

PLANTAR PRESSURE CORRELATIONS WITH INDIVIDUAL FACTORS IN RUGBY SCRUM

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ABSTRACT

Plantar pressure is related to injuries in the lower extremities and can be influenced by certain individual factors. However, the pressures of complex but important actions in team sports, such as rugby scrum, have not yet been analyzed. The aim of the study was to examine whether there is a relationship between plantar pressure and individual factors such as age, height, weight or foot size during the rugby scrum gesture. The plantar pressures of 24 men and 20 women, all healthy rugby players, were recorded using the BioFoot® system, during various scrum situations. Positive correlations were found with weight, height and foot height (pearson $r > 0.33$ and $p < 0.05$), especially in the forefoot and toes area. These results can serve to better understand the behavior of plantar pressure in a gesture that has not been studied so far.



KEY WORDS

plantar pressure, rugby, scrum.



INTRODUCTION

Due to Newton's third law and the action-reaction principle, when a person places his foot on the ground (to perform any action), reciprocal forces appear between the person and the ground. In this way, the person exerts a force on the ground that will

depend on his own weight and the type of movement he makes, and the ground will exert an equal force at that instant but in the opposite direction, called the reaction force (1-3). The measurement of these forces is essential to understand the distribution of pressures exerted on the sole of the foot. Baropodometry is a tool to explore the behaviour of the plantar footprint. This method identifies support components and load pressure levels according to established zones (4). Repeatedly high plantar pressure means increased impact on the adjacent knee and hip joints, which can lead to injury. and hip joints and may cause overuse or repetitive injuries due to the accumulation of these micro-impacts (5). It is also known that fatigue-induced changes in plantar pressure sustained over time can lead to various overuse injuries and stress fractures due to loss of motion technique and alteration of the optimal pressure pattern (6). In this sense, plantar pressure analysis is important for the diagnosis and treatment of different pathologies (7).

In team sports, most of the situations that occur are in a standing situation, with one or both feet resting on the ground (8). or both feet on the ground. In this case, plantar pressure analysis also provides both information about the body schema (8, 9) and information about the performance of the individual (10). There is little research that has dealt with plantar pressure in rugby, focusing mainly on the running action (11). However, other very important phases of the game have been left unexamined, such as the scrum. The rugby scrum is a fundamental component of the sport. It is the phase in which play is restarted after an infringement due to an opponent's foul or breakdown, which consists of an organised formation of 8 players from each team, in which both teams compete for possession of the ball (12, 13). It represents both a powerful offensive skill, which provides a base for launching attacks, and a defensive skill, which aims to disrupt the opponent's possession. Given its intense physical nature and the presence of impacts, the scrum can place very high biomechanical demands on players' musculoskeletal structures and, therefore, can expose players to the risk of both acute and chronic (overuse) injuries (12, 13). While scrums may be associated with a number of potential injury risk factors, there is currently very little scientifically obtained quantitative data that attempts to identify and describe them. There is a lack of information on the forces and movements involved in the actual scrum and consequently little objective knowledge on how performance can be optimised and injury prevented (13).

The ability to apply force against the ground and against the opposing team during this phase can be of great interest to players and coaches because of the tactical advantage it brings (12, 14). The scarce scientific literature reflects that the joints most involved in the push-off (hip and knee) should be positioned in 90° flexion to maximise their efficiency in the push-off. The trunk must be in a neutral, strong and stable position and have coordination of various motor patterns to avoid injury. In addition, the shoulders must always be in line with (or higher than) the hips, avoiding a downward thrust that causes the scrum to collapse (15). The position of the feet is personal and depends on the individual player, but a dorsiflexion of approximately 60° is recommended (16). Less dorsiflexion can alter the rest of the body structure (17), worsening the ideal technical position for the thrust (Figure 1) (18). With this ankle dorsiflexion, most of the pressure of the foot falls on the forefoot, the area from which the push-off forces start.

