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REVIEW

# Skin tribology in sport

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**Abstract**

This review describes the principles of skin friction and wear for the benefit of sports scientists, engineers and clinicians. Skin exhibits complex behaviour, defying tribological laws for dry contact; hence, its friction and wear characteristics are affected by sliding speed, normal load, and contact area. Some sports seek to increase skin friction to enhance performance; however, this needs to be offset against injury risk given that skin abrades when slid across a rough and hard surface, delaminates when slid across a smooth and hard surface, and chafes or blisters when repeatedly rubbed against some fabrics. Whilst skin interactions can both define and hinder athlete performance, there exists a need to better understand skin biomechanics to optimise the balance of risk versus reward.

## 1 | INTRODUCTION

The coefficient of friction [CoF] defines the resistance of one surface when sliding over another. Three laws define dry friction, with Amontons' first and second stating that frictional force is proportional to the normal load and is independent of the apparent contact area. The third law, introduced by Coulomb, states that kinetic friction is independent of sliding speed. Skin friction, however, fails to obey these laws, given its complex viscoelastic deformation and surface adhesions [1, 2]. Skin CoF is influenced by factors including physiology, the contacting surface, and environmental conditions.

Whilst mechanical systems have well-established theories to control and mitigate friction, knowledge gaps remain in understanding skin tribology and injury epidemiology [3–8]. Such an understanding is particularly important in sport, where external factors can vary the interactions between an athlete's skin and their surroundings (e.g. equipment, playing surface), potentially influencing performance and competition; however, such demands need to be balanced against injury risk. Some sports strive to optimise skin friction to maximise performance, for example the application of chalk to increase grip in elite shot put. Others seek maximum friction through the adoption of intermediary materials, for example the use of golf gloves. Managing skin friction is known to directly and indirectly influence playing performance [9].

This study reviews the literature to present an enhanced understanding of skin tribology, whilst also drawing together design strategies that maximise performance and minimise injury risk, within a sporting environment. This review may appeal to those interested in developing their understanding of skin friction fundamentals from a sport, biological or engineering perspective.

## 2 | SKIN

### 2.1 | Skin tribology

Skin friction is governed by two main mechanisms: adhesion and deformation [10, 11]. At the contact between skin and a material, van der Waals bonds are formed between asperities, creating a sliding resistance due to adhesion. Skin's soft and elastic behaviour means it will conform around the counteracting surface, requiring a force to deform the skin during relative movement. Both factors are influenced by an individual's skin properties, plus the loading conditions, contact material and environmental conditions [1].

Skin is bio-mechanically complex due to its anisotropic, non-linear elastic, and viscoelastic behaviours [12]. Skin is generally taut to the body frame, meaning it is in constant tension created by the arrangement and orientation of collagen fibres in the dermis. The geometry of the maximum skin tension over the entire body is known as Langer's Lines. The collagen fibres that lay parallel to Langer's Lines are in greater tension, providing a stiffer response than when perpendicularly loaded, producing anisotropic behaviour [13]; hence, the interaction orientation will determine

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the skin deformation characteristics and, thus, the frictional response.

Skin can dissipate energy and may contribute to friction [10], with each layer having unique mechanical properties that contribute to the combined highly non-linear response [12]. The basement membrane (Figure 1), a microstructural network at the epidermal and dermal junction, is an important structure for the frictional properties of skin. This subsurface structure combines individual layers that influence the global deformation [13, 14].

At low strains, under uniaxial tension, collagen fibres are slack and non-load bearing; therefore, the skin's structural response is dictated by the elastin components, making skin relatively soft. As strain levels increase, the skin rapidly stiffens due to the recruitment of collagen fibres until they have straightened, which progresses from a non-linear to a linear, elastic response. This allows the skin to change shape and recover during biomechanical movements [16]. Skin is also viscoelastic, caused by the dermis' extracellular matrix, a viscous gel that biomechanically serves as a time-dependent energy absorber that protects skin from mechanical failure [17].

