2021

Influence of age and maturation status on sprint acceleration characteristics in junior Australian football

Toby Edwards

Jonathon Weakley

Harry G. Banyard

Ashley Cripps

Benjamin Piggott

See next page for additional authors

Follow this and additional works at: https://researchonline.nd.edu.au/health_article

Part of the [Life Sciences Commons](#), and the [Medicine and Health Sciences Commons](#)

This article was originally published as:

Edwards, T., Weakley, J., Banyard, H. G., Cripps, A., Piggott, B., Haff, G. G., & Joyce, C. (2021). Influence of age and maturation status on sprint acceleration characteristics in junior Australian football. *Journal of Sports Sciences*, 39 (14), 1585-1593.

Original article available here:

[10.1080/02640414.2021.1886699](https://doi.org/10.1080/02640414.2021.1886699)

This article is posted on ResearchOnline@ND at . For more information, please contact researchonline@nd.edu.au.

Authors

Toby Edwards, Jonathon Weakley, Harry G. Banyard, Ashley Cripps, Benjamin Piggott, G. Gregory Haff, and Christopher Joyce

©2021. This manuscript version is made available under the CC-BY-NC-ND 4.0 International license <http://creativecommons.org/licenses/by-nc-nd/4.0/>

This is an Author's Original Manuscript of an article published by Taylor & Francis Group in the *Journal of Sports Sciences* on 14 February 2021, available online: <https://www.tandfonline.com/doi/full/10.1080/02640414.2021.1886699>

Edwards, T., Weakley, J., Banyard, H.G., Cripps, A., Piggott, B., Haff, G.G., & Joyce C. (2021). Influence of age and maturation status on sprint acceleration characteristics in junior Australian football. *Journal of Sports Sciences*, 39(14).
<https://doi.org/https://www.tandfonline.com/doi/full/10.1080/02640414.2021.1886699>

Influence of Age and Maturation Status on Sprint Acceleration Characteristics in Junior Australian Football

Running Head: Age and Maturation influence on Sprint F-v-p

Toby Edwards ¹, Jonathon Weakley ^{2,3}, Harry G. Banyard ⁴, Ashley Cripps ¹, Benjamin Piggott ¹, G. Gregory Haff ^{5, 6, 7}, Christopher Joyce ¹

¹ School of Health Sciences, The University of Notre Dame Australia, Fremantle, Australia

² School of Behavioural and Health Sciences, Australian Catholic University, Brisbane, Queensland, Australia

³ Carnegie Applied Rugby Research Centre, Institute for Sport, Physical Activity and Leisure, Leeds Beckett University, Leeds, United Kingdom

⁴ Department of Health and Medical Sciences, Swinburne University of Technology, Melbourne, Australia

⁵ Centre for Exercise and Sport Science Research, Edith Cowan University, Perth, Australia

⁶ Australian Centre for Research into Injury in Sport and its Prevention (ACRISP), Edith Cowan University, Joondalup, WA 6027, Australia.

⁷ Directorate of Sport, Exercise, and Physiotherapy, University of Salford, Salford, Greater Manchester, United Kingdom.

Toby Edwards
University of Notre Dame Australia
School of Health Sciences
33 Phillimore Street
Fremantle, Western Australia, 6160
AUSTRALIA
toby.edwards1@my.nd.edu.au
+61 8 9433 0224

Abstract word count: 250

Text-only word count: 4074

Number of tables: 3

Number of figures: 2

ABSTRACT

This study aimed to investigate the influence of chronological age and maturation status on sprint acceleration force, velocity and power profiles in junior Australian football (AF) players. Biological maturity of 109 subjects was assessed and subjects were subsequently grouped according to predicted years from peak height velocity (PHV) (pre-, mid-, and post-PHV) and chronological age (13 years, 14 years, and 15 years). A one-way multivariate analysis of variance and magnitude-based decisions were used to determine between-group differences. Instantaneous velocity was measured during two maximal 30m sprints via radar gun with the velocity-time data used to derive the velocity, force, and power characteristics, and split times (5m, 10m, 15m, 20m, 25m, and 30m) of each trial. Chronologically, the greatest differences were observed between the 13 and 14 year old groups with the latter group *likely* faster at all distances (Effect Size [ES] -0.34 to -0.51) and producing *likely* greater relative maximum power ($P_{\max}$) (ES=0.44) and theoretical maximal velocity (V_0) (ES=0.49). The post-PHV group was *likely* faster at all distances above 15m than the pre- and mid-PHV groups (ES -0.38 to -0.61), and demonstrated a greater ability to apply force at faster velocity (V_0 ; ES=0.59) and orient the force in a horizontal direction ($D_{\text{H}}\%$; ES=-0.49) than the mid-PHV group. No differences in relative theoretical maximal force (F_0) were observed between groups. Considering these findings, practitioners should aim to improve relative lower limb strength through heavy sled push or sled pulls and traditional strength training exercises to improve relative F_0 in junior AF players.

Key Words: kinetics, kinematics, force, velocity, power, youth

INTRODUCTION

Children and adolescents mature at different rates (1) leading to biological variations of up to 3 years in individuals of the same chronological age (2). The implications of this in junior sporting competitions can provide early maturing adolescents an advantage over their late maturing counterparts through improved physical and physiological capacities (3-7). In junior Australian football (AF), physical capacities have consistently been linked to talent identification, talent pathway progression and performance (8-10). For example, sprint performance has been shown to differentiate between elite and sub-elite footballers and is often associated with team selection, particularly in State and National talent pathways (8-10). Therefore, the identification of the accelerative and maximal velocity capacities during sprint running and the influence of age and maturation status is a key focus for developing and identifying talented young AF athletes.