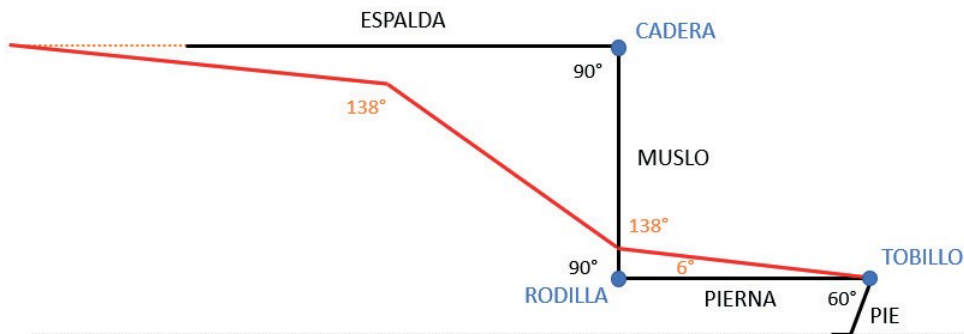


Figure 1: Body image of the anatomical position of the scrum push (black: position at the starting point, red: position after the forward push).

Differences in anatomical structures and individual anthropometric characteristics lead to differences in both the kinematics and kinetics of lower limb movement (19-24). It is therefore possible that individual factors such as age, height, weight or foot size may influence plantar pressure, in this case in rugby players during a scrum, and may help to understand the development of pathologies in this sport. The influence of these factors on this particular scrum gesture has not been studied, but there is some scientific evidence to suggest that there may be a relationship between weight (25, 26), height (27) and foot size (21) with plantar pressure in general, so it is hypothesised that these relationships may also occur in this sporting gesture.

In this sense, the aim of the present study was to study whether there is a relationship between plantar pressure and certain individual factors such as age, height, weight or foot size during the rugby scrum.

MATERIALS Y METHODS

Participants

The study population were amateur rugby players of regional category, Spanish nationality and ages between 13 and 45 years. Thus, the sample consisted of 44 athletes (20 females and 24 males; age = 22 ± 6 years; height = 1.70 ± 0.10 m; weight = 76.6 ± 20.4 kg; foot size = 41 ± 3).

Inclusion and exclusion criteria were:

- Inclusion criteria: healthy rugby players, who played in the 1st, 2nd or 3rd row position, were within the established age range (13 - 45 years) and played rugby at amateur level.
- Exclusion criteria: players who were injured or recovering from injury, had a serious injury in the last year and were not within the age range.

All participants were fully informed about the protocol, the experimental sessions, the importance of their involvement in the sessions and the risks/benefits associated with the practice of physical activity, and signed an informed consent prior to their participation in the project. This study was approved by the University's ethics committee (UCV/2020-2021/172), complying with the requirements established in the declaration of Helsinki.

Protocol

Each participant underwent a single measurement session. First, age and foot size were asked. Then, athletes were weighed and measured for height following the protocol of Norton and Olds (28). For weight, a scale with a measurement error of 100 g was used, and the measurement was taken with as little clothing as possible. Height was measured using a measuring rod, with the player's feet together, heels, buttocks and upper back touching the measuring rod, and head positioned in the Frankfort plane (which is the plane in which the lower edge of the eye socket is in a horizontal line with the upper notch of the ear tragus). This position was to be maintained throughout the measurement process, with the measurement being taken at the highest point of the head during a deep inspiration. Both measurements were always taken at 20:00 h, taking the measurements at the same place and time and with the same scout, as recommended in the literature (29).

Next, all players performed a specific and standardised warm-up, established on the basis of the World Rugby™ ACTIVATE Injury Prevention Exercise Programme (30). This warm-up consisted of a first part of mobility and muscle activation. This was followed by exercises involving acceleration, deceleration and changes of direction. Finally, we moved on to a more specific warm-up where we worked in scrum position, and emphasised static and dynamic lumbo-pelvic stability work and activation of the core and neck musculature.

Once the warm-up was over, the players were given a 5-minute rest period while the test to be performed was explained to them, so that they could perform the measurements without fatigue. The players then performed a number of scrums. In each scrum one player was measured and each player performed two repetitions of the activity. The measurement time was 10 s, which is approximately the time that elapses in a scrum from the moment the players enter the scrum until the ball is released and the players separate.

