The effect of bio-banding on physical and psychological 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 indicators of talent identification in academy soccer players. Seventy-two 11 to 14-year-old soccer players were bio-banded using percentage of estimated adult stature attainment (week 1), maturity-offset (week 2) or a mixed-maturity method (week 3). Players contested five maturity (mis)matched small-sided games with physical and psychological determinants measured. Data were analysed using a series of Bayesian hierarchical models, fitted with different response distributions and different random and fixed effect structures. Few between-maturity differences existed for physical measures. *Pre*-peak height velocity (PHV) and *post*-PHV players differed in PlayerLoad™ (anterior-posterior and medial-lateral) having effect sizes above our criterion value. Estimated adult stature attainment explained more of the variance in eight of the physical variables and showed the greatest individual differences between maturity groups across all psychological variables. *Pre*-PHV and *post*-PHV players differed in positive attitude, confidence, competitiveness, total psychological score (effect sizes = 0.43-0.69), and session rating of perceived exertion. The maturity-offset method outperformed the estimated adult stature attainment method in all psychological variables. Maturity-matched bio-banding had limited effect on physical variables across all players while enhancing a number of psychological variables considered key for talent identification in *pre*-PHV players.

Keywords: maturation; bio-banding; soccer; talent identification; psychological; physical;

INTRODUCTION

The onset of the adolescent growth spurt (i.e. peak height velocity [PHV]) is highly individualised[1] with onset and cessation likely occurring in academy soccer players between 9.7-10.7 and 13.8-15.2 years[1 2]. The unpredictable nature of the adolescent growth spurt, during which PHV is achieved is a major contributing factor to the over-selection of early-maturing players who possess transient superior anthropometric (i.e. stature, body mass) and physical performance (speed, power strength) characteristics[3-5]. That said, there is conjecture within the literature as to the effect of maturation on match-play physical performance, with Lovell et al[6] reporting more high-intensity distance covered by late-maturing players yet Buchheit et al[7] reporting the opposite. Similarly, it is unclear if late-maturing players either already possess, or gain, a psychological advantage over their early-maturing counterparts[8] across the development pathway. These psychological aspects are important, as late-maturing players have been characterised as being achievement-oriented and highly skilled (between 13 and 14 years[9]), which are central to the onset and cessation of PHV[1 2]. This is also important for practitioners, as soccer academy recruitment staff place greater value on psychological characteristics than technical/tactical and physical factors during talent selection[10]. Psychological attributes such as 'confidence', 'competitiveness', 'X-Factor', and 'positive attitude' (see Larkin & O'Connor[11]) appear to be valued the most. Therefore, given that the timing and tempo of biological maturity influences the physical and psychological development of children[12], it is important that 'bio-banding' methods possess the capacity to identify talented soccer players according to their physical and psychological characteristics. The differing effects of maturation can confound the identification of talent and result in the 'false-positive' selection of players possessing temporary, age-related enhancements in key selection metrics such as match running performance[13] and likely thwart the size of the talent pool.

Given the asynchronous relationship between child growth rate and decimal age[1 2], 'bio-banding' is an alternative method to chronological age groupings for grouping players. Bio-banding categorises adolescent players according to their discrete maturity status bandings, using maturity estimate equations that either model normal growth curves of adolescents, with child anthropometric characteristics[14-16] and-or which encompass mid-parent height[17]. Therefore, bio-banding results in groups of players that exhibit reduced variance in anthropometric characteristics that can confound selection and playing position allocation[3 4 18].

To reduce the effect of these maturity-related issues, a method termed 'bio-banding' has been developed[19-21]. Bio-banding eliminates the use of chronological age groups by categorising adolescent players according to discrete maturity-status bandings[19-22]. Bio-banding programmes have been well received by both early and late-maturing players during bio-banded tournaments[22] and researchers have suggested that bio-banding might reduce the incidence of player injury[23] and enhance talent selection processes and player perceptions of maturity-matched formats[22]. Despite bio-banding being introduced by national leagues[22] and professional academies[20], there is limited applied[20-22] evidence for its efficacy for uncovering multi-disciplinary components of soccer talent. Although the limitations associated with estimating the stage of maturation using the original[14] and subsequent iterations[15 16] of the maturity offset measures are well documented[24-28], it remains unclear if either the maturity offset[21] or percentage of estimated adult stature attainment[20 22] methods should be used to 'bio-band' players. There is also little evidence on the effects of bio-banding on psychological characteristics and small-sided game formats as are typically used in talent identification[29]. Therefore, the aim of this study was to examine the effect of bio-banding on important aspects of physical and psychological components of talent identification during bio-banded small-sided games.

METHODS

Study design

Following ethics committee approval (approval number 1819011) and parental consent, participating players completed a full familiarisation one week prior to the commencement of testing. For the experimental trials, 72, 11 to 14-year-old male academy soccer players from three UK-based soccer academies participated in a three-week, repeated-measures study. Using two separate anthropometric-based methods for estimating biological maturity status, 24 players from each academy were bio-banded using the Khamis and Roche (1994) method (Khamis-Roche[17]) in week 1 and the Fransen et al. (2019) method (Fransen[16]) in week 2, while a mixed-maturity grouping method was used in week 3.

Using previously published methods (See Fenner et al 2016[29]), each week players completed a standardised 15-minute warm-up prior to contesting five, four versus four small-sided games (18.3 m x 23 m pitch), lasting 5 min each (25 min total playing time) on an outdoor 3G surface. A 'round-robin' small-sided games mini-league format was used, during which players' physical and psychological responses were measured during 'matched' (e.g. *pre*-PHV vs *pre*-PHV) and 'mismatched' (e.g. post-PHV vs *pre*-PHV) small-sided games. Each team received a minimum of five and maximum of 15 minutes of low-intensity recovery between small-sided games. During this time, players performed one of three standardised technical drills to maintain match-readiness. The sequence of small-sided games was repeated for each bio-banding method, interspaced by one week.

Participants

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) which 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. 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.

Anthropometric and Maturity measurements

Player body-mass and stature were recorded according to previously published methods[2]. In week 1, the Khamis-Roche[17] method used the interactions between stature, body-mass, age and mid-parental height to estimate player maturity status, reporting a measurement error of 2.2 cm between actual and estimated adult stature in male athletes aged between 4 and 18 years[17]. As with previous work[22], the present study collected self-reported stature of both biological parents and was adjusted for over-estimations using equations based on measured and self-reported stature of U.S. adults.[30] This method is validated against criterion skeletal maturity[31] with an adjusted threshold of 87.0 to 92.0% of estimated adult stature attainment. Although it is acknowledged that PHV typically onsets at approximately 86% estimated adult stature attainment[22], to permit common terms to be used, bandings were defined in the present study as '*post*-PHV' (> 92.0 % estimated adult stature attainment), '*circa*-PHV' (87.0 – 92.0% estimated adult stature attainment) and '*pre*-PHV' (< 87.0 % estimated adult stature attainment).

Estimated years to PHV were calculated using the Fransen[16] method to bio-band players in week 2. This equation was developed using an 'enhanced' predictive model based on original methods[14]. Player maturity offset was determined by subtracting decimal age in years from predictive age at PHV to give the estimated years to PHV. Similar to a previous study[14], the following 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), *post*-PHV (>0.0 years to PHV).

Players who had competed in weeks 1 and 2 were randomly assigned to six 'mixed' maturity teams by a practitioner with no prior knowledge of players somatic characteristics. This 'mixed' maturity condition served as a surrogate control. Unfortunately, we could not use a true control condition based on chronological age grouping, as the number of small-sided games required for this was greater than the number of players participating and the time available in which to collect data. In consultation with academy staff it was decided that a true control condition would cause unreasonable disruption to the players games and athletic development programmes. For the purpose of analysis, teams were aggregated into three 'mixed' maturity bandings to permit pairwise comparisons of anthropometric, age and maturity characteristics.

Physical Measures

To provide valid and reliable information[32], players wore a manufacturer-provided vest that housed a micro-electro-mechanical systems device (Optmeye X4, Catapult Innovations, Melbourne, Australia) containing a 10 Hz global positioning satellite (GPS) chip and 100 Hz accelerometer. Total distance [m], maximum running speed [$km \cdot h^{-1}$], high-speed running distance using arbitrary speed thresholds[13] [HSR: >13 $km \cdot h^{-1}$; m], vector magnitude PlayerLoad™ ($PlayerLoad_{VM}$) and individual-component planes of PlayerLoad^{TM} (anterior-posterior PlayerLoad^{TM} [PlayerLoad$_{AP}$], medial-lateral PlayerLoad^{TM} [PlayerLoad$_{ML}$] and vertical PlayerLoad^{TM} [PlayerLoad$_{V}$]) were recorded. The mean (SD) number of satellites and horizontal dilution of position during the small-sided games was 10.4 (2.2) and 1.0 (0.2) respectively, which are considered as standard for good GPS signal coverage[33]. Mean heart rate (beats·min^{-1}) was recorded every 5 s (T31, Polar Electro Oy, Finland) via a chest strap synced to the same micro-electro-mechanical systems device as mentioned above. Players provided a session rating of perceived exertion (sRPE)[34] after each small-sided game, which was subsequently multiplied by the small-sided game's duration (i.e. 5 minutes) to obtain sRPE-training load (sRPE-TL). To control for bias and coercion, each player provided an sRPE independently using the category-ratio scale[35].