These complex bio-mechanical behaviours mean skin does not conform to Amontons' Laws. Instead, the contact area increases with increasing pressure, with skin deforming around the asperities of the opposing surface, until maximum contact. These conditions will also dictate the predominant wear regime: abrasive wear with a rough, hard surface or adhesive wear with smooth and/or soft surfaces.

Anatomical location affects friction due to the variations in skin hydration, thickness, hair and composition of the surface hydrolipid film. Hydration influences the elastic modulus. Initially with increasing compliancy, hydrated skin achieves increased contact area and so increases both adhesion and deformation [18]. Once fully saturated; however, a fluid film forms on the skin acting as a lubricant, which reduces resistance [19–23]. Additionally, when skin is hydrated, the greater water content may increase the viscoelastic effects of energy dissipation, potentially hindering elastic recoil and so increasing friction. Skin can become thin when over-extended [24], though the stratum corneum can also gradually thicken in response to repeated mechanical loading, typically on the hands and feet [25]. This can increase resistance to abrasion, reduce elasticity and so increase friction [26]. The main function of body hair is protection, regulation of temperature and contributions to the sensory function of skin, however, it also influences skin friction. The presence of hair acts as an intermediate layer between skin and the contact material, which subsequently reduces the adhesion component of friction. The hydrolipid film found on the surface of the skin is an emulsion of sweat and sebum. Sebum is a naturally produced mixture of lipids, wax esters, and triglycerides. The thickness of the sebum layer has negligible effects on the frictional behaviour of skin; however, the composition of sebum varies between individuals, which contributes to significant differences in frictional responses [27].

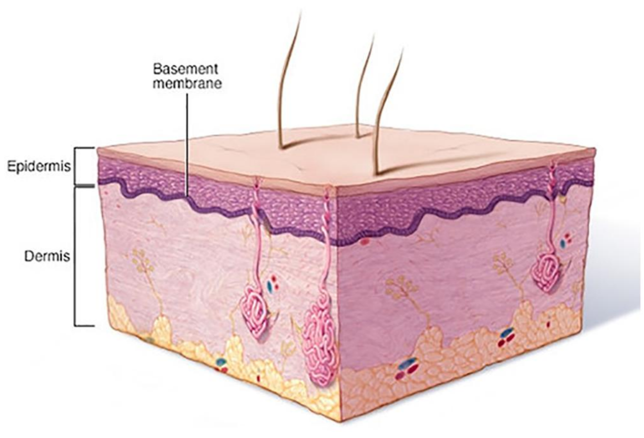


**FIGURE 1** Schematic diagram of skin layers [15]

## 2.2 | Skin friction measurement techniques

Skin friction testing involves the measurement of normal load and resistive force as skin slides relative to a contact material. The most common devices apply a constant normal load, monitoring the resistive force of a testing probe that moves with linear or rotational motion across skin. The constant normal load can be regulated using spring load [1], static load [2], or servomechanisms [28]. The rotational testing can be further divided into two categories where the rotational axis lies parallel or perpendicular to the skin plane. The perpendicular rotational axis is limited by velocity variation [that is between the inside and outside of the test material as it traverses across the skin]. The parallel rotational axis requires minimal surface area, consistent velocity and normal load when performing a measurement. With human in vivo testing, the main limitations are ethical constraints on repeated number of tests and the inherent variability between individuals. Therefore, in research where a large database is required, tests are performed on human or animal ex vivo samples. The results from such preliminary experiments can then be compared with in vivo results and used to make informed decisions based on the context of the research. Synthetic surrogates offer a more consistent test material, providing insight into the skin friction and behaviour. Furthermore, numerical models have been utilised to simulate various contact parameters for interactions between skin and rigid bodies to provide an insight into the global frictional response [14].