Procedure

The BioFoot® plantar pressure measurement system (IBV, Valencia, Spain) was used for the plantar pressure analysis. BioFoot® is a footwear system that measures plantar pressure at the interface between the shoe and the foot. It consists of a pair of thin (0.7 mm) flexible polyester insoles, each containing 64 piezoelectric sensors 0.5 mm thick and 5 mm in diameter. The insoles are available in different sizes, allowing a good match with the shoe surface regardless of shoe size. These insoles are connected to an amplifier that is attached to each ankle, which in turn is connected to a transmission module that is attached to the participant's waist by means of a belt. Data is sent from the amplifier to be recorded on a computer and then processed by a program that displays pressure, contact time and cadence parameters. The system uses the units of kilopascals (1 kPa = 1/98 kg/cm²). The sampling frequency was 200 Hz, taking 10 s recordings, as explained above (31). Due to material limitations, it was decided to analyse only the pressure on the dominant foot. The dominant foot of each athlete was established according to the scientifically validated procedure of van Melick, Meddeler (32), i.e. by asking the athlete with which leg he/she would kick a ball. The athletes wore their own shoes for the test. However, despite this difference in shoes, all athletes performed the measurement with multi-cushioned boots that were relatively similar in design.

The sole of the foot was divided into 9 zones, following the division of Huang et al (33). This division can be seen in Figure 2. The variables analysed for each zone were peak pressures and mean peak pressures.

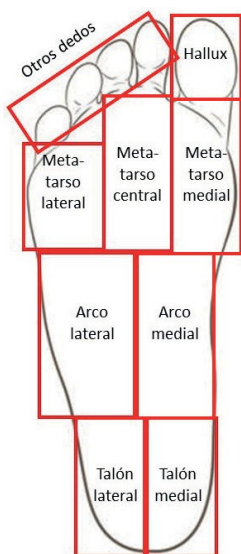


Figure 2: The nine segments into which the foot has been divided.

Statistical analysis and data processing

The variables were collected in an Excel spreadsheet and statistically processed using the SPSS statistical software SPSS

26 (SPSS Inc., Chicago, IL). Correlations were established between the controlled quantitative variables (age, weight, height and foot size) and the plantar pressure patterns. These correlations were established from Pearson's bivariate correlations. Significant correlations ($p < 0.05$) were classified as weak ($\pm 0.2 < r < \pm 0.5$), moderate ($\pm 0.5 \leq r < \pm 0.8$), or strong ($r \geq \pm 0.8$) (34).

RESULTS

Tables 1 and 2 below show the Pearson correlations found between age, weight, height and foot size with peak (Table 1) and mean peak pressures (Table 2). Significant correlations are highlighted in bold.

Table 1: Correlation coefficient (Pearson's r) and bilateral significance (p -value) between age, weight, height and height of the foot and the maximum pressures in the nine foot zones studied. P Max: maximum pressure. H: Hallux or first toe, D: Rest of toes, MM: Medial metatarsal, MC: Central metatarsal, ML: Lateral metatarsal, AM: Medial arch, AL: Lateral arch, TM: Medial heel, TL: Lateral heel. * p -value significant ($p < 0.05$), ** p -value highly significant ($p < 0.01$).

		PMaxH	PMax D	PMax MM	PMax MC	PMax ML	PMax AM	PMax AL	PMax TM	PMax TL
Age	Correlation coefficient (Pearson's r)	0,02	0,03	0,35	-0,02	-0,04	0,04	0,05	0,04	0,20
	Bilateral significance (p-value)	0,91	0,86	0,02*	0,91	0,81	0,79	0,76	0,81	0,20
Weight	Correlation coefficient (Pearson's r)	0,36	0,58	0,18	0,07	0,09	0,08	0,01	0,07	0,17
	Bilateral significance (p-value)	0,02*	<0,01**	0,24	0,67	0,57	0,60	0,96	0,65	0,28