The natural development of sprinting during childhood and adolescence is a non-linear process, where enhanced improvement can occur at different maturational periods (1, 2). Specifically in males, marked improvements in sprinting has been identified between the ages of 7 to 15, after which the rate of improvements have been shown to lessen (11). Evidence also suggests that there is a strong relationship between sprinting development and maturational related physical and physiological characteristics (2, 4, 5, 12, 13). Improvements in sprinting performance prior to the onset of peak height velocity (PHV) can be primarily attributed to central nervous system adaptations including increased neuromuscular function, enhanced neuromuscular recruitment, and coordination (2). Sprinting performance improvements between mid- and post-PHV have been associated with increases in muscle cross-sectional area and maximal strength (2). However, children in the mid-PHV period of maturation may

experience decreases in sprinting performance during a period of ‘adolescent awkwardness’ which is associated with reduced co-ordination as a result of rapid changes in limb length (2).

In junior AF, large (7.2%) significant differences were reported in 20m sprint time between early and late maturing players at the same chronological age (4). Furthermore, significant large negative correlations were found between years to and from PHV (Y-PHV) and 20 m sprint time ($r = -0.53$) (4). These findings in junior AF are consistent with results from youth soccer where it is reported that there is a substantial positive effect of maturation on maximal sprinting acceleration and speed when anthropometric variables were accounted for (14). However, the measurement of maximal sprint acceleration and speed presents only a basic analysis of sprint performance and cannot identify differences in the underlying biomechanical characteristics between athletes. Compared to pre-PHV, mid- and post-PHV adolescents demonstrate greater physical and physiological capacities (maximal strength, muscle cross sectional area etc) acknowledging changes in the kinetics and kinematics (force, velocity, power etc) of maximal sprint acceleration is important and can support practitioners in identifying key development foci when prescribing training for adolescent athletes.

Previous research exploring the effects of maturational status on the kinetics and kinematics of maximal sprint velocity suggest that differences in spatiotemporal characteristics differ as a child experiences maturation (12, 13, 15). Prior to the onset of PHV, males have been shown to be more reliant on increased stride frequency (15) with those later in the maturation process more reliant on increased stride length (15). This greater reliance on increased stride length and stabilisation of stride frequency may be attributed to an increase in limb length and relative strength around the time of PHV (2). However, significant differences still exist between pre-

and post-PHV when stride length is normalised to leg length, indicating that other variables such as power may better explain the changes in sprinting performance through maturation (13). Direct measures of ground reaction forces (GRF) during maximal sprint acceleration efforts in untrained school children have demonstrated maturation specific alterations of force production in the period leading into PHV (12). Specifically, an accelerated period of sprint development was identified in males 4.5 to 3.5 years to PHV compared to males 5.5 to 4.5 year to PHV, with higher maximal velocities achieved through an ability to produce higher anteroposterior GRFs across shorter ground contacts (12). Further, it was apparent that males generated higher propulsive forces through an improved ability to reverse the braking forces and better utilise the stretch-shortening cycle (12). Collectively these findings support the consideration of maturation assessment and maturation-specific alterations when evaluating sprint acceleration performance and prescribing training in youth athletes.

Field-based assessments of sprint acceleration kinetics and kinematics have enabled practitioners to feasibly measure sprinting force, velocity, and power characteristics to identify individual strengths and weaknesses in the force-velocity profile to justify training prescription to improve sprinting performance. Further, specific sprint training interventions including resisted sled pushing and pulling have been shown to improve sprint acceleration force, velocity, and power characteristics (16, 17). However, whilst previous research has used the field-based assessment of sprint acceleration kinetics and kinematics to provide descriptive information individual force-velocity-power profiles in youth athletes at various ages across several sports (18-23), there is a paucity of research that has directly compared the influences of age and maturation on these characteristics using a field-based approach. Therefore, this study aims to establish the influence of chronological age and maturation status on sprint acceleration force, velocity and power characteristics in junior AF players using an applied

field-based macroscopic method. This will assist practitioners in prescribing specific and non-specific training for youth athletes with consideration of athlete's maturational assessment alterations in sprint acceleration force, velocity, and power characteristics.

METHODS

Experimental Approach to the Problem

This study aimed to investigate the influence of chronological age and maturation status on sprint acceleration force, velocity and power profiles in junior AF players. Subjects were categorised according to their chronological age and stage of maturation. All testing occurred on a grassed surface during the off-season on a single day at least 24 hours after the subjects' last training exposure. Subjects wore their normal football boots and training clothing for the testing. A hand-held multi-function weather meter (WindMate – 350, WeatherHawk, Utah, USA) was used to quantify environmental conditions including air temperature, humidity, wind speed, and wind direction that were used to derive mechanical sprint characteristics through inverse dynamics.

Subjects

A total of 109 junior AF players from the same development academy volunteered to participate in this study. Following an assessment of maturity, subjects were subsequently grouped according to predicted Y-PHV (pre-, mid- post-PHV) and chronological age (13 years, 14 years, 15 years). This approach allowed for the assessment of any maturity related differences in maximal sprint acceleration. Descriptive characteristics of subjects are reported in Table 1. All subjects were free from any musculoskeletal or neuromuscular injuries that

would have affected their ability to perform the required test. The University Human Research Ethics Committee approved the research (Reference #018162F).