Psychological measures

Four Union of European Football Associations (UEFA) C to UEFA B qualified coaches from each academy (total: n = 12) independently assessed players for evidence of four key psychological attributes - 'confidence', 'competitiveness', 'X-Factor', 'positive attitude' that youth coaches and recruiters perceive as most important when identifying players for talent identification programmes[11 36]. Although these psychological constructs might be limited in psychometric grounding, it was considered that that these measures reflect 'real-world' academy practices and therefore likely possess a high-level of ecological validity. Coaches were provided with an operational definition for each of these attributes (see Table 1) which were piloted with practitioners for content validity (two UEFA B Licence coaches, 10 years coaching experience). These attributes were given a score between 0 and 5. Each point described the players' performance during the small-sided games using the following criteria: 1 – *poor*, 2 – *below average*, 3 – *average*, 4 – *very good* and 5 – *excellent* and the points accrued over five small-sided games for psychological measures were aggregated to represent their overall score out of 20.

*****Table 1 about here*****

Statistical analysis

Descriptive statistics are reported as means and standard deviations. Differences between the banding categories (*pre*-PHV, *circa*-PHV, *post*-PHV) for Fransen[16] and Khamis-Roche[17] were determined using a series of Bayesian hierarchical models fitted with different response distributions and different random and fixed effect structures. Models were fitted for each measured parameter when teams were matched and mismatched with those more or less mature. As a control comparison, the same models were fitted for teams comprising of players of maturation groups playing each other.

Delta total (δt), an effect size similar to a Cohen's d for mixed effect models, was calculated from posterior distributions[37]. A lower bound threshold of 0.4 was set for δt based on the probability of superiority[38]. Probability of direction (pd)[39], the probability of a difference in a particular direction, is reported. A number of techniques were used to determine whether Fransen[16] or Khamis-Roche[17] banding equations better explained the data, in terms of out- of -sample prediction and relative evidence; Bayesian R squared[40], Leave-One-Out cross-validation (LOO)[41], and Bayes Factors. Bayes Factors compared the marginal likelihoods of the two models (Fransen[16] or Khamis-Roche[17]) with an equal prior probability.

All analyses were conducted using R[42] and with the Bayesian Regression Models in Stan (brms) package which uses Stan (Stan Development Team, 2018)[43]. All models were checked for convergence ($\hat{r} = 1$), with the graphical posterior predictive checks showing the models selected had no systematic discrepancies between the predictive distribution yrep compared to the observed data y[44].

RESULTS

The descriptive statistics for each of the overall banding categories for physical and psychological variables are shown in Table 2.

*******Table 2 about here*******

Physical characteristics

The largest estimated differences across physical measures are between *pre*-PHV and *circa*-PHV maturing, with PlayerLoad_{AP}, (Fransen[16]) and PlayerLoad_{ML} (Khamis-Roche[17]) having effect sizes above our criterion value (see Table 2). Differences for mixed comparison groups were generally widely dispersed ($PlayerLoad_{AP}$ = 0.13 to 0.60; PL_{ML} = 0.15 to 0.73 - see supplementary table 1 and 3). *Post*-PHV players showed the higher estimated means for $PlayerLoad_{AP}$ values (pd = 84.79%), and *pre*-PHV-maturing higher estimated $PlayerLoad_{ML}$ values (pd = 100%). Estimated differences between *pre* and *post*-PHV are also the largest for maximum velocity (Fransen[16]) and high-speed running distance (Khamis-Roche[17]), but these fell below the 0.4 criterion value and had lower probabilities of direction (pd = 63.91% and 74.48%). The only other estimated difference in physical measures above our criterion effect size value, was for mean heart rate (Fransen[16]) when the on-time groups played each other (pd = 95.96%).

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

Psychological characteristics

The Khamis-Roche[17] method shows the greatest individual differences between maturation groups across all psychological variables (see Table 3). The largest differences and the only variables above our 0.4 effect size threshold being between *pre* and *post*-PHV players in: positive attitude, confidence, competitiveness, total psychological score (Figure 1) and sRPE-TL (Figure 2). As a comparison, difference for the mixed comparison groups were more dissipated (positive attitude = 0.10 to 0.45; confidence = 0.07 to 0.40; competitiveness = 0.04 to 0.35, and sRPE = 0.36 to 0.81- see supplementary table 1 and 2). *Pre*-PHV players across all these measures show the highest ratings and lowest uncertainty (pd = 100%). Although below our effect size criterion for X-factor ratings, the biggest differences are between the Khamis-Roche[17] on-time groups playing each other, but the difference is highly uncertain (pd = 55.39%). Khamis-Roche[17] *pre* versus *post*-PHV players is almost as high but far less uncertain; *post*-PHV players having higher ratings (pd = 98.64%).

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

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

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

Variance explained out-of-sample prediction and relative evidence

In terms of variance explained (R^2), out-of-sample prediction (LOOIC) and relative evidence (Bayes Factors), the Khamis-Roche[17] method explained more of the variance in eight of the physical variables, but only outperformed the Fransen[16] method across all indices used in two of the variables - PlayerLoad™ per minute and PlayerLoad$_{ML}$ (see Table 4). In terms of the psychological variables, the Fransen[16] method outperformed Khamis-Roche[17] in all variables.

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

DISCUSSION

The main findings of our study are that (1) maturity-matched bio-banding had little effect on physical variables, (2) *pre*-PHV players showed enhanced psychological characteristics when compared to *post*-PHV players during maturity mis-matched bio-banded small-sided games, and (3) the Khamis-Roche[17] explained more of the variance in eight of the ten physical variables, with the Fransen[16] method outperforming the Khamis-Roche[17] method in all of the measured psychological variables.

Despite *post*-PHV players typically possessing superior, transient maturity-related fitness characteristics[3], maturity-matched bio-banding, intuitively had limited effect on physical variables. That said, there were few differences in physical performance variables to start with during the most extreme condition – when *pre*-PHV players played *post*-PHV players. Therefore, limiting the inferences that can be made about the effectiveness of bio-banding to manipulate physical outputs. Although the small-sided game dimensions, player numbers, and rules implemented within the present study were valid as a tool for talent identification[29] and commonplace within the tested soccer academies, the small playing area (52.6 m^2 per player) and short duration (5 min) could have restricted any physical (dis)advantages being afforded to a specific maturity group during mis-matched small-sided games. For instance, larger pitch areas elicit greater physical demands and more opportunity for players to record higher running speeds[45]. However, little physical differences have been shown to exist during bio-banded full match-play formats of longer duration[20]. This absence is replicated within the present study and was perhaps related to external loads being related to the narrow score-lines, with greater distances covered at higher intensities when small-sided games end in a draw[46], which can be considered less likely during maturity mis-matched small-sided games. This is of significance, given that superior physical fitness has been shown to characterise retained academy soccer players[18] and that ultimately players will play on larger pitches as they get older. Therefore, more research exploring the effect and match-to-match variability of pitch size during bio-banded small-sided games is warranted.

Despite this, meaningful differences in PlayerLoad$_{AP}$ (δt = 0.48 to 0.59) and PlayerLoad$_{ML}$ (δt = 0.65 to 0.75) were identified during mis-matched games (*pre*-PHV vs *post* PHV), with *pre*-PHV players experiencing higher values. This difference was reduced during the mixed condition and largely eliminated during maturity-matched (*pre*-PHV vs *pre*-PHV) games. The mixed maturity condition was used in the current study to simulate traditional chronological age groupings, where enhanced anthropometric and performance characteristics appear. However, it is important to note that the mixed condition did not result in 'normal' chronological age groupings and comprised of players from different chronological ages. This likely enhanced the variance in maturity-associated anthropometric and physical fitness characteristics, which perhaps exaggerates the effectiveness of both bio-banding interventions.

Heightened levels of PlayerLoad^{TM} facets in *pre*-PHV players may be indicative of reduced postural control[47] and is of particular relevance to athlete development practitioners, given that adolescent soccer players may experience transient reductions in biomechanical efficiency (known as 'adolescent awkwardness'[48]), which likely coincide with periods of accelerated growth in stature[1,2], while the associated musculature develops at a slower rate[48,49]. In addition to added PlayerLoad^{TM}, *pre*-PHV players also accumulated greater sRPE-TL when contesting mis-matched bio-banded small-sided games. Although there were meaningful differences between-maturity groups for sRPE-TL during miss-matched small-sided games, measures of internal load (mean heart rate) showed no reasonable difference between groups. This is possibly the result of *pre*-PHV players perceiving a different facet (e.g. technical, tactical, psychological) of small-sided game performance as physical exertion.

Our findings suggest that performing in maturity mis-matched bio-banded small-sided games might provide *pre*-PHV players with playing conditions that allow them to demonstrate a number of enhanced highly-desirable psychological characteristics, specifically during the Khamis-Roche[17] method (δt = 0.43 to 0.69). These findings might be partially explained by the 'underdog hypothesis'[8 50] which postulates that *pre*-PHV players have developed superior psychological skills that enable them to compete with their more mature counterparts on absolute terms[50]. More specifically, it could be suggested that *pre*-PHV players possessed more advanced self-regulatory skills, which represents the extent to which individuals are metacognitively, motivationally, and behaviourally proactive participants in their learning process[51]. This is important because self-regulatory skills have been found to differentiate expert athletes from their less-skilled counterparts[52]. It is possible that the *pre*-PHV players possess greater potential for success at senior level owing to their enhanced ability to self-regulate the thoughts, feelings, or actions that they use to achieve various goals. However, testing this hypothesis was not within the scope of the present study.