Height	Correlation coefficient (Pearson's r)	0,20	0,57	0,18	0,04	-0,11	-0,01	0,05	-0,06	0,37
	Bilateral significance (p-value)	0,20	<0,01**	0,23	0,80	0,48	0,94	0,75	0,69	0,01*
Foot size	Correlation coefficient (Pearson's r)	0,31	0,55	0,15	0,07	0,05	0,03	-0,03	-0,06	0,31
	Bilateral significance (p-value)	0,04*	<0,01**	0,33	0,64	0,75	0,84	0,87	0,70	0,04*

Table 2: Correlation coefficient (Pearson's r) and bilateral significance (p-value) between age, weight, height and height of the foot and the mean maximum pressures in the nine areas of the foot studied. P Med Max: maximum mean pressure. H: Hallux or first toe, D: Rest of toes, MM: Medial metatarsal, MC: Central metatarsal, ML: Lateral metatarsal, AM: Medial arch, AL: Lateral arch, TM: Medial heel, TL: Lateral heel. * p-value significant ($p < 0.05$), ** p-value highly significant ($p < 0.01$).

		PMedMaxH	PMedMax D	PMedMax MM	PMedMax MC	PMedMax ML	PMedMax AM	PMedMax AL	PMedMax TM	PMedMax TL
Age	Correlation coefficient (Pearson's r)	0,04	0,10	0,22	0,11	-0,08	0,02	0,01	0,05	0,15
	Bilateral significance (p-value)	0,80	0,53	0,16	0,48	0,62	0,90	0,96	0,77	0,32
Weight	Correlation coefficient (Pearson's r)	0,33	0,53	-0,04	0,02	-0,03	0,07	0,13	0,02	0,21
	Bilateral significance (p-value)	0,03*	<0,01**	0,81	0,89	0,84	0,65	0,42	0,89	0,18
Height	Correlation coefficient (Pearson's r)	0,14	0,48	-0,10	-0,15	-0,28	-0,07	0,07	0,09	0,33
	Bilateral significance (p-value)	0,35	<0,01**	0,50	0,34	0,07	0,64	0,65	0,56	0,03*
Foot size	Correlation coefficient (Pearson's r)	0,26	0,54	-0,17	-0,08	-0,12	0,02	0,08	0,04	0,26
	Bilateral significance (p-value)	0,09	<0,01**	0,29	0,60	0,43	0,90	0,60	0,78	0,09

For age, a weak correlation was found between age and medial metatarsal peak pressure ($r(42) = 0.35$, $p = 0.02$), but no correlation was found with mean peak pressure ($p = 0.15$). With respect to weight, weak correlations were found between weight and maximum hallux pressure ($r(42) = 0.36$, $p = 0.02$) and mean maximum hallux pressure ($r(42) = 0.36$, $p = 0.02$). maximum hallux pressure ($r(42) = 0.33$, $p = 0.03$). For weight, moderate correlations were also found between weight and maximum pressure of the rest of the toes ($r(42) = 0.58$; $p < 0.01$), and between weight and maximum mean pressure of the rest of the toes ($r(42) = 0.53$; $p < 0.01$). In the case of height, a moderate correlation was found with the maximum pressure of the rest of the toes ($r(42) = 0.57$; $p < 0.01$) and a weak correlation with the maximum mean pressure ($r(42) = 0.48$; $p < 0.01$). In the lateral heel, correlations were also found between height and peak pressure and mean peak pressure ($r(42) = 0.37$; $p = 0.01$) and ($r(42) = 0.33$; $p = 0.02$), respectively. Finally, weak correlations were observed between shoe size and peak pressures at the hallux ($r(42) = 0.31$, $p = 0.04$) and lateral heel ($r(42) = 0.31$, $p = 0.04$), and moderate correlations at the rest of the toes ($r(42) = 0.55$, $p < 0.01$). Moderate correlations were also found between shoe size and mean maximum pressure in the rest of the toes ($r(42) = 0.54$; $p < 0.01$) (maximum and mean maximum pressures, respectively). A summary of these results is shown in figure 3.