**** INSERT TABLE 1 HERE ****

Procedures

Assessment of Maturity

All subjects had standing height, sitting height and body mass recorded upon arriving to the testing session. Heights were measured to the nearest 0.1 cm using a stadiometer (PE, Sportforce, Australia) and body masses were measured to the nearest 0.01 kg using an electric scale (Model UC-321, A&D Mercury Pty. Ltd., Australia). To measure sitting height, subjects sat on a 42-cm seat, with their buttocks and shoulders against the stadiometer, the height of the seat was subtracted from the overall sitting height value. For all anthropometric measures, subjects removed their footwear. Maturation status was estimated using the anthropometric measures collected, with Y-PHV calculated using a standardised predictive equation [equation 1] (24). This method of assessment provides a reliable and practical method of assessing maturation status and has been used in several studies with similar populations (3-5).

$$\begin{aligned} \text{Maturity offset} = & - [9.236 + 0.0002708 * \text{Leg Length and Sitting Height interaction}] - \\ & [0.001663 * \text{Age and Leg Length interaction}] + [0.007216 * \text{Age and Sitting Height interaction}] \\ & + [0.02292 * \text{Weight by Height ratio}] \end{aligned}$$

[equation 1]

Participants were grouped into maturational intervals according to their maturity offset, whereby pre-PHV: < -0.5 Y-PHV, mid-PHV: -0.5 to 0.5 Y-PHV, and post-PHV: >0.5 Y-PHV.

Sprint Acceleration Test

All subjects completed a 10-minute standardised warmup that included low intensity running and plyometrics, joint mobility exercises, and athletics drills, followed by three incremental sprints of 30 – 40 m at 70%, 80%, and 90% of self-perceived maximal velocity prior to testing. Following this, each subject performed two maximal 30 m sprint accelerations from a two-point standing position with at least three minutes rest between trials. Subjects were instructed that no backward movement was allowed prior to the start of the sprint, and to begin each sprint at their own convenience to eliminate the influence of reaction time. Verbal encouragement was given to all subjects to sprint through the 30m distance.

Sprint Acceleration Test Data Processing

A Stalker Acceleration Testing System (ATS) II radar device (Stalker ATS II; Applied Concepts, Dallas, TX, USA) recorded the instantaneous velocity-time data of each trial. The radar device was fixed 10 m behind the starting line on a tripod 1 m above the ground corresponding approximately to the participant's centre of mass and was operated remotely via connection to a laptop to limit the possible variability introduced by manual operation (16, 17, 25). The raw instantaneous velocity-time data was collected and manually processed in a commercially available software package (STATS; Stalker ATS II Version 5.0.2.1; Applied Concepts, Dallas, TX, USA). The processed data file for each sprint acceleration was used to

derive sprint acceleration force, velocity and power characteristics and sprint times (5m, 10m, 15m, 20m, 25m, 30m) in a custom-made Microsoft Excel spreadsheet (26, 27). The average of the two maximal sprint trials from each subject was used for statistical analysis.

Sprint Acceleration Test Variables

Sprint acceleration force, velocity, and power characteristics derived from the instantaneous velocity-time data included absolute and relative theoretical maximum force (F_0), which represents the maximal horizontal force output at the initial push of the athlete onto the ground; theoretical maximal velocity (V_0), which represents the maximal sprint velocity of the athlete should there be no mechanical resistances against the movement and corresponds to an athletes' ability to produce horizontal force at high running velocities; absolute and relative maximum power ($P_{\max}$), which represents the maximal horizontal power output of the athlete; slope of the force-velocity relationship (S_{fv}), which represents the balance between an athlete's force and velocity capabilities; maximum ratio of force ($RF_{\max}$), which represents the ratio of horizontal force to the corresponding resultant force; and, decrease in ratio of force (D_{rf}), which represents the decrease in ratio of force with increasing velocity (28). Comparisons between this macroscopic approach and the multiple force plate method revealed acceptable high validity (horizontal force [Fh], resultant force [Fres], S_{fv} ; $r = 0.826 - 0.978$) (26, 27). All variables had a coefficient of variation (CV) < 5% therefore displaying acceptable reliability, showed low absolute bias between methods (1.88 – 8.04%) and were almost perfectly correlated with polynomial and linear regressions (mean $R^2 = 0.997 - 0.999$) (26, 27). The high agreement between these results provide evidence that the estimation of overground sprinting kinetics using a simple field-based method is a valid and reliable approach to assess sprint acceleration

characteristics. For a complete overview of the formulas and data processing approach see Morin et al (26) and Samozino et al (27).

Statistical Analysis

The means and standard deviations for all mechanical sprint characteristics and split times were calculated for each maturity group. A Shapiro-Wilk test of normality confirmed all variables were normally distributed. A one-way multivariate analysis of variance (MANOVA) was performed to compare means for all variables. A Tukey post-hoc analysis was performed when significant main effects and interaction were reported to control for type one error and assess pairwise comparisons. Alpha was set at $p < 0.05$.

Magnitude-based decisions (MBD) were derived using a modified statistical Excel spreadsheet available online from sportsci.org (29). The MBD approach was used because traditional statistical approaches do not indicate the magnitude and likelihood of an effect and, when interpreted correctly, this method provides practitioners with greater clarity of application. Hedge's g effect size (ES) and 90% confidence intervals (90%CI) were used to determine differences in mechanical sprint characteristics between groups. Threshold values of 0.2, 0.6, 1.2, 2.0, and 4.0 were used to represent trivial, small, moderate, large, very large, and extremely large effects, respectively. The probability that differences were higher or lower than, or similar to the smallest worthwhile difference ($0.2 \times$ between-subject standard deviation) was qualitatively evaluated as possibly, 25% - 74.9%; likely, 75% to 94.9%; very likely, 95% to 99.5%; and extremely likely, $>99.5\%$. When the magnitude of difference was extremely likely small and demonstrated a mean difference greater than a moderate standardised effect ($ES > 0.6$), the probability of change being greater than a moderate effect ($0.6 \times$ between-subject

standard deviation) was assessed. The same process was followed for all variables and ES. The true difference was assessed as unclear if the chance of both substantially positive and negative values was >5% (29).