The present study showed that the Khamis-Roche[17] method explained more of the variance in eight of the physical variables, while the Fransen[16] method explained a greater proportion of the variance in the psychological variables. This would suggest that neither method outperforms the other and therefore both methods have strengths and weakness that need to be explored and understood. Although each method provides a non-invasive, cost- and time effective alternative to estimate biological maturity status, the disparity in these findings is likely influenced by the limitations in the methods to bio-band players. Unlike the original Mirwald et al.[14] equation, the enhanced Fransen[16] regression equation was developed using the original data-set[14], but validated implementing a polynomial model to better represent the non-linear development of anthropometric and physical performance characteristics of an ethnically diverse sample of adolescent soccer players. However, unlike the Fransen[16] method, the Khamis-Roche[17] method encompasses a 'genetic component' by including mid-biological parental height to estimate adult stature attainment. However, it is likely that parental height is often self-reported and measures are corrected for over-estimation[30]. In addition, it was validated against the Fels longitudinal study[31] using white, middle-class families of upper socioeconomic status. Therefore, the usefulness and accuracy of both methods may be questioned given the increasingly diverse nature of contemporary soccer clubs[53] (see review by Towlson et al[25]). That said, the predicted age at PHV using the Fransen method failed to coincide with the observed age at PHV, using a limited (n =17) longitudinal sample of academy soccer players[54]. In addition, the Khamis-Roche[17] method has also been shown to possess superior prediction qualities by identifying 96% of players as experiencing the adult height window[28], whereas original methods[14] for estimating age at PHV correctly identified 65% as experiencing PHV[28]. Despite this, the lack of consensus for a preferred method of bio-banding players is likely to be a result of a combination of the aforementioned limitations, practicalities absence of governing body consensus for the application maturity estimation equations. However, as indicated within this study, both the Fransen[16] and Khamis-Roche[17] methods show some early evidence of being acceptable methods for bio-banding academy soccer players on the proviso that the limitations and practicalities of implementation are carefully considered in relation to player characteristics being assessed.

Conclusion

Our study suggests that maturity-matched bio-banding intuitively had limited effect on a number of physical variables during maturity matched bio-banded formats. However, these findings also continued during maturity mis-matched bio-banded formats which limits the inferences that can be made regarding the effectiveness of bio-banding to manipulate physical outputs. That said, maturity mis-matched bio-banding is an effective format to enhance coaches ability to identify key psychological player characteristics, which are likely displayed in times of adversity, notably when competing against taller, stronger and faster players. That said, although mis-matched maturity bio-banded small-sided games may elicit desirable psychological responses, practitioners should also consider that such mis-matched maturity bio-banding formats can also provoke increases in facets of PlayerLoad™. Such increases could influence a players risk of sustaining a non-contact injury whilst experiencing 'adolescent awkwardness'[48] typically onset during periods of accelerated growth, although more research is required on this. Lastly, evidence to support a single method to bio-band players is inconclusive, despite the authors acknowledging superior prediction qualities of the Khamis-Roche[17] method[28]. We would suggest that soccer academy practitioners take a nuanced approach to bio-banding and consider which format (i.e. maturity matched or maturity mis-matched) of bio-banding will likely provide players with an optimum playing environment to exhibit characteristics considered important for player (de)selection processes. Therefore, the practical applications of this study are three-fold: 1) maturity miss-matched bio-banding (i.e. *pre*-PHV vs *post*-PHV) provides a suitably challenging playing environment that affords less mature players the opportunity to display key psychological characteristics considered desirable during talent selection, and which otherwise would be hidden during chronologically banded match-play, 2) maturity (miss)matched bio-banding offers little value for practitioners when trying to assess physical match-play activities. However, the influence of relative pitch-size during such game formats should be examined, 3) although this study shows no conclusive evidence for the preference of either maturity estimation equation, practitioners should consider the estimation error within each bio-banding method and the implications this may have on the (miss)categorisation of players.

Disclosure of interest

The authors report no conflicts of interests.

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REFERENCES

1. Philippaerts RM, Vaeyens R, Janssens M, et al. The relationship between peak height velocity and physical performance in youth soccer players. *J Sports Sci* 2006;24(3):221-30. doi: 10.1080/02640410500189371 [published Online First: 2005/12/22]

2. Towlson C, Cobley S, Parkin G, et al. When does the influence of maturation on anthropometric and physical fitness characteristics increase and subside? *Scand J Med Sci Sports* 2018;28(8):1946-55. doi: 10.1111/sms.13198 [published Online First: 2018/04/19]

3. Lovell R, Towlson C, Parkin G, et al. Soccer Player Characteristics in English Lower-League Development Programmes: The Relationships between Relative Age, Maturation, Anthropometry and Physical Fitness. *PLoS One* 2015;10(9):e0137238. doi: 10.1371/journal.pone.0137238 [published Online First: 2015/09/04]

4. Towlson C, Cobley S, Midgley AW, et al. Relative Age, Maturation and Physical Biases on Position Allocation in Elite-Youth Soccer. *Int J Sports Med* 2017;38(3):201-09. doi: 10.1055/s-0042-119029 [published Online First: 2017/02/22]

5. Deprez D, Fransen J, Boone J, et al. Characteristics of high-level youth soccer players: variation by playing position. *J Sports Sci* 2015;33(3):243-54. doi: 10.1080/02640414.2014.934707 [published Online First: 2014/07/08]

6. Lovell R, Fransen J, Ryan R, et al. Biological maturation and match running performance: A national football (soccer) federation perspective. *J Sci Med Sport* 2019;22(10):1139-45. doi: 10.1016/j.jsams.2019.04.007 [published Online First: 2019/05/06]

7. Buchheit M, Mendez-Villanueva A. Effects of age, maturity and body dimensions on match running performance in highly trained under-15 soccer players. *J Sports Sci*

2014;32(13):1271-8. doi: 10.1080/02640414.2014.884721 [published Online First: 2014/05/03]

8. Cumming SP, Searle C, Hemsley JK, et al. Biological maturation, relative age and self-regulation in male professional academy soccer players: A test of the underdog hypothesis. *Psychology of Sport and Exercise* 2018;39:147-53.

9. Zuber C, Zibung M, Conzelmann A. Holistic Patterns as an Instrument for Predicting the Performance of Promising Young Soccer Players - A 3-Years Longitudinal Study. *Front Psychol* 2016;7:1088. doi: 10.3389/fpsyg.2016.01088 [published Online First: 2016/08/12]

10. Towlson C, Perry J, Levett N, et al. Practitioners' perspectives of soccer talent according to playing position and the FA's four-corner model in academy soccer. Under Review. *International Journal of Sport Science and Coaching* 2019;Accepted

11. Larkin P, O'Connor D. Talent identification and recruitment in youth soccer: Recruiter's perceptions of the key attributes for player recruitment. *PLoS One* 2017;12(4):e0175716. doi: 10.1371/journal.pone.0175716 [published Online First: 2017/04/19]

12. Malina RM, Bouchard C, Bar-Or O. Growth, Maturation, and Physical activity: Human Kinetics Publishers 2004.

13. Buchheit M, Mendez-Villanueva A, Simpson B, et al. Match running performance and fitness in youth soccer. *Int J Sports Med* 2010;31(11):818-25.

14. Mirwald RL, Baxter-Jones AD, Bailey DA, et al. An assessment of maturity from anthropometric measurements. *Med Sci Sports Exerc* 2002;34(4):689-94. doi: 10.1097/00005768-200204000-00020 [published Online First: 2002/04/05]

15. Moore SA, McKay HA, Macdonald H, et al. Enhancing a Somatic Maturity Prediction Model. *Med Sci Sports Exerc* 2015;47(8):1755-64. doi: 10.1249/mss.0000000000000588 [published Online First: 2014/11/26]

16. Fransen J, Bush S, Woodcock S, et al. Improving the Prediction of Maturity From Anthropometric Variables Using a Maturity Ratio. *Pediatr Exerc Sci* 2018;30(2):296-307. doi: 10.1123/pes.2017-0009 [published Online First: 2017/06/13]

17. Khamis HJ, Roche AF. Predicting adult stature without using skeletal age: the Khamis-Roche method. *Pediatrics* 1994;94(4 Pt 1):504-7. [published Online First: 1994/10/01]

18. Deprez DN, Fransen J, Lenoir M, et al. A retrospective study on anthropometrical, physical fitness, and motor coordination characteristics that influence dropout, contract status, and first-team playing time in high-level soccer players aged eight to eighteen years. *J Strength Cond Res* 2015;29(6):1692-704. doi: 10.1519/jsc.0000000000000806 [published Online First: 2015/05/27]

19. Cumming SP, Lloyd RS, Oliver JL, et al. Bio-banding in Sport: Applications to Competition, Talent Identification, and Strength and Conditioning of Youth Athletes. *Strength & Conditioning Journal* 2017;39(2):34-47. doi: 10.1519/ssc.0000000000000281

20. Abbott W, Williams S, Brickley G, et al. Effects of Bio-Banding upon Physical and Technical Performance during Soccer Competition: A Preliminary Analysis. *Journal of Sports* 2019;7(8) doi: 10.3390/sports7080193 [published Online First: 2019/08/17]

21. Romann M, Lüdin D, Born D-P. Bio-banding in junior soccer players: a pilot study. *BMC Research Notes* 2020;13(1):240. doi: 10.1186/s13104-020-05083-5

22. Cumming SP, Brown DJ, Mitchell S, et al. Premier League academy soccer players' experiences of competing in a tournament bio-banded for biological maturation.

