11	(0.04 to 0.20)	1611.30
Turning	0.26	(0.12 to 0.40)	253.40	0.24	(0.11 to 0.37)	228.00
Dribbling	0.24	(0.17 to 0.30)	3073.80	0.35	(0.29 to 0.41)	3069.90
Interception	0.07	(0.02 to 0.13)	1287.70	0.07	(0.02 to 0.13)	1257.80
Goals	0.15	(0.05 to 0.25)	629.00	0.12	(0.04 to 0.22)	655.40
Shots on Target	0.07	(0.02 to 0.14)	1153.70	0.07	(0.02 to 0.13)	1216.60
Shots off Target	0.11	(0.04 to 0.19)	757.70	0.11	(0.04 to 0.20)	736.60
Ground ball challenge	0.10	(0.03 to 0.18)	1470.40	0.08	(0.02 to 0.18)	1471.50
SEI	0.35	(0.28 to 0.42)	1175.30	0.37	(0.30 to 0.42)	1496.00
Distance to the nearest teammate	0.39	(0.32 to 0.45)	2396.00	0.46	(0.40 to 0.51)	2712.80

Distance to the nearest opponent	0.38	(0.32 to 0.44)	2576.00	0.45	(0.39 to 0.50)	2927.30
Distance to Centroid	0.39	(0.32 to 0.45)	2478.60	0.44	|(0.38 to 0.49)	2816.20
Distance to Opponent Centroid	0.36	(0.30 to 0.42)	2643.30	0.44	|(0.38 to 0.49)	3019.60