**** INSERT TABLE 2 HERE ****

RESULTS

Mean $\pm$ standard deviation (SD) of mechanical sprint characteristics and split times for all age and maturity groups are presented in Table 2 and Table 3, respectively. The one-way MANOVA reported statistically significant differences in mechanical sprint characteristics between age and maturations groups ($p < 0.05$). The between-subjects effect revealed that age and maturation status had a significant effect on all mechanical sprint variables and split times ($p < 0.05$). Tukey's HSD post-hoc tests showed statistically significant differences in several mechanical sprint characteristics and split times between age and maturation groups (Tables 2 and 3).

**** INSERT TABLE 3 HERE ****

ES and inference relating to mechanical sprint characteristics and split times between age groups are reported in Figure 1. The 14 year old group was *likely* taller and heavier than the 13 year old group. Despite being heavier, the 14 year old group reached *likely* greater $V_{\max}$ and faster split times >10 m. Further, *likely* superior sprint acceleration characteristics were observed in 14 year olds compared to 13 year olds including absolute F_0 and $P_{\max}$, relative $P_{\max}$,

V_0 , and RF_{max} . The 15 year old group displayed *likely* and *possibly* greater V_0 and V_{max} than the 14 year old group, however all other anthropometric, sprint acceleration characteristics, and split time differences were *unclear*.

**** INSERT FIGURE 1 HERE ****

Mean $\pm$ SD of all variables associated with maturation analyses are presented in Table 1. Significant differences ($p < 0.05$) were identified in all variables except leg length between all maturity groups. ES and inference relating to mechanical sprint characteristics and split times between maturity groups are reported in Figure 2. The mid-PHV group was *likely* taller and heavier than the pre-PHV group. *Likely* greater absolute F_0 and P_{max} was displayed by the mid-PHV group compared to the pre-PHV group with all other sprint acceleration characteristics and split times showing *unclear* differences.

The post-PHV group were *very likely* and *possibly* taller and heavier than the mid-PHV group, respectively. Despite being heavier, the post-PHV group was also reached *very likely* greater V_{max} and was *likely* faster at all distances >20 m and *possibly* faster at 15 m compared to the mid-PHV group. *Very likely* and *extremely likely* differences in absolute F_0 and P_{max} with *likely* differences in V_0 , S_{fv} , and D_{rf} also observed between the post-PHV and mid-PHV groups.

**** INSERT FIGURE 2 HERE ****

DISCUSSION

This is the first study to investigate the influence of age and maturation on the force, velocity and power profiles of maximal sprint accelerations in male junior AF players. The results confirmed our hypothesis that chronologically older and earlier maturing athletes will display superior sprint acceleration characteristics and split times compared to their younger and later maturing counterparts. Specifically, a period of rapid development of sprint acceleration characteristics is observed between 13 and 14 year old age groups before stabilising between the ages of 14 and 15. Across the three stages of maturation it was evident in this study that the post-PHV group demonstrated superior sprint acceleration characteristics and faster split times than the pre and mid-PHV groups. Additionally, the maturity period of accelerated development of sprint acceleration characteristics seems to occur from mid- to post-PHV. The findings of this study further highlight the importance of continual assessment and monitoring of individual differences in growth and maturation in youth AF.

The greatest differences in mechanical sprint characteristics occurred between the ages of 13 and 14 compared to 14 and 15 suggesting a period of enhanced sprint acceleration development (Table 2). This is highlighted by *possibly* faster 5 m split time and *likely* faster split times at distances > 10 m in 14 versus 13 year old groups and *unclear* differences in all split times between 15 and 14 year old groups, supporting the non-linear development of speed in youth (1, 2). Interestingly, the 14 year old group displayed *likely* greater relative $P_{\max}$ compared to the 13 year old group through *likely* greater V_0 with *unclear* differences in relative F_0 . This indicates a superior ability to apply relative horizontal force at higher velocities (mid to late phase acceleration) (28) and explains the *likely* higher $V_{\max}$ recorded in 14 year olds compared to 13 year olds (28). Whilst *likely* increases in body mass were found between these two age

groups, the *unclear* difference in relative F_0 suggest that the increase in body mass did not elicit positive effects on relative maximal strength, resulting in no improvement in the ability to apply relative horizontal force at low velocities (early acceleration). Despite *unclear* differences in split times, similar results were found between the 15 and 14 year old age groups with the former displaying *likely* superior V_0 demonstrating a better ability to apply force at high velocities leading to *possibly* higher $V_{\max}$ recordings during sprint acceleration. Previously, a temporal slower development phase of sprinting ability has been observed in boys between the ages of 8.8 and 12.1 years old. During this phase, mean propulsive force remained constant with decreased step frequency, regardless of the specific phase of sprinting (30). Sprinting ability rapidly improved after the period of temporal slower development due to increasing propulsive forces during initial and middle acceleration phases (30). This supports the current study's findings of a period of enhanced sprint acceleration development from 13 to 14 years of age before stabilising from 14 to 15 years of age in junior AF players. These results may be explained through stages of maturational development demonstrated in this study and previous research (3-7, 12, 13, 15).