Journal Sports Science 2018;36(7):757-65. doi: 10.1080/02640414.2017.1340656 [published Online First: 2017/06/20]

23. Baxter-Jones A, Helms P, Maffulli N, et al. Growth and development of male gymnasts, swimmers, soccer and tennis players: a longitudinal study. *Annals of Human Biology* 1995;22(5):381-94.

24. Kozieł SM, Malina RM. Modified Maturity Offset Prediction Equations: Validation in Independent Longitudinal Samples of Boys and Girls. *Sports Med* 2018;48(1):221-36. doi: 10.1007/s40279-017-0750-y [published Online First: 2017/06/14]

25. Towlson C, Salter J, Ade JD, et al. Maturity-associated considerations for training load, injury risk, and physical performance within youth soccer: One size does not fit all. *J Sport Health Sci* 2020 doi: 10.1016/j.jshs.2020.09.003 [published Online First: 2020/09/23]

26. Nevill A, Burton RF. Commentary on the Article "Improving the Prediction of Maturity From Anthropometric Variables Using a Maturity Ratio". *Pediatr Exerc Sci* 2018;30(2):308-10. doi: 10.1123/pes.2017-0201 [published Online First: 2017/11/22]

27. Fransen J, Baxter-Jones A, Woodcock S. Responding to the Commentary on the Article: "Improving the Prediction of Maturity From Anthropometric Variables Using a Maturity Ratio". *Pediatr Exerc Sci* 2018;30(2):311-13. doi: 10.1123/pes.2017-0249 [published Online First: 2017/12/26]

28. Parr J, Winwood K, Hodson-Tole E, et al. Predicting the timing of the peak of the pubertal growth spurt in elite youth soccer players: evaluation of methods. *Ann Hum Biol* 2020:1-23. doi: 10.1080/03014460.2020.1782989 [published Online First: 2020/06/17]

29. Fenner JS, Iga J, Unnithan V. The evaluation of small-sided games as a talent identification tool in highly trained prepubertal soccer players. *J Sports Sci* 2016;34(20):1983-90. doi: 10.1080/02640414.2016.1149602 [published Online First: 2016/03/05]

30. Epstein LH, Valoski AM, Kalarchian MA, et al. Do children lose and maintain weight easier than adults: a comparison of child and parent weight changes from six months to ten years. *Obes Res* 1995;3(5):411-7. doi: 10.1002/j.1550-8528.1995.tb00170.x [published Online First: 1995/09/01]

31. Malina RM, Chamorro M, Serratosa L, et al. TW3 and Fels skeletal ages in elite youth soccer players. *Ann Hum Biol* 2007;34(2):265-72. doi: 10.1080/03014460701207601 [published Online First: 2007/06/15]

32. McLean BD, Cummins C, Conlan G, et al. The Fit Matters: Influence of Accelerometer Fitting and Training Drill Demands on Load Measures in Rugby League Players. *Int J Sports Physiol Perform* 2018;13(8):1083-89. doi: 10.1123/ijspp.2017-0729 [published Online First: 2018/02/13]

33. Malone JJ, Lovell R, Varley MC, et al. Unpacking the black box: applications and considerations for using GPS devices in sport. *International journal of sports physiology and performance* 2017;12(s2):S2-18-S2-26.

34. Coutts A, Reaburn P, Murphy A, et al. Validity of the session-RPE method for determining training load in team sport athletes. *J Sci Med Sport* 2003;6:525.

35. Foster C, Florhaug JA, Franklin J, et al. A new approach to monitoring exercise training. *Journal of Strength and Conditioning Research* 2001;15(1):109-15.

36. Towlson C, Cope E, Perry JL, et al. Practitioners' multi-disciplinary perspectives of soccer talent according to phase of development and playing position. *International Journal of Sports Science & Coaching* 2019;14(4):528-40. doi: 10.1177/1747954119845061

37. Hedges LV. Effect Sizes in Cluster-Randomized Designs. *Journal of Educational and Behavioral Statistics* 2007;32(4):341-70. doi: 10.3102/1076998606298043

38. McGraw KO, Wong SP. A common language effect size statistic. *Psychological bulletin* 1992;111(2):361.

39. Makowski D, Ben-Shachar MS, Chen SHA, et al. Indices of Effect Existence and Significance in the Bayesian Framework. *Front Psychol* 2019;10:2767. doi: 10.3389/fpsyg.2019.02767 [published Online First: 2020/01/11]

40. Gelman A, Goodrich B, Gabry J, et al. R-squared for Bayesian Regression Models. *The American Statistician* 2019;73(3):307-09. doi: 10.1080/00031305.2018.1549100

41. Vehtari A, Gelman A, Gabry J. Practical Bayesian model evaluation using leave-one-out cross-validation and WAIC. *Statistics and Computing* 2017;27(5):1413-32. doi: 10.1007/s11222-016-9696-4

42. Team RC. R: A Language and Environment for Statistical Computing (Version 3.5. 2, R Foundation for Statistical Computing, Vienna, Austria, 2018). *There is no corresponding record for this reference[Google Scholar]* 2019

43. Team SD. RStan: the R interface to Stan. *R package version* 2016;2(1)

44. Gabry J, Simpson D, Vehtari A, et al. Visualization in Bayesian workflow. *Journal of the Royal Statistical Society: Series A (Statistics in Society)* 2019;182(2):389-402. doi: 10.1111/rssa.12378

45. Owen A, Twist C, Ford P. Small-sided games: The physiological and technical effect of altering pitch size and player numbers. *Insight* 2004;7(2):50-53.

46. Lorenzo-Martínez M, de Dios-Álvarez VM, Padrón-Cabo A, et al. Effects of score-line on internal and external load in soccer small-sided games. *International Journal of Performance Analysis in Sport* 2020;20(2):231-39. doi: 10.1080/24748668.2020.1736938

47. Wachholz F, Tiribello F, Mohr M, et al. Adolescent Awkwardness: Alterations in Temporal Control Characteristics of Posture with Maturation and the Relation to Movement Exploration. *Brain Sciences* 2020;10:216. doi: https://doi.org/10.3390/brainsci10040216

48. Quatman-Yates CC, Quatman CE, Meszaros AJ, et al. A systematic review of sensorimotor function during adolescence: a developmental stage of increased motor awkwardness? *Br J Sports Med* 2012;46(9):649-55. doi: 10.1136/bjsm.2010.079616 [published Online First: 2011/04/05]

49. Ryan D, McCall A, Fitzpatrick G, et al. The influence of maturity status on movement quality among English Premier League academy soccer players. *Sport Perf Sci Rep* 2018;32:1-3.

50. Gibbs BG, Jarvis JA, Dufur MJ. The rise of the underdog? The relative age effect reversal among Canadian-born NHL hockey players: A reply to Nolan and Howell. *International Review for the Sociology of Sport* 2012;47(5):644-49. doi: 10.1177/1012690211414343

51. Zimmerman BJ. Development and adaptation of expertise: The role of self-regulatory processes and beliefs. *The Cambridge handbook of expertise and expert performance* 2006;186:705-22.

52. Toering T, Elferink-Gemser MT, Jordet G, et al. Self-regulation of learning and performance level of elite youth soccer players. *International Journal of Sport Psychology* 2012;43(4):312.

53. Merkel U. German football culture in the new millennium: ethnic diversity, flair and youth on and off the pitch. *Soccer & Society* 2014;15(2):241-55. doi: 10.1080/14660970.2013.849189

54. Teunissen JWA, Rommers N, Pion J, et al. Accuracy of maturity prediction equations in individual elite male football players. *Ann Hum Biol* 2020;47(4):409-16. doi: 10.1080/03014460.2020.1783360 [published Online First: 2020/10/01]

Tables and figures

Table 1. Psychological characteristics and associated operational definitions used by coaches to score players during small-sided game match-play.