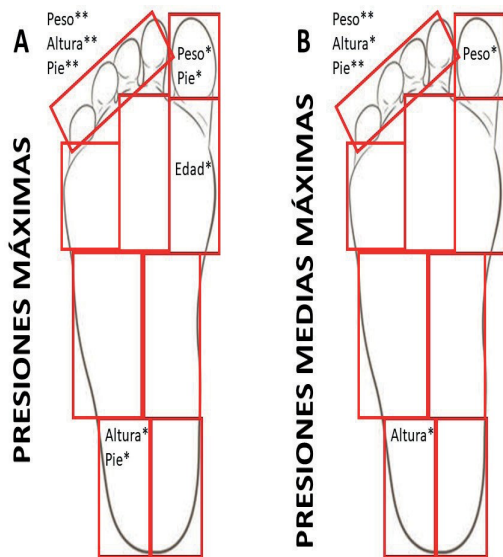


Figure 3: Summary of the correlations observed in the different areas of the foot. Figure A Peak pressures. Figure B Mean peak pressures (* weak correlation ($\pm 0.2 < r < \pm 0.5$), ** moderate correlation ($\pm 0.5 \leq r < \pm 0.8$)).

All observed correlations are positive, i.e. the greater the height, weight or size of the foot, the more pressure is exerted on that area, as indicated by the correlation coefficients in Tables 1 and 2.

DISCUSSION

During the scrum push-off there is a large dorsiflexion of the foot (16). In this gesture, the body weight is mainly supported in the forefoot area, and then the hip and knee are extended to perform the thrust. Generally, the pressures shown in other areas are due to repositioning movements in order to be able to push off again. It is therefore logical that the correlations found in this study are mostly seen in the forefoot and toes, as in the other areas, the pressure is very low in this sporting gesture.

In sport in general, there is some evidence that some individual factors may be related to plantar pressure (21, 25-27). However, in the present investigation, in the case of age, only a weak correlation was found in the medial metatarsal area, and only in the maximum pressure. From the lack of results in this case and the lack of existing scientific literature it can be inferred that age is not a relevant factor that can affect plantar pressure in healthy subjects and in young or adult age. Although during the developmental stages of childhood, it is possible that plantar pressures may be altered (35-37); once youth is reached, these pressure parameters remain stable throughout adulthood.

Weight has classically been directly related to higher plantar pressures (25). Body weight explains 14% of the variance in peak plantar pressures in both healthy and diabetic subjects (24). According to some research (38-40), subjects with higher body weight tend to load less the inside of the forefoot area, which could explain the higher correlation observed in the lateral part of the forefoot compared to the medial part. This result was also observed in the present study, where a higher correlation was found in the area of the rest of the toes than in the hallux area. This weak correlation

could be caused by a lower plantar pressure on the medial forefoot area, as shown in previous studies (38-40).

Regarding height, scientific evidence is scarce, but there is one study that observed a relationship between height and plantar pressure (27). As in the present investigation, this study showed the existence of certain correlations between height and plantar pressure (27). study showed the existence of certain correlations between height and plantar pressures in the forefoot. These correlations were stronger in the area of the rest of the toes, as were the correlations with body weight. It is believed that taller subjects and also those with greater body weight have poorer balance and are therefore forced to exert greater pressure on the lateral forefoot area in order to rebalance (38-40). This factor is important because, if heavier and taller subjects tend to exert more pressure in the toe area, this area could be a potential area of risk, as it is not designed to withstand high pressure over time.

On the other hand, it could be thought that the larger the foot size, the more the plantar pressures are distributed among all the zones and therefore, the lower the plantar pressures will be, as well as their ratio (21). However, in the present study, correlations were also found in the hallux area and the rest of the toes. In the case of the hallux, this correlation has only been observed for the maximum pressure variable and it is a weak correlation. However, in the case of the rest of the toes, it is a moderate correlation, both in the case of the maximum pressure and in the case of the mean maximum pressure. This higher correlation could also be due to the fact that people with more shoes tend to be taller and heavier (41, 42), tending to exert more pressure on the lateral forefoot area than the medial, as discussed above.