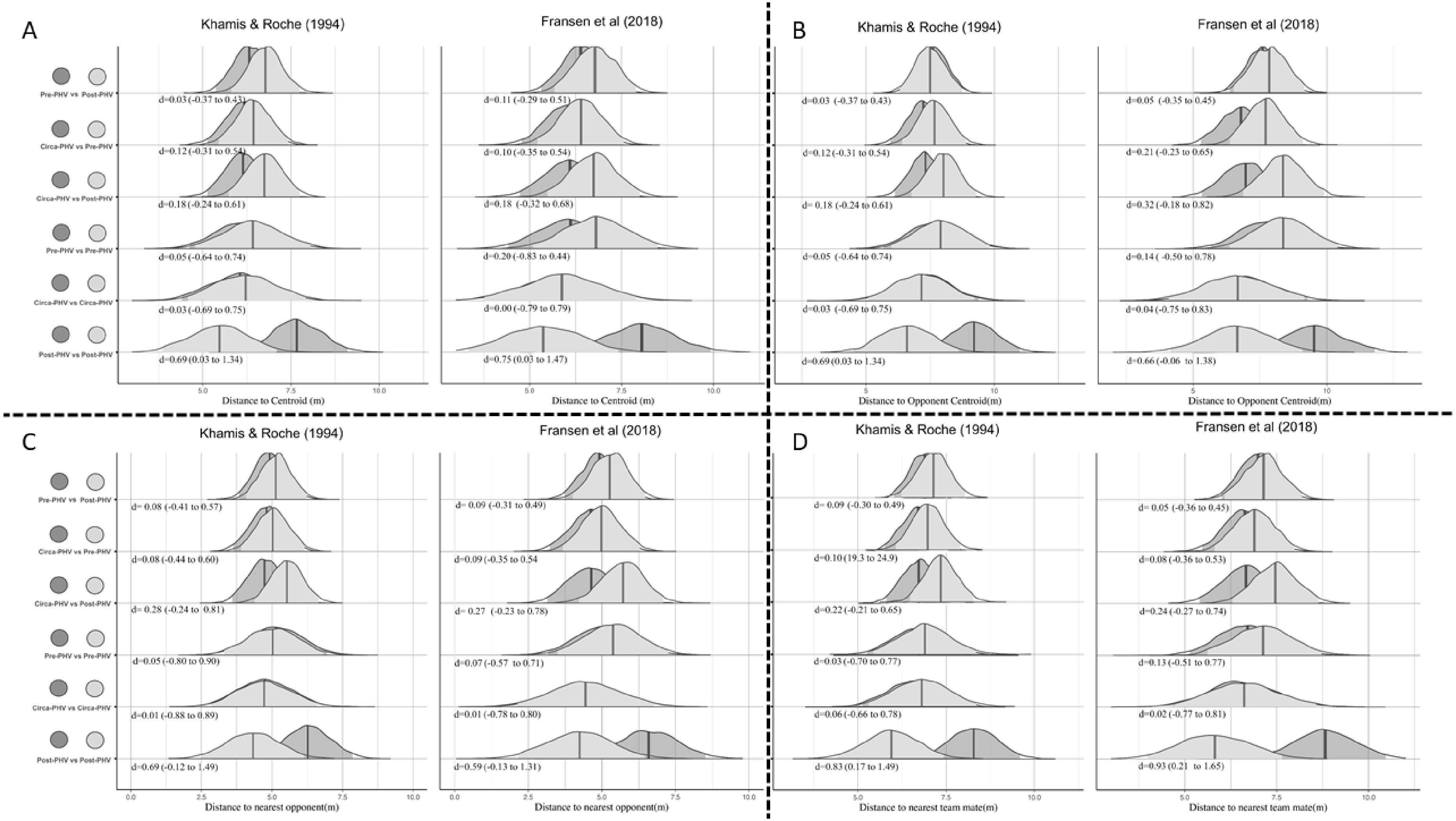
A
Khamis & Roche (1994)
Fransen et al (2018)
Pre-PHV vs Post-PHV
Circa-PHV vs Pre-PHV
Circa-PHV vs Post-PHV
Pre-PHV vs Pre-PHV
Circa-PHV vs Circa-PHV
Post-PHV vs Post-PHV
d=0.03 (-0.37 to 0.43)
d=0.12 (-0.31 to 0.54)
d=0.18 (-0.24 to 0.61)
d=0.05 (-0.64 to 0.74)
d=0.03 (-0.69 to 0.75)
d=0.69 (0.03 to 1.34)
d=0.11 (-0.29 to 0.51)
d=0.10 (-0.35 to 0.54)
d=0.18 (-0.32 to 0.68)
d=0.20 (-0.83 to 0.44)
d=0.00 (-0.79 to 0.79)
d=0.75 (0.03 to 1.47)
Distance to Centroid (m)
B
Khamis & Roche (1994)
Fransen et al (2018)
d=0.03 (-0.37 to 0.43)
d=0.12 (-0.31 to 0.54)
d= 0.18 (-0.24 to 0.61)
d=0.05 (-0.64 to 0.74)
d=0.03 (-0.69 to 0.75)
d=0.69 (0.03 to 1.34)
d=0.05 (-0.35 to 0.45)
d=0.21 (-0.23 to 0.65)
d=0.32 (-0.18 to 0.82)
d=0.14 (-0.50 to 0.78)
d=0.04 (-0.75 to 0.83)
d=0.66 (-0.06 to 1.38)
Distance to Opponent Centroid(m)
C
Khamis & Roche (1994)
Fransen et al (2018)
Pre-PHV vs Post-PHV
Circa-PHV vs Pre-PHV
Circa-PHV vs Post-PHV
Pre-PHV vs Pre-PHV
Circa-PHV vs Circa-PHV
Post-PHV vs Post-PHV
d= 0.08 (-0.41 to 0.57)
d=0.08 (-0.44 to 0.60)
d= 0.28 (-0.24 to 0.81)
d=0.05 (-0.80 to 0.90)
d=0.01 (-0.88 to 0.89)
d=0.69 (-0.12 to 1.49)
d= 0.09 (-0.31 to 0.49)
d=0.09 (-0.35 to 0.54
d= 0.27 (-0.23 to 0.78)
d=0.07 (-0.57 to 0.71)
d=0.01 (-0.78 to 0.80)
d=0.59 (-0.13 to 1.31)
Distance to nearest opponent(m)
D
Khamis & Roche (1994)
Fransen et al (2018)
d= 0.09 (-0.30 to 0.49)
d=0.10 (19.3 to 24.9)
d=0.22 (-0.21 to 0.65)
d=0.03 (-0.70 to 0.77)
d=0.06 (-0.66 to 0.78)
d=0.83 (0.17 to 1.49)
d= 0.05 (-0.36 to 0.45)
d=0.08 (-0.36 to 0.53)
d=0.24 (-0.27 to 0.74)
d=0.13 (-0.51 to 0.77)
d=0.02 (-0.77 to 0.81)
d=0.93 (0.21 to 1.65)
Distance to nearest team mate(m)