Attribute	Operational definition
Positive Attitude	*Positive reaction after a mistake; how they handle disappointments; resilience; ability to overcome adversities; not wanting to give up*
Confidence	*Brave; wants to be involved; wants the ball; wants the ball under pressure; wants to get into positions to receive the ball all of the time; have the guts to try and fail and do something different.*
Competitive	*Resolve; desire; hunger; strong willed; determination; intense; fighting approach towards wanting the ball; winning mentality.*
X-Factor	*Unpredictable, creative, thinks outside of the box.*

Table 2. Descriptive statistics for psychological and physical variables according Fransen et al. and Khamis & Roche (1994)

	Fransen			Khamis		
Variable	*Post*-PHV mean ± sd	*Circa*-PHV mean ± sd	*Pre*-PHV mean ± sd	*Circa*-PHV mean ± sd	*Circa*-PHV mean ± sd	*Pre*-PHV mean ± sd
Positive attitude (AU)	2.90 ± 0.97	2.76 ± 1.00	2.72 ± 0.97	2.82 ± 0.93	2.95 ± 0.90	2.82 ± 0.94
Confidence (AU)	2.89 ± 1.02	2.71 ± 1.00	2.71 ± 1.03	2.80 ± 0.97	2.76 ± 1.00	2.74 ± 1.00
Competitive (AU)	2.86 ± 1.03	2.69 ± 1.00	2.71 ± 1.05	2.80 ± 1.00	2.80 ± 0.92	2.77 ± 1.05
X-Factor (AU)	2.25 ± 1.05	2.16 ± 1.00	2.25 ± 1.08	2.28 ±1.02	2.43 ± 1.01	2.22 ± 1.03
Psych total (AU)	10.61 ± 3.90	9.99 ± 3.89	9.95 ± 4.03	10.48 ± 3.75	10.75 ± 3.72	10.23 ± 3.92
sRPE-TL (AU)	19.42 ± 6.12	21.07 ± 5.77	24.16 ± 6.62	19.42 ± 6.13	22.54 ± 7.07	25.00 ± 7.31
Mean heart rate (beats·min^{-1})	163.88 ± 14.59	155.65 ± 24.88	155.05 ± 25.37	160.32 ± 17.61	158.18 ± 23.52	155.30 ± 24.63
Total distance (m)	455.28 ± 58.38	429.59 ± 91.18	455.17 ± 51.11	455.47 ± 63.22	462.43 ± 68.43	457.11 ± 65.63
Total PlayerLoad (AU)	55.36 ± 10.15	58.74 ± 10.01	60.56 ± 9.62	56.03 ± 10.60	58.35 ± 9.15	60.90 ± 9.61
PlayerLoad per min (AU·min^{-1})	55.36 ± 10.15	58.74 ± 10.01	60.56 ± 9.62	56.03 ± 10.60	58.35 ± 9.15	60.90 ± 9.61
PlayerLoad$_{AP}$ (AU)	26.77 ± 2,00	26.29 ± 2.30	25.76 ± 2.44	26.73 ± 1.93	27.25 ± 2.57	26.11 ± 2.73
PlayerLoad$_{ML}$ (AU)	28.62 ± 1.33	28.92 ± 1.46	29.67 ± 1.23	28.37 ± 1.42	29.17 ± 1.22	29.42 ± 1.27
PlayerLoad$_{V}$ (AU)	44.61 ± 2.15	44.80 ± 2.48	44.57 ± 1.99	44.90 ± 2.09	43.58 ± 2.62	44.46 ± 2.65
PlayerLoad per metre (AU·m^{-1})	0.11 ± 0.03	0.10 ± 0.01	0.11 ± 0.03	0.10 ± 0.01	0.11 ± 0.03	0.11 ± 0.03
Relative intensity (m·min^{-1})	89.69 ± 12.00	87.15 ± 13.08	90.13 ± 10.58	89.58 ± 12.90	90.03 ± 13.60	90.19± 13.88
Max velocity (km·h^{-1})	5.16 ± 0.617	4.786 ± 096	4.88 ± 0522	5.12 ± 0.61	4.900 ± 0.600	4.92 ± 0.600
High-speed running distance (m)	39.90 ± 21.05	31.34 ± 19.52	33.90 ± 18.86	37.77 ± 19.51	33.31 ± 20.19	34.56 ± 21.34

Key: Session rating of perceived exertion training load (sRPE-TL); Individual-component planes of PlayerLoad™ (PlayerLoad$_{AP}$ - anterior-posterior PlayerLoad™, Platerload$_{ML}$ - medial-lateral PlayerLoad™, PlayerLoad$_{V}$ - vertical PlayerLoad™).

Table 3. Estimated marginal mean range and effect size for physical variables for according Fransen et al and, Khamis & Roche (1994)