## 2.3 | Skin failure

Skin strength is the summation of collagen fibril strength and the collagen-matrix interaction [12]. At low strain rates, the bonds between the collagen fibrils and the matrix fail as the fibrils deform along the loading axis; therefore, the strength is determined by crosslinks between collagen fibrils. At high strain rates, the ultimate tensile strength increases due to the viscous shearing between the collagen and extracellular support matrix. The mechanical behaviour of skin produces a positive relationship between the ultimate tensile strength and strain rate; however, as the strain rate increases, the failure strain decreases [12]. Additionally, the bundled arrangement of collagen fibres along Langer's lines produces the highest ultimate tensile strength. Skin is stiffer when exposed to an external force parallel to the fibre alignment, as opposed to a perpendicular interaction [24]. Langer's line symmetry around the spine means there should be an equal response on the left and right side of the body.

## 3 | SKIN FRICTION INJURIES

Skin, especially that covering the hands and feet, is in frequent contact with its surroundings, meaning that it will experience friction as it slides over another surface. Using a pen, a grab-rail or holding a glass are everyday examples of the skin interacting with an opposing surface to achieve a desired function. Too little friction and the design of these objects would have to be revised to ensure enhanced functionality, whilst excessive friction will likely cause the user to cease the task or identify a different object to enable successful completion. In a sporting environment, however, increasing contact loads and velocities, a task-based mindset and an environment that is influenced by competitors, can lead to an entirely different friction scenario, one that may cause acute or chronic skin injury.

An abrasion is an acute injury, caused by the removal of the superficial skin layer. This is most likely when sliding over a rough surface [5], for example, when falling during road cycling ('road rash') or when performing a sliding stop on a bare, dry cricket outfield. Such injuries are generally considered minor and typically have minimal bleeding, though are painful due to the exposed nerve endings [29]. Abrasions can be prevented by covering vulnerable body parts, with cricketers now using elasticated bandaging to protect their elbows when fielding. Whilst these materials should be scaled-up (e.g. thicker, denser) for interactions with potentially higher speeds or greater loads, such precautions can be overlooked to avoid impinging athlete performance (e.g. cycling). Lubricants can also be beneficial in minimising abrasion, though re-application is needed especially in instances of frequent contact with the same skin region. Some sports can benefit from this approach, with the repeated 'time-outs' in boxing providing ideal opportunity for the ring-side support team to reapply petroleum jelly around the eye, reducing abrasive injury risk [30].

In contrast to the acute nature of abrasive injuries, chronic damage can occur with repeated rubbing against clothes or other skin regions. Chafing is identified by irritated red skin, which can be exacerbated by prolonged exposure and/or abrasive fabrics [5]. Skin with relatively high hydration generally exhibits a higher frictional coefficient, so is more susceptible to chafing. Instances where skin is exposed to relatively high 'normal' (i.e. perpendicular) and/or 'shear' (i.e. parallel) loading, also increases chafing. Such factors can manifest in instances of inner thigh chafing, caused by skin-to-skin rubbing. This is especially prevalent in those athletes with increased lower limb muscle mass and those who perform repeated cycles. Overlying fabrics can also influence chafing. Clothing folds and seams are design features that typically increase fabric friction, meaning skin may become irritated and red in regions including the neck/collar interaction. Jogger's nipple is caused by the repeated sliding of a runner's vest relative to the areola tissue and can ultimately cause skin swelling, bleeding or crusting. Innovative technologies now produce overlying fabric that remains dry and light-weight, which are the two important attributes to minimise friction [31, 32]. The tissue, however, will become moist with perspiration, increasing the frictional coefficient. The dynamic nature of the activity and the localised tissue mass will determine the magnitude and frequency of tissue displacement, a significant contributor to chafing risk. Indeed, the constraining effect of a sports bra means jogger's nipple is less common in female athletes [33]. Athletes may also create a barrier between the skin and fabric by using adhesive plaster or petroleum jelly, to reduce risk.