This study of plantar pressure has provided further insight into the previously unknown field of the rugby scrum. The relevance of the pressure of the foot on the forefoot during this sporting gesture has been demonstrated. This study, like that of Priego Quesada et al. (43) (carried out in paddle tennis) aims to lay the foundations of knowledge about plantar pressure in sports in which it had not been applied until now, as is the case of rugby and paddle tennis.



LIMITATIONS AND FUTURE PATHS

During the development of the study, several limitations were encountered, such as the assessment of the foot type of each individual participant (cavus, neutral or flat foot), a factor that could influence the distribution of plantar pressure. Similarly, differences in sporting level and sporting experience could not be controlled for. Further studies will be required to corroborate the results obtained. On the other hand, it was considered to provide all the athletes with the same model of shoes to standardise the measurement, but it was also taken into account that a new model of shoes to which the athlete is not accustomed could be counterproductive and could be used in a different way. to which the athlete is not used to could be counterproductive and alter their motor patterns (44). Another limitation of the study was the age range of the participants analysed (13-45 years), as it will not be the same to evaluate a player who is in a growth phase as compared to one who is already developed. Future research could narrow the age range in their measurements.

Also, given the results of the present study, future studies should investigate effective strategies to reduce plantar pressures in the area of the other toes, especially in those

who are large or heavy. In addition, further research on plantar pressure in rugby (both in the scrum phase and in the other phases of the game) would be of interest as this knowledge is necessary to optimise injury prevention, rehabilitation and physical preparation in this sport. Likewise, it may be of great interest to extend this study to different environments, leagues or countries, and even to analyse the differences between men and women, trying to control multiple variables that may affect the athlete and that this study has not been able to take into account.

The study of factors that may have an effect on plantar pressure may also be interesting to investigate in order to compare between subjects, to see if the plantar pressure patterns shown by a single subject correspond to what they should. Furthermore, this data could be used for industrial footwear design and injury prevention, adapting or creating specific models according to the individual factors that have been seen, and avoiding excess pressure in certain areas that are not designed to support an excessive load.



CONCLUSIONS

The results of the present study show that individual factors such as height, weight and foot size can influence the plantar pressure of rugby players during the scrum, specifically in the forefoot and toe area. The correlations observed between these factors are positive, whereby the greater the height, weight or size of the foot, the greater the plantar pressure. However, the age of the player does not seem to have a relationship with plantar pressure. These results may help to better understand the behaviour of plantar pressure in this particular rugby scrum.



REFERENCES

1. Encarnación-Martínez A. Análisis biomecánico de la marcha nórdica: efectos de la experiencia y de la velocidad de práctica sobre el patrón de presión plantar, las fuerzas de reacción del suelo y los niveles de impacto [Tesis doctoral]. Valencia: Universitat de València; 2012.
2. Arriscado D, Martínez J. Muscular strength training in young football players. *J. Sport Health Res.* 2017;9(3):329-38.
3. Pedro Núñez Ád. Pliometría contextualizada en el fútbol y el baloncesto. Mejoras esperadas vs reales. *Sportis.* 2016;2(1):36-57.
4. Perdomo, L. R., Yepes, C. A. R., & Vargas, M. E. Alteraciones en la presión plantar posterior a un protocolo de fatiga neuromuscular en máquina isoinercial. *SPORT TK.* 2021;10(2): 61-75.
5. Escamilla-Martínez E, Martínez-Nova A, Gómez-Martín B, Sánchez-Rodríguez R, Fernández-Seguí LM. The effect of moderate running on foot posture index and

plantar pressure distribution in male recreational runners. *J Am Podiatr Med Assoc.* 2013;103(2):121-5.

6. Willems TM, De Ridder R, Roosen P. The effect of a long-distance run on plantar pressure distribution during running. *Gait Posture.* 2012;35(3):405-9.

7. Camargo LH, Riaño P, Vázquez R. Visualización de la presión plantar en software libre. En: Conferencia Iberoamericana de Complejidad, Informática y Cibernética: CICIC 2011; Orlando, Florida ~ EE.UU.: International Institute of Informatics and Systemics; 2011.