Banding	Variable	*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)	*Circa*-PHV vs *Pre*-PHV	(95% HDI)	*Pre*-PHV vs *Post*-PHV	(95% HDI)
Fransen et al	Mean heart rate (beats·min^{-1})	164 to 159	(155 to 168)	149 to 160	(140 to 168)	162 to 165	(153 to 174)	155 to 156	(149 to 162)	153 to 160	(147 to 166)	159 to 160	(153 to 165)
	effect size	0.22	(-0.30 to 0.72)	0.43	(-0.07 to 0.90)	0.13	(-0.36 to 0.64)	0.07	(-0.23 to 0.36)	0.29	(0.00 to 0.59)	0.04	(-0.23 to 0.34)
Khamis & Roche	Mean heart rate (beats·min^{-1})	159 to 155	(150 to 163)	158 to 155	(149 to 163)	162 to 163	(152 to 171)	154 to 153	(148 to 158)	154 to 161	(148 to 167)	160 to 160	(155 to 165)
	effect size	0.19	(-0.29 to 0.67)	0.13	(-0.38 to 0.62)	0.04	(-0.49, to 0.61)	0.04	(-0.24 to 0.32)	0.33	(0.04 to 0.61)	0.02	(-0.27 to 0.29)
Fransen et al	Total distance (m)	432 to 448	(414 to 473)	455 to 452	(433 to 476)	489 to 481	(466 to 503)	430 to 428	(414 to 445)	444 to 442	(427 to 459)	442 to 450	(424 to 474)
	effect size	0.03	(-0.34 to 0.39)	0.03	(-0.31 to 0.39)	0.11	(-0.24 to 0.45)	0.02	(-0.21 to 0.23)	0.03	(-0.19 to 0.24)	0.18	(-0.02 to 0.38)
Khamis & Roche	Total distance (m)	433 to 462	(419 to 485)	495 to 508	(474 to 531)	499 to 502	(475 to 525)	442 to 440	(427 to 455)	460 to 458	(445 to 473)	451 to 476	(436 to 497)
	effect size	0.22	(-0.21 to 0.67)	0.20	(-0.24 to 0.62)	0.05	(-0.40 to 0.52)	0.13	(-0.13 to 0.40)	0.03	(-0.23 to 0.28)	0.16	(-0.10 to 0.42)
Fransen et al	Total PlayerLoad (AU)	58.80 to 57.8	(54 .50 to 62.10	59.20 to 58.90	(55.60 to 62.40)	61.20 to 60.80	(57.80 to 64.30)	57.20 to 56.50	(54.00 to 59.60)	57.80 to 57.40	(55.4 0 to 59.90)	57.50 to 58.80	(53.90. to 60.00)
	effect size	0.09	(-0.27 to 0.44)	0.02	(-0.18 to 0.45)	0.03	(-0.32 to 0.38)	0.07	(-0.14, to 0.29)	0.03	(-0.18 to 0.24)	0.1	(-0.10 to 0.31)
Khamis & Roche	Total PlayerLoad (AU)	56.4 to 57.8	(54.70 to 63.00)	62.90 to 61.80	(58.80 to 65.80)	63.30 to 61.80	(58.80 to 65.00)	58.00 to 58.00	(54.40 to 60.20)	59.40 to 58.40	(56.20. to 64.6)	58.00 to 58.50	(55.90. to 60.20)
	effect size	0.23	(-0.11 to 0.54)	0.11	(-0.18 to 0.45)	0.14	(- 0.19 to 0.47)	0.16	(-0.04 to 0.34)	0.09	(-0.12 to 0.28)	0.04	(-0.04 to 0.23)
Fransen et al	PlayerLoad per min (AU.min^{-1})	11.7 to 11.6	(10.92. to 12.40)	11.8 to 11.6	(11.00 to 12.50)	12.1 to 12.1	(11.40 to 12.70)	11.3 to 11.3	(10.80 to 11.80)	11.1 to 11.2	(10.70 to 11.80)	11.4 to 11.3	(10.80 to 11.9)
	effect size	0.08	(-0.30 to 0.45)	0.08	(-0.27 to 0.43)	0.00	(-0.37 to 0.36)	0.02	(-0.22 to 0.24)	0.03	(-0.18 to 0.25)	0.07	(-0.15 to 0.28)
Khamis & Roche	PlayerLoad per min (AU.min^{-1})	12 to 11.6	(10. 90 to 12.60)	12.5 to 12.1	(11.50 to 13.10)	12.60 to 12.30	(11.70 to 13.20)	11.50 to 11.30	(10. 8 to 12.00)	11.5 to 11.5	(11.00 to 11.9)	11.6 to 11.5	(11.10 to 12.00)
	effect size	0.20	(-0.14 to 0.53)	0.18	(-0.15 to 0.52)	0.13	(--0.23 to 0.48)	0.10	(--0.10 to 0.30)	0.00	(-0.20, to 0.20]	0.03	(-0.18 to 0.24)
Fransen et al	PLayerLoad$_{AP}$ (AU)	27.30 to 27.00	(26.30 to 28.00)	26.00 to 26.4	(25.30 to 27.00)	25.60 to 25.40	(24.70 to 26.40)	26.30 to 27.10	(25.80 to 27.70)	26.40 to 25.50	(25.10 to 26.90)	25.6 to 26.9	(25.00 to 27.40)
	effect size	0.14	(-0.19 to 0.49)	0.17	(-0.15 to 0.49)	0.12	(-0.20 to 0.47)	0.34	(0.14 to 0.55)	0.36	(0.33 to 0.77)	0.59	(0.40 to 0.80)
Khamis & Roche	PlayerLoad$_{AP}$ (AU)	27.50 to 27.00	(27.00 to 28.00)	27.00 to 27.00	(26.30 to 27.80)	25.60 to 25.40	(24. 70 to 26.00)	27.10 to 27.20	(26.50 to 27.70)	27.20 to 25.90	(25.40 to 27.70)	25.90 to 27.20	(25.40 to 27.70)
	effect size	0.19	(-0.14 to 0.53)	0.01	(-0.32 to 0.36)	0.29	(-0.07 to 0.65)	0.04	(-0.15 to 0.25)	0.54	(0.33 to 0.77)	0.48	(0.26 to 0.69)
Fransen et al	PlayerLoad$_{ML}$(AU)	27.30 to 27.00	(26.30 to 28.00)	26.00 to 26.40	(25.3 to 27.00)	25.60 to 25.40	(24.70 to 26.40)	26.30 to 27.10	(25.80 to 27.7)	26.40 to 25.50	(25.10 to 26.90)	25.60 to 26.90	(25.00 to 27.40)
	effect size	0.08	(-0.25 to 0.42)	0.01	(-0.31 to 0.34)	0.16	(-0.18 to 0.47)	0.36	(0.16 to 0.56)	0.23	(-0.04 to 0.43)	0.65	(0.43 to 0.85)
Khamis & Roche	PlayerLoad$_{ML}$ (AU)	28.30 to 28.70	(27.90 to 29.10)	28.60 to 28.90	(28.20 to 29.30)	29.10 to 29.20	(28.70 to 29.60)	29.10 to 28.60	(28.40 to 29.40)	29.10 to 29.40	(28.80 to 29.70)	29.50 to 28.60	(28.30. to 29.80)
	effect size	0.29	(-0.02 to 0.61)	0.24	(-0.07 to 0.54)	0.13	(-0.18 to 0.46)	0.31	(0.14 to 0.51)	0.18	(0.02 to 0.37)	0.75	(0.54 to 0.95)
Fransen et al	PlayerLoad$_{V}$ (AU)	38.30 to 38.00	(35.80. to 40.50)	39.30 to 38.90	(36.80. to 41.50)	40.70 to 40.50	(38.40. to 42.80)	37.60 to 36.90	(36.90 to 39.20)	37.90 to 38.20	(36.30 to 39.50)	38.20 to 37.10	(35.50 to 39.70)
	effect size	0.04	(-0.28 to 0.40)	0.06	(-0.26 to 0.40)	0.03	(-0.31 to 0.35)	0.10	(-0.12 to 0.31)	0.03	(-0.17 to 0.23)	0.15	(-0.04 to 0.34)
Khamis & Roche	PlayerLoad$_{V}$ (AU)	39.20 to 44.3	(35.80 to 41.10)	41.30 to 40.20	(38.20 to 43.20)	41.60 to 41.00	(38.90 to 43.70)	37.50 to 36.80	(35.30 to 38.60)	38.30 to 38.60	(36.80 to 40.10)	38.40 to 38.0	(36.50 to 39.60)
	effect size	0.19	(-0.11 to 0.50)	0.15	(-0.16 to 0.43)	0.08	(-0.26 to 0.39	0.10	(-0.08 to 0.30)	0.04	(-0.15 to 0.23)	0.06	(-0.13 to 0.25)
Fransen et al	PlayerLoad per metre (AU.m^{-1})	0.10 to 0.10	(0.09 to 0.11)	0.12 to 0.10	(0.09 to 0.11)	0.10 to 0.10	(0.09 to 0.11)	0.11 to 0.10	(0.10 to 0.12)	0.11 to 0.11	(0.10 to 0.11)	0.11 to 0.11	(0.10 to 0.11)
	effect size	0.17	(-0.34 to 0.66))	0.07	(-0.44 to 0.57)	0.07	(-0.40 to 0.57)	0.30	(0.02 to 0.60)	0.01	(-0.27 to 0.29)	0.01	(-0.26 to 0.29)
Khamis & Roche	PlayerLoad per metre (AU.m^{-1})	0.11 to 0.10	(0.10 to 0.11)	0.106 to 0.104	(0.09 to 0.12)	0.11 to 0.10	(0.09 to 0.12)	0.107 to 0.106	(0.10 to 0.13)	0.11 to 0.11	(0.10 to 0.12)	0.11 to 0.11	(0.10 to 0.11)
	effect size	0.14	(-0.35 to 0.68)	0.30	(0.02 to 0.60)	0.30	(-0.27 to 0.82)	0.06	(-0.22 to 0.35)	0.03	(-0.25 to 0.31)	0.05	(-0.25 to 0.33)
Fransen et al	Relative intensity (m·min^{-1})	91.20 to 91.00	(86.00 to 95.7)	91.90 to 91.20	(86.90 to 96.00)	97.20 to 96.50	(92.00 to 101.50)	86.9 to 87.8	(83.90 to 90.00)	87.00 to 87.20	(84.10 to 90.00)	88.50 to 86.80	(83.90 to 91.20)
	effect size	0.02	(-0.46 to 0.48)	0.07	(-0.41 to 0.51)	0.06	(-0.38 to 0.52)	0.08	(-0.22 to 0.34)	0.01	(-0.25 to 0.28)	0.13	(-0.14 to 0.39)
Khamis & Roche	Relative intensity (m·min^{-1})	95.00 to 92.50	(87.90. to 99.60)	98.20 to 99.50	(93.80 to 104.20)	99.20 to 100.30	(94.40 to 105.10)	87.70 to 86.90	(83.90 to 97.70)	88.90 to 90.20	(85.90 to 93.10)	89.1 to 87.2	(84.10. to 92.20)
	effect size	0.19	(-0.25 to 0.64)	0.09	(-0.34 to 0.53)	0.08	(-0.39 to 0.53)	0.06	(-0.19 to 0.32)	0.09	(-0.17 to 0.36)	0.14	(-0.11 to 0.40)
Fransen et al	Max velocity (km·h^{-1})	4.75 to 4.73	(4.44 to 5.01)	4.83 to 4.81	(4.56 to 5.08)	4.95 to 5.21	(4.69 to 5.48)	4.97 to 4.97	(4.78 to 5.15)	4.89 to 4.88	(4.70 to 5.06)	4.87 to 4.90	(4.71 to 5.08)
	effect size	0.03	(-0.4 to 0.46)	0.02	(-0.38 to 0.43)	0.32	(-0.07 to 0.74)	0.00	(-0.25 to 0.26)	0.01	(-0.23 to 0.26)	0.05	(-0.18 to 0.29)
Khamis & Roche	Max velocity (km·h^{-1})	4.94 to 4.85	(4.60 to 5.18)	5.03 to 5.08	(4.79 to 5.31)	5.06 to 5.15	(4.80 to 5.39)	4.87 to 5.08	(4.73 to 5.21)	5.04 to 4.95	(4.82 to 5.17)	4.84 to 5.01	(4.71 to 5.15)
	effect size	0.15	(-0.39 to 0.69)	0.08	(-0.42 to 0.63)	0.14	(-0.44 to. 0.71)	0.34	(0.05 to 0.65)	0.14	(-0.15 to 0.43)	0.28	(-0.02 to 0.57)
Fransen et al	High-speed running distance (m)	29.80 to 30.90	(21.80 to 39.4)	30.7 to 33.7	(23.50 to 41.80)	35.7 to 36.4	(27.80 to 44.00)	37.5 to 35.4	(30.3 to 42.00)	35.6 to 32.7	(23.5 to 43.30)	35.5 to 32.00	(26.9 to 43.30)
	effect size	0.06	(-0.46 to 0.57)	0.14	(-0.34 to 0.65)	0.03	(-046 to 0.54)	0.10	(-0.19 to 0.41)	0.15	(-014 to 0.43)	0.17	(-0.11 to 0.45)
Khamis & Roche	High-speed running distance (m)	32.90 to 24.60	(16.60 to 40.20)	40.40 to 40.40	(32.50 to 47.90)	40.30 to 38.00	(29.40 to 48.60)	34.20 to 35.60	29.50 to 40.20)	37.00 to 38.00	(32.40 to 42.50)	32.5 to 34.5	(27.90 to 39.00)
	effect size	0.40	(-0.09 to o.88)	0.00	(-0.47 to 0.48)	0.14	(-0.40 to 0.61)	0.07	(-0.21 to 0.35)	0.05	(-0.24 to 0.32)	0.09	(-0.18 to 0.38)

Key: Individual-component planes of PlayerLoad™ (anterior-posterior PlayerLoad™ [$PlayerLoad_{AP}$], medial-lateral PlayerLoad™ [$PlayerLoad_{ML}$] and vertical PlayerLoad™ [$PlayerLoad_{V}$]); Highest Density Interval (HDI)

Table 4. Estimated marginal mean range for psychological variables according Fransen et al. and Khamis & Roche (1994)