The influence of maturation status and sprint acceleration characteristics is most prominent in post-PHV compared to pre- and mid-PHV. Whilst *unclear* differences were found in 5 m and 10 m split times between maturity groups, the post-PHV group were *likely* faster than pre- and mid-PHV groups at all distances > 15 m. These findings are consistent with previous research in junior AF (4, 5) and youth soccer (14) that confirm the positive effect of maturation on sprint acceleration performance. Regarding the underlying sprint acceleration characteristics, the post-PHV group displayed *likely* superior V_0 than the pre- and mid-PHV leading to *likely* and *very likely* higher $V_{\max}$ respectively. These differences in sprint acceleration characteristics may be attributed to improvements in motor coordination (2) that occur through the maturation

process allowing the post-PHV group to reach higher velocities (2, 11). Further, the *likely* difference in S_{FV} and D_{RF} between the post- and mid-PHV groups demonstrates the post-PHV group greater application and superior orientation of horizontal force at higher velocities (28). Since *unclear* differences in S_{FV} and D_{RF} were observed between other maturation group comparisons it is speculated that the mid-PHV group may be experiencing a period deemed ‘adolescent awkwardness’ resulting in reduction in co-ordination limiting their ability to effectively apply and orient horizontal forces at increasing velocity (2, 28). Previous research investigating the kinetics and kinematics of maximal velocity running across maturity reported significant differences in speed, step length, step frequency, vertical and horizontal force, and horizontal power between pre-PHV and mid and post-PHV groups (13). Interestingly, only relative vertical force and speed were significantly different between mid and post-PHV groups (13). However, the only prior study to investigate the influence of maturity status on sprint acceleration GRF’s found similar results between boys 4.5 – 3.5 years prior to PHV compared to boys 5.5 – 4.5 years prior to PHV (12). Using a 52-force plate system to derive sprint acceleration GRF’s the authors reported a 12.4% increase in V_{max} in boys 4.5 – 3.5 years prior to PHV which was attributable to greater mean antero-posterior GRF’s across shorter ground contact times (12). Nonetheless, it is difficult to compare the results of the current study due to the large differences in the maturation status of the participants (12) and data collection methods (13).

Significant differences in body mass existed between all maturation groups which would explain the *likely* and *very likely* differences in absolute F_0 and absolute P_{max} between all maturation group comparisons. Whilst these differences may not directly transfer to faster split times, the benefit of producing greater force and power during maximal sprint accelerations in contact sports such as AF should not be ignored. Further, heavier athletes with similar

370 acceleration capacities and split times will possess a higher momentum ($p = m \times v$) than lighter
371 athletes which may assist in technical and tactical areas of the game including making and
372 breaking tackles, and gathering contested possession of the ball which have been identified as
373 key performance indicators in junior AF (31). Interestingly however, *unclear* differences were
374 observed in relative F_0 between all maturation group comparisons. This is surprising as existing
375 research has reported increases in strength and power at the time of PHV (2) as a result of
376 increased muscle cross-sectional area (6) and neuromuscular function and recruitment (2). This
377 suggests that the differences in body mass between groups does not elicit positive effects on
378 relative horizontal force application at low velocities (early acceleration). These specific
379 findings have important practical considerations for strength and conditioning practitioners
380 looking to improve sprint acceleration performance, particularly in young AF players
381 experiencing maturation who should focus on improving force producing capacity at low
382 velocities (F_0). To develop this capacity, the prescribed sprint and resistance training program
383 should include exercises where force is applied against an external resistance (16, 17, 32).
384 Previously, youth athletes who had attained mid-PHV maturity status have improved maximal
385 sprinting speed performance after resisted sled towing intervention at loads of 2.5 to 10% body
386 mass through increased step frequency and antero-posterior force and power production, with
387 trivial changes in pre-PHV athletes (32). More recently, in post-PHV boys, heavy sled pulling
388 and pushing at loads more than 50% velocity decrease were more effective than unresisted
389 sprinting in improving short distance sprint performance through increasing initial
390 acceleration, force, and power (16, 17). Further, changes in sprint performance (split time) after
391 a heavy sled pushing and pulling training intervention were reflected in changes in sprint
392 acceleration force, velocity, power profiles suggesting the adaptations are specific to the
393 training stimulus employed (16). These exercises may be particularly suitable for youth athletes
394 as they are less complex than traditional barbell exercises and can be performed with heavier

load. Additionally, they encourage greater magnitude of anteroposterior ground reaction force specific to early sprint acceleration (16, 17, 33).

PRACTICAL APPLICATION

It is evident in the current study that sprint acceleration performance naturally improves with age and maturation status primarily through changes in V_0 whilst relative F_0 remains stable. This suggests that as junior AF players increase in age and experience maturation, their ability to apply large magnitudes of horizontal force at increasing velocities improves whilst no changes occur in relative force application at low velocities (28). Specifically, the age group comparison revealed a period of enhanced sprint acceleration development between 13 and 14 years before stabilising from 14 to 15 years old. Maturation status also influenced sprint acceleration characteristics with post-PHV players recording faster split times > 15 m and more efficient horizontal force application than the pre- and mid-PHV players. No differences were observed in relative F_0 between age or maturation group comparisons. It is suggested that practitioners aim to improve force producing capacities of the lower limb, technique, and coordination in junior AF players experiencing maturation through heavy sled pushes and sled pulls (16, 17, 32, 33). Improving an athlete's relative lower limb strength through these modalities can not only improve their ability to apply force at low velocities, it also provides the foundation for improving maximal power (16, 17) that may potentially improve other aspects of the force-velocity profile.