8. Derrick TR. The effects of knee contact angle on impact forces and accelerations. *Med Sci Sports Exerc.* 2004;36(5):832.

9. Garrick J, Requa R. The epidemiology of foot and ankle injuries in sports. *Clin Podiatr Med Surg.* 1989;6(3):629-37.

10. Bayne H, Kat CJ, editors. Effect of foot position on the compression and lateral force production of a player in a rugby scrum. En: ISBS-Conference Proceedings Archive; 2016.

11. Ripani M, Ciccarelli A, Morini S, Ricciardi G, Michielon G. Evaluation of foot support in rugby players: a baropodometric analysis. *Sport Sci Health.* 2006;1(3):104-8.

12. Kaplan KM, Goodwillie A, Strauss EJ, Rosen JE. Rugby injuries. *Bull Hosp Jt Dis.* 2008;66(2):86-93.

13. Preatoni E, Wallbaum A, Gathercole N, Coombes S, Stokes KA, Trewartha G. An integrated measurement system for analysing impact biomechanics in the rugby scrum. *Proc Inst Mech Eng P J Sport Eng Technol.* 2012;226(3-4):266-73.

14. Preatoni E, Cazzola D, Stokes K, England M, Trewartha G. Pre-binding prior to full engagement improves loading conditions for front-row players in contested Rugby Union scrums. *Scand J Med Sci Sports.* 2016;26(12):1398-407.

15. Hendricks S, Till K, Brown JC, Jones B. Rugby union needs a contact skill-training programme. *Br J Sports Med.* 2017;51(10):829-30.

16. Wu W-L, Chang J-J, Wu J-H, Guo L-Y. An investigation of rugby scrummaging posture and individual maximum pushing force. *J. Strength Cond. Res.* 2007;21(1):251-8.

17. Boland RA, Adams RD. Effects of ankle dorsiflexion on range and reliability of straight leg raising. *J of Physiother.* 2000;46(3):191-200.
18. The MyoQuip Blog. Body height in the rugby scrum: the value of equal hip and knee joint angles [Internet]. Blog TM, editor2006. [cited 2021]. Available from: <http://myoquip.blogspot.com/2006/11/body-height-in-rugby-scrum-value-of.html?m=1>.
19. Chiu M-C, Wang M-J. The effect of gait speed and gender on perceived exertion, muscle activity, joint motion of lower extremity, ground reaction force and heart rate during normal walking. *Gait Posture.* 2007;25(3):385-92.
20. Cho S-H, Park JM, Kwon OY. Gender differences in three dimensional gait analysis data from 98 healthy Korean adults. *Clin Biomech (Bristol, Avon).* 2004;19(2):145-52.
21. Chung M-J, Wang M-J. Gender and walking speed effects on plantar pressure distribution for adults aged 20-60 years. *Ergonomics.* 2012;55(2):194-200.
22. Simoneau GG, Hoenig KJ, Lepley JE, Papanek PE. Influence of hip position and gender on active hip internal and external rotation. *J Orthop Sports Phys Ther.* 1998;28(3):158-64.
23. Smith LK, Lelas JL, Kerrigan DC. Gender differences in pelvic motions and center of mass displacement during walking: stereotypes quantified. *J Womens Health Gen Based Med.* 2002;11(5):453-8.
24. Kornfeind P, Eckl M, Baca A. A single step analysis of plantar pressure distribution in tennis specific movements. *J J Hum Sport Exerc.* 2019;14(2). Available from: <https://dx.doi.org/10.14198/jhse.2019.142.14>
25. Cavanagh PR, Sims DS, Sanders LJ. Body mass is a poor predictor of peak plantar pressure in diabetic men. *Diabetes care.* 1991;14(8):750-5.
26. Encarnación-Martínez A, Catalá-Vilaplana I, Berenguer-Vidal R, Sanchis-Sanchis R, Ochoa-Puig B, Pérez-Soriano P. Treadmill and Running Speed Effects on Acceleration Impacts: Curved Non-Motorized Treadmill vs. Conventional Motorized Treadmill. *Int. J. Environ. Res. Public Health.* 2021;18(10):5475.
27. Hsi W-L, Kang J-H, Lai J-S. Distribution of plantar pressure on the second metatarsal head during walking. *J. Formos. Med. Assoc..* 2004;103(7):540-5.