Banding	Variable	***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)	***Circa*-PHV vs *Pre*-PHV**	(95% HDI)	***Pre*-PHV vs *Post*-PHV**	(95% HDI)
Fransen et al	Positive attitude	2.52 to 2.76	(2.2 to 3.1)	2.80 to 2.8	(2.46 to 3.13)	2.83 to 3.12	(2.52 to 3.43)	2.63 to 2.75	(2.42 to 2.98)	2.76 to 2.81	(2.54 to 3.03)	2.66 to 2.95	(2.44 to 3.17)
	Effect Size	0.25	(-0.14 to 0.65)	0.02	(-0.35 to 0.41)	0.29	(0.09 to 0.67)	0.12	(-0.10 to 0.35	0.05	(-0.16 to 0.28)	0.29	(0.07 to 0.52)
Khamis & Roche	Positive attitude	2.68 to 2.69	(2.34 to 3.02)	2.78 to 3.04	(2.44 to 3.38)	3.15 to 3.41	(2.81 to 3.75	2.64 to 2.89	(2.45 to 3.10)	2.82 to 2.97	(2.60 to 3.17)	2.55 to 3.17	(2.34 to 3.38)
	Effect Size	0.00	(-0.47 to 0.45)	0.30	(-0.16 to 0.76)	0.26	(-0.20 to 0.76)	0.27	(-0.00 to 0.52)	0.16	(-0.10 to 0.43)	0.69	(0.42 to 0.96)
Fransen et al	Confidence	2.45 to 2.74	(2.12 to 3.07)	2.61 to 2.86	(2.28 to 3.20)	2.93 to 2.94	(2.58 to 3.26)	2.62 to 2.71	(2.40 to 2.94)	2.82 to 2.82	(2.58 to 3.05)	2.62 to 2.82	(2.39 to 3.05)
	Effect Size	0.28	(-0.09 to 0.66)	0.25	(-0.13 to 0.63)	0.01	(-0.36 to 0.38)	0.09	(-0.14 to 0.30)	0.00	(-0.22 to 0.22)	0.19	(-0.03 to 0.41)
Khamis & Roche	Confidence	2.59 to 2.74	(2.24 to 3.12)	2.74 to 3.04	(2.40 to 3.40)	3.06 to 3.28	(2.72 to 3.63)	2.59 to 2.83	(2.37 to 3.06)	2.79 to 2.93	(2.16 to 3.15)	2.52 to 3.02	(2.29 to 3.24)
	Effect Size	0.15	(-0.30 to 0.59)	0.28	(-0.16 to 0.73)	0.23	(-0.26 to 0.68	0.24	(-0.01to 0.49)	0.14	(-0.11 to 0.40)	0.50	(0.24 to 0.75)
Fransen et al	Competitive	2.60 to 2.91	(2.27 to 3.24)	2.64 to 2.66	(2.31 to 3.02)	2.78 to 3.12	(2.45 to 3.24)	2.61 to 2.66	(2.38 to 2.88)	2.68 to 2.76	(2.45 to 2.99)	2.67 to 2.86	(2.45 to 3.10)
	Effect Size	0.29	(-0.12 to 0.69)	0.03	(-0.36 to 0.43)	0.33	(-0.09 to 0.72)	0.05	(-0.19 to 0.27)	0.08	(-0.14 to 0.31)	0.18	(-0.05 to 0.40)
Khamis & Roche	Competitive	2.81 to 2.89	(2.46 to 3.25)	2.81 to 3.04	(2.45 to 3.38)	2.94 to 3.14	(2.57 to 3.47)	2.55 to 2.88	(2.32 to 3.10)	2.80 to 2.81	(2.57 to 3.04)	2.53 to 2.95	(2.32 to 3.18)
	Effect Size	0.07	(-0.40 to 0.50)	0.24	(-0.24 to 0.67)	0.20	(-0.29 to 0.68	0.33	(0.09 to 0.60)	0.01	(-0.25 to 0.27)	0.43	(0.16 to 0.68)
Fransen et al	X-Factor	2.08 to 2.21	(1.69 to 2.58)	2.10 to 2.12	(1.73 to 2.51)	2.15 to 2.15	(1.76 to 2.53)	1.99 to 2.18	(1.74 to 2.41)	2.22 to 2.26	(1.96 to 2.50)	2.04 to 2.25	(1.80 to 2.50)
	Effect Size	0.12	(-0.33 to 0.54	0.03	(-0.41 to 0.48)	0.01	(-0.43 to 0.46)	0.18	(-0.14, to 0.41)	0.05	(-0.21 to 0.30)	0.20	(-0.05 to 0.45)
Khamis & Roche	X-Factor	2.22 to 2.31	(1.84 to 2.69	2.22 to 2.56	(1.81 to 2.96)	2.34 to 2.50	(1.97 to 2.92)	2.06 to 2.20	(1.82 to 2.44)	2.27 to 2.42	(2.04 to 2.65)	2.11 to 2.44	(1.89 to 2.68)
	Effect Size	0.09	(-0.41 to 0.56)	0.34	(-0.15to 0.80)	0.15	(-0.37 to 0.65)	0.13	(-014 to 0.41)	0.14	(-0.14 to 0.41)	0.31	(0.04 to 0.58)
Fransen et al	sRPE-TL	22.30 to 22.30	19.70 to 25.10	22.70 to 22.90	(19.90 to 25.60)	21.60 to 21.90	18.80 to 24.70)	21.00 to 25.20	(19.80 to 26.60)	21.70 to 23.90	(20.30 to 25.20)	20.60 to 24.80	(19.30 to 26.20)
	Effect Size	0.05	(-0.33 to 0.43)	0.06	(-0.31 to 0.45)	0.18	(-0.19 to 0.57)	0.42	(0.19 to 0.66)	0.33	(0.12 to 0.55)	0.44	(0.21 to 0.66)
Khamis & Roche	sRPE-TL	19.20 to 21.00	(16.50 to 23.80)	22.10 to 22.50	(19.40 to 25.30)	22.90 to 23.20	(20.20 to 26.40)	19.70 to 24.30	(18.30 to 25.70)	21.40 to 24.10	(18.30 to 25.70)	19.50- to 25.90	(18.20 to 27.30
	Effect Size	0.34	(0.040 to 0.73)	0.12	(-0.25 to 0.51)	0.017	(-0.38 to 0.44)	0.58	(0.36 to 0.81)	0.33	(0.09 to 0.56)	0.74	(0.50 to 0.99)

Key: Session rating of perceived exertion training load (sRPE-TL); Highest Density Interval (HDI)

Table 5. Summary table of model fit, variance explained and Bayes factor by Khamis & Roche (1994), Fransen et al (2018) and stature for all of the above KPIs in bonded match-play

Variable	Fransen				Khamis				Stature		
	R^2	(95% HDI)	LOOIC	BF>	R^2	(95% HDI)	LOOIC	BF>	R^2	(95% HDI)	LOOIC
Positive attitude (AU)	0.57	(0.53:0.6)	1492.90	yes	0.37	(0.32:0.42)	1666.70	no	0.41	(0.37:0.45)	2433.90
Confidence (AU)	0.59	(0.56:0.62)	1508.50	yes	0.42	(0.37:0.47)	1717.00	no	0.45	(0.41:0.48)	2492.50
Competitive (AU)	0.57	(0.53:0.6)	1566.30	yes	0.42	(0.36:0.46)	1718.30	no	0.43	(0.39:0.47)	2514.50
X-Factor (AU)	0.50	(0.46:0.55)	1505.50	yes	0.40	(0.34:0.45)	1652.70	no	0.39	(0.35:0.43)	2390.80
Psych total (AU)	0.61	(0.58:0.64)	3437.10	yes	0.46	(0.41:0.5)	3625.10	no	0.47	(0.44:0.51)	5393.40
sRPE-TL (AU)	0.60	(0.57:0.63)	4266.60	yes	0.59	(0.55:0.62)	4354.50	no	0.53	(0.50:0.56)	6625.20
Mean heart rate (beats·min^{-1})	0.33	(0.27:0.39)	5431.10	yes	0.37	(0.31:0.42)	5452.50	no	0.36	(0.30:0.41)	5444.50
Total distance (m)	0.59	(0.56:0.63)	6966.00	yes	0.44	(0.39:0.48)	7347.30	no	0.34	(0.30: 0.38)	11026.50
Total PlayerLoad (AU)	0.66	(0.63:0.68)	4394.30	yes	0.71	(0.68:0.73)	4396.40	no	0.67	(0.64: 0.69)	6559.80
PlayerLoad per min (AU.min^{-1})	0.63	(0.6:0.66)	2302.60	no	0.67	(0.64:0.7)	2270.10	yes	0.65	(0.62:0.67)	3371.50
PlayerLoad$_{AP}$ (AU)	0.68	(0.66:0.71)	2335.70	yes	0.68	(0.65:0.7)	2526.00	no	0.58	(0.55:0.60)	3826.80
PlayerLoad$_{ML}$ (AU)	0.71	(0.68:0.73)	1631.90	no	0.74	(0.72:0.76)	1560.90	yes	0.69	(0.67: 0.71)	2493.10
PLayerLoad$_{V}$ (AU)	0.70	(0.68:0.72)	2253.00	yes	0.71	(0.69:0.73)	2472.60	no	0.62	(0.59: 0.64)	3740.50
PlayerLoad per metre (AU·m^{-1})	0.38	(0.32:0.43)	-3102.10	no	0.26	(0.2:0.32)	-3182.40	yes	0.28	(0.23:0.32)	-4752.00
Relative intensity (m·min^{-1})	0.38	(0.32:0.43)	4876.10	yes	0.43	(0.38:0.48)	5191.70	no	0.40	(0.35:0.44)	7495.40
Max velocity (km·h^{-1})	0.47	(0.43:0.52)	1137.20	no	0.23	(0.17:0.29)	1168.40	yes	0.22	(0.17: 0.27)	1977.70
High-speed running distance (m)	0.31	(0.25:0.37)	5594.30	yes	0.36	(0.31:0.41)	5829.60	no	0.36	(0.318:0.41)	5831.00

Key: Session rating of perceived exertion training load (sRPE-TL); PlayerLoad™ (PL); Individual-component planes of PlayerLoad™ (anterior-posterior PlayerLoad™ [PlayerLoad$_{AP}$], medial-lateral PlayerLoad™ [PlayerLoad$_{ML}$] and vertical PlayerLoad™ [PlayerLoad$_{V}$]); 95% highest density interval (95% HDI); Variance explained (R^2); Leave one out information criterion (LOOIC); Bayes Factor (BF).