Figure 1

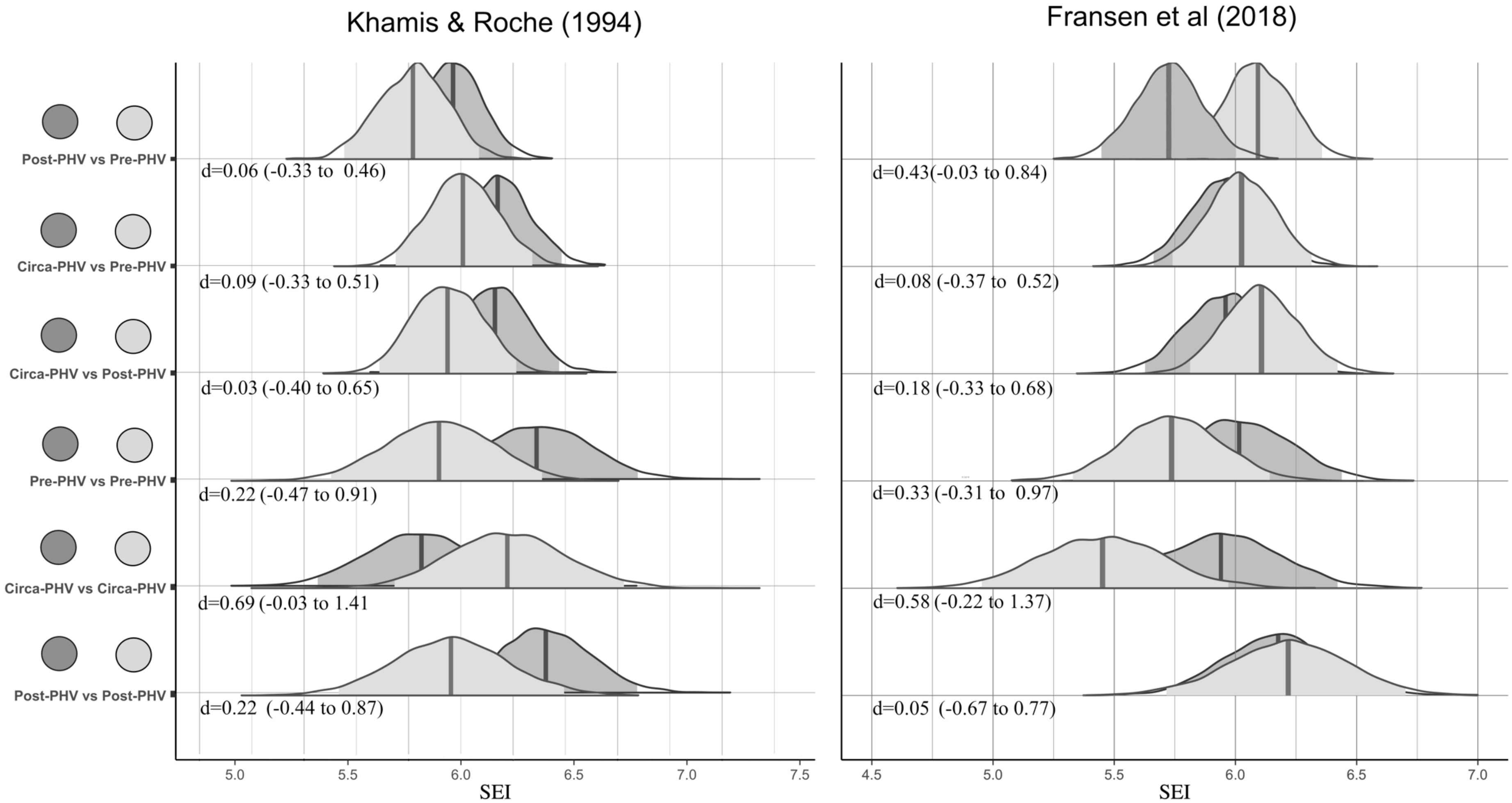
Khamis & Roche (1994)
Fransen et al (2018)
Post-PHV vs Pre-PHV
Circa-PHV vs Pre-PHV
Circa-PHV vs Post-PHV
Pre-PHV vs Pre-PHV
Circa-PHV vs Circa-PHV
Post-PHV vs Post-PHV
d=0.06 (-0.33 to 0.46)
d=0.09 (-0.33 to 0.51)
d=0.03 (-0.40 to 0.65)
d=0.22 (-0.47 to 0.91)
d=0.69 (-0.03 to 1.41
d=0.22 (-0.44 to 0.87)
d=0.43(-0.03 to 0.84)
d=0.08 (-0.37 to 0.52)
d=0.18 (-0.33 to 0.68)
d=0.33 (-0.31 to 0.97)
d=0.58 (-0.22 to 1.37)
d=0.05 (-0.67 to 0.77)
5.0
5.5
6.0
6.5
7.0
7.5
4.5
5.0
5.5
6.0
6.5
7.0
SEI
SEI

Figure 2.