ACKNOWLEDGEMENTS

The authors would like to thank all the athletes, coaches, and strength and conditioning staff for their participation in this study.

REFERENCES

1. Philippaerts, RM, Vaeyens, R, Janssens, M, Van Rentergham, B, Matthys, D, Craen, R, Bourgois, J, Vrijens, J, Beunen, G, Malina, RM. The relationship between peak height velocity and physical performance in youth soccer players. *J Sport Sci* 24: 221-230, 2006.
2. Malina, RM, Bouchard, C, Bar-Or, O. *Growth, Maturation, and Physical Activity*. Champaign, IL: Human kinetics, 2004
3. Cripps, AJ, Hoppe, L, Joyce, C. Maturity, physical ability, technical skill and coaches' perception of semi-elite adolescent Australian footballers. *Pediatr Exerc Sci* 28: 535-541, 2016.
4. Gastin, PB, Bennett, G. Late maturers at a performance disadvantage to their more mature peers in junior Australian football. *J Sports Sci* 32: 563-571, 2014.
5. Gastin, PB, Bennett, G, Cook, J. Biological maturity influences running performance in junior Australian football. *J Sci Med* 16: 140-145, 2013.
6. Jones, B, Weaving, D, Tee, J, Darrall-Jones, J, Weakley, J, Phibbs, P, Read, D, Roe, G, Hendricks, S, Till, K. Bigger, stronger, faster, fitter: the differences in physical qualities of school and academy rugby union players. *J Sports Sci* 36:2399-2404, 2018.
7. Till, K, Cobley, S, O'Hara, J, Cooke, C, Chapman, C. Considering maturation status and relative age in the longitudinal evaluation of junior rugby league players. *Scand J Med Sci Sports* 24: 569-576, 2014.
8. Burgess, D, Naughton, G, Hopkins, W. Draft-camp predictors of subsequent career success in the Australian Football League. *J Sci Med Sport* 15: 561-567, 2012.

9. Robertson, S, Woods, C, Gastin, P. Predicting higher selection in elite junior Australian Rules football: The influence of physical performance and anthropometric attributes. *J Sci Med Sports* 18: 601-606, 2015.
10. Woods, CT, Cripps, A, Hopper, L, Joyce, C. A comparison of the physical and anthropometric qualities explanatory of talent in the elite junior Australian football development pathway. *J Sci Med Sports* 20: 684-688, 2017.
11. Rumpf, MC, Lockie, RG, Cronin, JB, Jalilvand, F. Effect of different sprint training methods on sprint performance over various distances: A brief review. *J Strength Cond Res* 30: 1767-1785, 2016.
12. Colyer, SL, Nagahara, R, Takai, Y, Salo, AIT. The effect of biological maturity status on ground reaction force production during sprinting. *Scand J Med Sci Sports*. Epub ahead of print. Doi: 10.1111/sms.13680.
13. Rumpf, MC, Cronin, JB, Oliver, J, Hughes, M. Kinematics and kinetics of maximum running speed in youth across maturity. *Pediatr Exerc Sci* 27: 277-284, 2015.
14. Mendez-Villanueva, A, Buchheit, M, Kuitunen, S, Douglas, A, Peltola, E, Bourdon, P. Age-related differences in acceleration, maximum running speed, and repeated-sprint performance in young soccer players. *J Sports Sci* 29:477-484, 2011.
15. Meyers, RW, Oliver, JL, Hughes, MG, Cronin, JV, Lloyd, RS. Maximal sprint speed in boys of increasing maturity. *Pediatr Exerc Sci* 27:85-94, 2015.
16. Cahill, MJ, Oliver, JL, Cronin JB, Clark, K, Cross, MR, Lloyd, RS, Lee, JE. Influence of resisted sled-pull training on the sprint force-velocity profile of male high school athletes. *J Strength Cond Res* 34: 2751-2759, 2020.

17. Cahill, MJ, Oliver, JL, Cronin JB, Clark, K, Cross, MR, Lloyd, RS. Influence of resisted sled-push training on the sprint force-velocity profile of male high school athletes. *Scand J Med Sci Sports* 30: 442-449, 2020.
18. Baumgart, C, Freiwald, J, Hoppe, MW. Sprint mechanical properties of female and different aged male top-level german soccer players. *Sports (Basel)* 6: 161, 2018.
19. Edwards, T, Piggott, B, Banyard, HG, Haff, GG, Joyce, C. Sprint acceleration characteristics across the Australian football participation pathway. *Sports Biomech*. Epub ahead of print, 2020. Doi: 10.1080/14763141.2020.1790641
20. Edwards, T, Piggott, B, Banyard, HG, Haff, GG, Joyce, C. Sprint acceleration force-velocity-power characteristics in drafted vs non-drafted junior Australian football players: Preliminary results. *Sci Med Football*. Epub ahead of print, 2020. Doi: 10.1080/24733938.2020.1830159
21. Haugen, TA, Breitschadel, F, Seiler, S. Sprint mechanical variables in elite athletes: Are force-velocity profiles sport specific or individual? *PLoS One* 14: e0215551, 2019.
22. Haugen, TA, Breitschadel, F, Seiler, S. Sprint mechanical properties in soccer players according to playing standard, position, age and sex. *J Sports Sci*, 38: 1070-1076, 2020.
23. Jimenez-Reyes, P, Garcia-Ramos, A, Cuadrado-Penafiel, C, Parraga-Montilla, JA, Morcillo-Losa, JA, Samazino, P, Morin, JB. Differences in Sprint Mechanical Force-Velocity Profile Between Trained Soccer and Futsal Players. *Int J Sports Physiol Perform*, 14:478-485, 2019.
24. Mirwald, RL, Baxter-Jones, AD, Bailey, DA, Beunen, GP. An assessment of maturity from anthropometric measurements. *Med Sci Sports Exerc* 34:689-694, 2002.