28. Norton K, Olds T. *Anthropometrica: a textbook of body measurement for sports and health courses*: UNSW press; 1996.
29. Muñoz-Marín D, Crespo-Coco M, Grijota-Pérez FJ, Iglesias-Sánchez P, Robles-Gil MC. Evaluación antropométrica y de condición física en jugadores de voleibol en edad escolar. Diferencias entre sexos. *Ágora Para Educ Física El Deporte*. 2016;18(1):77-88.
30. World-Rugby. Manual para programas de entrenamiento Activate, Manual. Programa de Ejercicios para Prevención de lesiones de World Rugby™: World Rugby; 2019 [cited 2021 22/07/2021]. Available from: https://passport.world.rugby/media/niiddaub/activate_manual-es-smallest-file-size.pdf.
31. Martínez-Nova A, Cuevas-García JC, Pascual-Huerta J, Sánchez-Rodríguez R. BioFoot® in-shoe system: Normal values and assessment of the reliability and repeatability. *The Foot*. 2007;17(4):190-6.
32. Van Melick N, Meddeler BM, Hoozeboom TJ, Nijhuis-van der Sanden MW, van Cingel RE. How to determine leg dominance: The agreement between self-reported and observed performance in healthy adults. *PloS one*. 2017;12(12):e0189876.
33. Huang P, Liang M, Ren F. Assessment of Long-Term Badminton Experience on Foot Posture Index and Plantar Pressure Distribution. *Appl Bionics Biomech*. 2019;2019:1-7.
34. O'Rourke N, Hatcher L, Stepanski EJ. *A step-by-step approach to using SAS for univariate & multivariate statistics*: SAS institute; 2005.
35. Hennig EM, Staats A, Rosenbaum D. Plantar pressure distribution patterns of young school children in comparison to adults. *Foot Ankle Int*. 1994;15(1):35-40.
36. Stebbins J, Harrington M, Giacomozzi C, Thompson N, Zavatsky A, Theologis T. Assessment of sub-division of plantar pressure measurement in children. *Gait Posture*. 2005;22(4):372-6.
37. Cortes Morales PJ, Dias de Jesus EE, Sierpinski TC. Analysis of Physical Fitness and Anthropometry of Students in School Physical Education. *Education, Sport, Health and Physical Activity (ESHPA)*. 2022;6(1):50-60.
38. Nyska M, McCabe C, Linge K, Laing P, Klenerman L. Effect of the shoe on plantar foot pressures. *Acta Orthop*. 1995;66(1):53-6.

39. Soames R. Foot pressure patterns during gait. *J Biomed Eng.* 1985;7(2):120-6.
40. Stott J, Hutton W, Stokes I. Forces under the foot. *J Bone Joint Surg Am.* 1973;55(2):335-44.
41. Awonuga AO, Merhi Z, Awonuga MT, Samuels T-A, Waller J, Pring D. Anthropometric measurements in the diagnosis of pelvic size: an analysis of maternal height and shoe size and computed tomography pelvimetric data. *Arch. Gynecol. Obstet.* 2007;276(5):523-8.
42. Robbins LM. Estimating height and weight from size of footprints. *J. Forensic Sci.* 1986;31(1):143-52.
43. Priego Quesada JI, Olaso Melis J, Llana-Belloch S, Pérez Soriano P, Gonzalez Garcia JC, Sanchís Almenara M. Estudio presurométrico y biomecánico del pie en el pádel. *Riccaf d Rev Iberoam Cienc Act Física.* 2014;3(1):21-6.
44. Reenalda J, Maartens E, Buurke JH, Gruber AH. Kinematics and shock attenuation during a prolonged run on the athletic track as measured with inertial magnetic measurement units. *Gait Posture.* 2019;68:155-60.