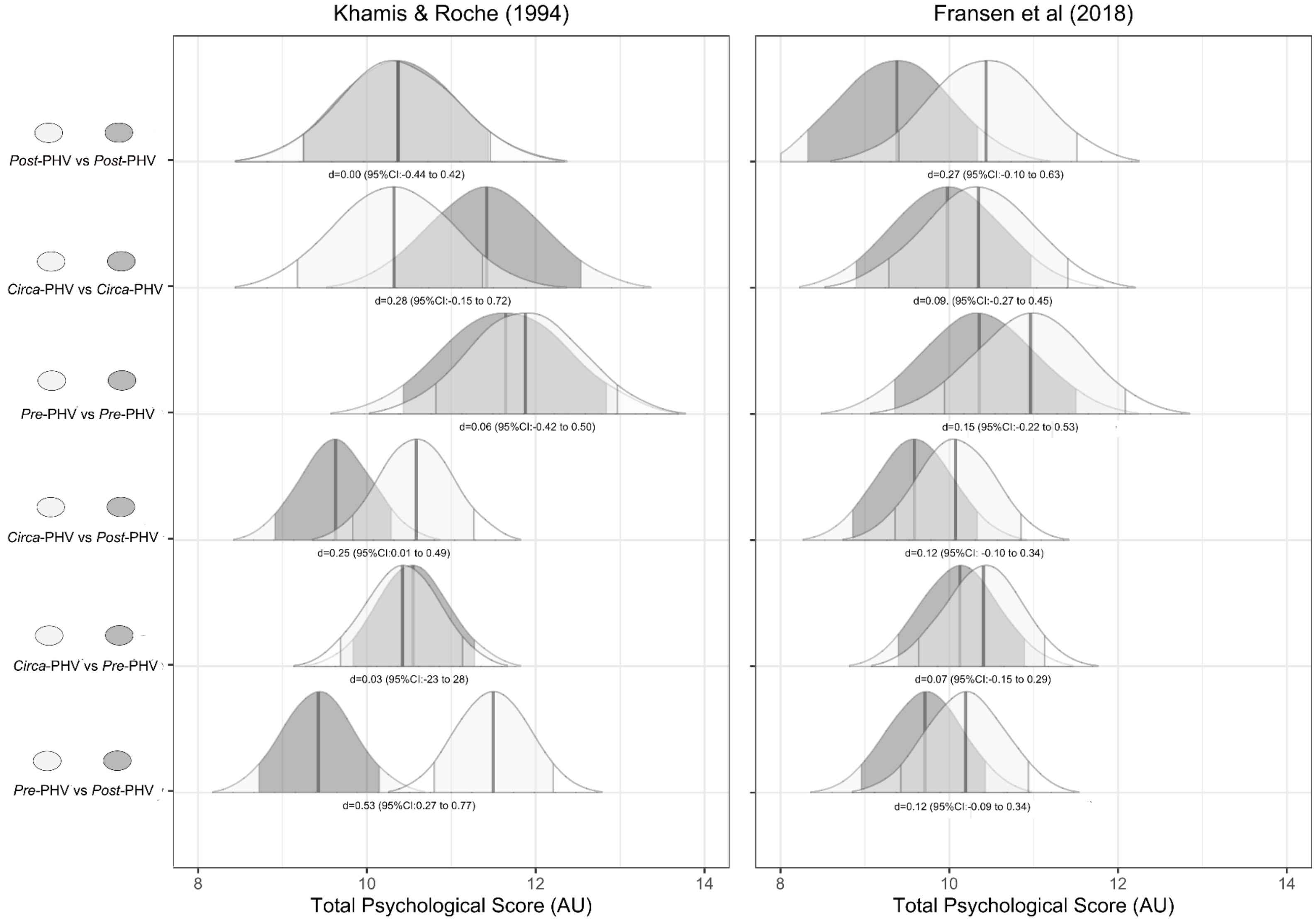

Figure 1. A comparison of the posterior distributions for total psychological score for each KR[17] and FR[16] maturation groups when playing matched or mis-matched groups.

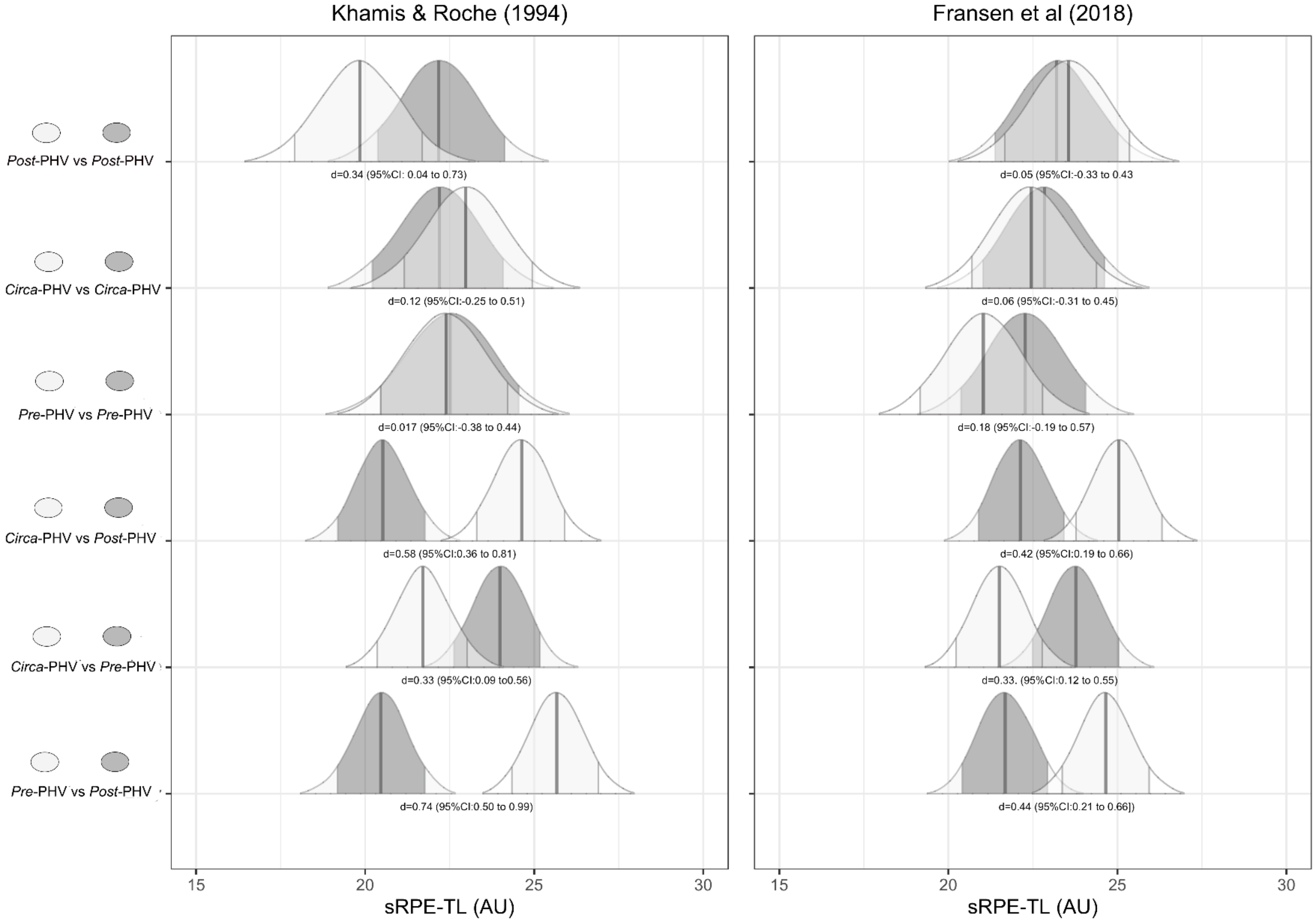

Figure 2. A comparison of the posterior distributions for session rating of perceived exertion-training load for each KR[17] and FR[16] maturation groups when playing matched or mis-matched groups.