25. Simperingham, KD, Cronin, JB, Pearson, SN, Ross, A. Reliability of horizontal force–velocity–power profiling during short sprint-running accelerations using radar technology. *Sports Biomech* 18: 88-99, 2017.
26. Morin, JB, Samozino, P, Murata, M, Cross, MR, Nagahara, R. A simple method for computing sprint acceleration kinetics from running velocity data: Replication study with improved design. *J Biomech*, 20:82-87, 2019.
27. Samozino, P, Rabita, G, Dorel, S, Slawinski, J, Peyrot, N, Saez de Villarreal, E, Morin, JB. A simple method for measuring power, force, velocity properties, and mechanical effectiveness in sprint running. *Scand J Med Sci Sports* 26: 648-658, 2016.
28. Morin, JB, Samozino, P. Interpreting power-force-velocity profiles for individualized and specific training. *Int J Sports Physiol Perform* 11: 267-272, 2016.
29. Hopkins, WG, Marshall, SW, Batterham, AM, Hanin, J. Progressive statistics for studies in sports medicine and exercise science. *Med Sci Sports Exerc* 41: 3-13, 2009.
30. Nagahara, R, Takai, Y, Haramura, M, Mizutani, M, Matsuo, A, Kanehisa, H, Fukunaga, T. Age-related differences in spatiotemporal variables and ground reaction forces during sprinting in boys. *Pediatr Exerc Sci* 30:335-344, 2018.
31. Woods, CT, Bruce, L, Veale, JP, Robertson, S. The relationship between game-based performance indicators and developmental level in junior Australian football: Implications for coaching. *J Sports Sci* 34: 2165-2169, 2016.
32. Rumpf, MC, Cronin, JB, Mohamad, IN, Mohamad, S, Oliver, JL, Hughes, MG. The effect of resisted sprint training on maximum sprint kinetics and kinematics in youth. *Eur J Sport Sci* 15:374-381, 2015.

- 515 33. Weakley, JJ, Till, K, Darrall-Jones, J, Roe, GAB, Phibbs, PJ, Read, DB, Jones, BL.
516 Strength and conditioning practices in adolescent rugby players: Relationship with
517 changes in physical qualities. *J Strength Cond Res* 33: 2361-2369, 2019.
518
519
520

521 **Table 1.** Athlete Anthropometric Characteristics

	13 y	14 y	15 y	Post PHV	Mid PHV	Pre PHV
Age (y)	-	-	-	14.12 ± 0.56*	13.28 ± 0.56	13.25 ± 0.58
Height (cm)	164.82 ± 7.57 [#]	172.43 ± 7.87	176.02 ± 10.18	174.81 ± 7.55*	166.60 ± 5.90**	158.16 ± 6.76
Weight (kg)	53.75 ± 8.23 [#]	63.32 ± 10.53	66.01 ± 12.79	66.88 ± 8.82*	53.42 ± 6.24**	47.28 ± 7.77
Y-PHV	-0.16 ± 0.61 [#]	1.00 ± 0.73	1.49 ± 0.95	1.29 ± 0.70*	0.06 ± 0.27**	-0.84 ± 0.33

522 [#] Significantly different from all other maturity groups p < .05523 ^{##} Significantly different from 13 year old p < .05

524 *Significantly different from all other maturity groups p < .05

525 **Significantly different from pre-PHV p < .05

526

527

528 **Table 2.** Comparison of Sprint Acceleration Characteristics and Split Times between Age Groups

	13 y	14 y	15 y	13-14 %Δ ± 90%CI	13-15 %Δ ± 90%CI	14-15 %Δ ± 90%CI
Abs F₀ (N)	394.12 ± 72.4	471.27 ± 88.11	486.21 ± 105.1	19.58 ± 7.01*	23.37 ± 10.02*	3.17 ± 9.50
F₀ (N/kg)	7.34 ± 0.78	7.46 ± 0.78	7.35 ± 0.59	1.64 ± 3.64	0.18 ± 4.85	-1.43 ± 4.79
V₀ (m/s)	7.48 ± 0.61	7.80 ± 0.67	8.12 ± 0.71	4.20 ± 2.94	8.59 ± 4.13*	4.21 ± 4.22
Abs P_{max} (W)	738.29 ± 157.93	919.10 ± 192.93	987.46 ± 224.97	24.49 ± 8.19*	33.75 ± 11.58*	7.44 ± 10.59
P_{max} (W/kg)	13.70 ± 1.73	14.53 ± 2.01	14.88 ± 1.37	6.07 ± 4.69	8.61 ± 5.83	2.40 ± 6.23
Fv Slope (N/kg/m/s)	-0.99 ± 0.13	-0.96 ± 0.14	-0.91 ± 0.12	-2.48 ± 4.67	-7.52 ± 6.48	-5.17 ± 6.67
RF max (%)	40.76 ± 2.31	41.77 ± 2.44	42.23 ± 1.62	2.48 ± 2.00	3.59 ± 2.56	1.09 ± 2.62
Drf (%)	-9.33 ± 129	9.06 ± 1.31	-8.55 ± 1.23	-2.89 ± 4.76	-8.30 ± 6.60	-5.56 ± 6.87
Max Speed (m/s)	7.13 ± 0.51	7.42 ± 0.57	7.68 ± 0.56	4.06 ± 2.60*	7.70 ± 3.53*	3.49 ± 3.70
5 m (s)	1.44 ± 0.07	1.41 ± 0.07	1.41 ± 0.04	-1.63 ± 1.63	-2.11 ± 2.15	-0.49 ± 2.12
10 m (s)	2.26 ± 0.11	2.22 ± 0.10	2.19 ± 0.07	-2.03 ± 1.60	-3.00 ± 2.11	-0.99 ± 2.13
15 m (s)	3.01 ± 0.14	2.95 ± 0.15	2.91 ± 0.10	-2.28 ± 1.63*	-3.62 ± 2.13*	-1.37 ± 2.23
20 m (s)	3.74 ± 0.18	3.65 ± 0.19	3.59 ± 0.14	-2.49 ± 1.70*	-4.10 ± 2.22*	-1.65 ± 2.37
25 m (s)	4.45 ± 0.22	4.33 ± 0.24	4.25 ± 0.18	-2.69 ± 1.78*	-4.51 ± 2.32*	-1.87 ± 2.51
30 m (s)	5.13 ± 0.24	5.01 ± 0.29	4.90 ± 0.22	-2.49 ± 1.86	-4.72 ± 2.38*	-2.28 ± 2.68

529 Abbreviations: Abs F₀ – absolute theoretical maximum force; F₀ – relative theoretical maximum force; V₀ – theoretical maximum velocity; Abs
530 P_{max} – absolute maximum power; P_{max} – maximum power; Fv Slope – slope of the force-velocity relationship; RF max; maximum ratio of
531 horizontal to total force. * = p < 0.05

532 **Table 3.** Comparison of Sprint Acceleration Characteristics and Split Times between Maturity Groups

	Post-PHV	Mid-PHV	Pre-PHV	Pre-Mid %Δ ± 90%CI	Pre-Post %Δ ± 90%CI	Mid-Post %Δ ± 90%CI
Abs F0 (N)	492.65 ± 80.53	399.88 ± 62.85	342.70 ± 65.85	16.68 ± 9.37*	43.75 ± 10.67*	23.20 ± 6.55*
F0 (N/kg)	7.36 ± 0.65	7.50 ± 0.92	7.25 ± 0.70	3.41 ± 5.96	1.58 ± 4.27	-1.77 ± 3.58
V0 (m/s)	7.89 ± 0.69	7.50 ± 0.60	7.54 ± 0.68	-0.56 ± 4.19	4.62 ± 4.32	5.21 ± 3.10*
Abs Pmax (W)	970.77 ± 178.06	750.87 ± 142.46	647.53 ± 1574.65	15.96 ± 11.37	49.92 ± 12.60*	29.29 ± 7.77*
Pmax (W/kg)	14.50 ± 1.77	14.04 ± 2.06	13.62 ± 1.59	3.10 ± 7.13	6.49 ± 5.99	3.29 ± 4.73
Fv Slope (N/kg/m/s)	-0.94 ± 0.12	-1.01 ± 0.14	-0.97 ± 0.14	3.55 ± 7.32	-3.06 ± 6.24	-6.38 ± 4.59
RF max (%)	0.42 ± 0.02	0.41 ± 0.03	0.41 ± 0.02	1.21 ± 3.08	2.73 ± 2.46	1.51 ± 2.03
Drf (%)	-8.85 ± 1.22	9.48 ± 1.32	-9.16 ± 1.39	3.49 ± 7.39	-3.38 ± 6.48	-6.65 ± 4.69
Max Speed (m/s)	7.50 ± 0.58	7.15 ± 0.50	7.16 ± 0.56	-0.11 ± 3.67	4.69 ± 3.77	4.81 ± 2.71*
5 m (s)	1.41 ± 0.06	1.42 ± 0.08	1.44 ± 0.06	-1.02 ± 2.61	-1.66 ± 1.88	-0.65 ± 1.67
10 m (s)	2.21 ± 0.09	2.25 ± 0.12	2.27 ± 0.09	-0.90 ± 2.51	-2.26 ± 1.92	-1.37 ± 1.65
15 m (s)	2.94 ± 0.13	3.00 ± 0.16	3.01 ± 0.12	-0.65 ± 2.51	-2.46 ± 2.04	-1.82 ± 1.69
20 m (s)	3.63 ± 0.18	3.72 ± 0.20	3.74 ± 0.17	-0.66 ± 2.56	-2.84 ± 2.19	-2.19 ± 1.76
25 m (s)	4.32 ± 0.22	4.43 ± 0.24	4.45 ± 0.21	-0.60 ± 2.65	-3.07 ± 2.35	-2.49 ± 1.84
30 m (s)	4.99 ± 0.28	5.12 ± 0.29	5.13 ± 0.24	-0.12 ± 2.69	-2.77 ± 2.49	-2.66 ± 1.94

533 Abbreviations: Abs F₀ – absolute theoretical maximum force; F₀ – relative theoretical maximum force; V₀ – theoretical maximum velocity; Abs
534 P_{max} – absolute maximum power; P_{max} – maximum power; Fv Slope – slope of the force-velocity relationship; RF max; maximum ratio of
535 horizontal to total force. * = p < 0.05

536 **Figure Legends**

537 **Figure 1.** Effect size and inference of differences in sprint acceleration characteristics and
538 split times between 13, 14, and 15 year old age groups.

539 **Figure 2.** Effect size and inference of differences in sprint acceleration characteristics and
540 split times between pre-, mid- and post- peak height velocity groups.