Repeated friction with high loading may cause skin blistering. Like chafing, these rarely prevent athlete participation; however, they typically cause greater discomfort and so are more likely to negatively influence performance [34]. Blisters can be identified as tender, fluid-filled vesicles, commonly found on the hands and feet. These structures should be preserved, as they provide natural infection control; however, the repetitive nature of sporting tasks means the epidermal roof is frequently detached. Blisters can be prevented by keeping the skin dry and eliminating sources of rubbing. Athletes may mitigate risk by changing equipment or technique, or introducing cushioned grips and gloves; however, in some instances these are insufficient, leading to the development of thick and hard calluses, which locally reinforces skin. Calluses are typically asymptomatic, commonly developing over the distal metacarpal heads or under the plantar metatarsal prominences. They lack innervation, allowing removal by filing or with a scalpel.

The aetiology of burn-related skin friction injuries is not yet fully understood. Friction burns appear different to thermal burns by causing damage to the superficial skin only [4], whilst other burn-related injuries include abrasion and dermal removal [5, 6]. Whilst athletes do anecdotally report injuries consistent with thermal burns, such events cannot be corroborated with data that demonstrates the required temperature increase. Cyclists falling in a velodrome appear to be the most likely athletes to experience a thermal-like, friction burn. Unlike falling onto asphalt, velodromes are typically smooth, wooden surfaces and so present a low risk of abrasive injury. This does, however, enable the athlete to slide relatively long distances and with a significant contact area [3]. This creates an environment that can generate significant thermal energy with very limited dissipation, meaning a heat-related burn may be plausible. Artificial turfs appear to provide a slightly more sympathetic environment as, despite generally enabling longer slides than natural turfs, players typically sustain only a part-abrasion, part-burn injury [7, 8]. Further research is required, however, to better understand the generation of thermal energy through friction. To perform such investigations, a new test device is required which simulates realistic loadings that players would experience when interacting with turf [35]. Additionally, the skin simulant for the Securisport, the current industry standard for assessing skin friendliness of artificial turfs, has limited suitability for this testing as its frictional performance is significantly different to ex vivo human skin samples, therefore, an alternative skin simulant is required [36].

## 4 | MANAGING SKIN TRIBOLOGY TO ENHANCE SPORTING PERFORMANCE

Managing the friction and wear between skin and equipment is a focus in many sports. In some instances, participants seek to increase friction even in dry contact as they strive for enhanced grip, whereas others try to minimise friction to enhance performance. Other adaptations are seen where climatic conditions may produce sub-optimal playing performances.

### 4.1 | Enhancing skin friction

Weightlifting, climbing, gymnastics and javelin are just some sports where athletes attempt to influence the skin-equipment CoF, despite already possessing a dry contact (the only potential exception is javelin, due to being performed outdoors). Agents are ordinarily applied to dry skin to increase friction with equipment, displacing the natural oils that provide an element of boundary lubrication. The secondary aim may be to absorb sweat. Carre et al. [37] evaluated four such agents (Powdered & Liquid Chalk, Rosin, & Venice Turpentine) applied to the finger and run against a polished steel surface, alongside a clean finger representing a ground truth. In dry conditions, Venice Turpentine, a tacky resin, was the only intervention to increase (double) CoF. The use of powdered chalk and Rosin reduced the frictional coefficient, adhering to the skin and so acting as a solid lubricant, reducing the skin-equipment contact area. Similar effects were observed when Rosin powder was applied to the skin when simulating baseball pitching. This hindered performance, by limiting the shear force imparted on the ball; however, it did achieve a more consistent frictional behaviour, an important attribute when trying to develop repeatable techniques in elite sport [38]. Chalk in suspension ('liquid chalk') ensures more precise and controlled application, with alcohol evaporation quickly leaving a chalk residual covering the skin; however, it provided a similar frictional coefficient to dry, natural skin.

### 4.2 | Mitigating climatic conditions.

Additives for optimising skin-equipment friction are only viable in sports that require a short, concerted effort. Rugby players rely on sufficient skin friction when throwing a pass, as it is necessary to impart spin to achieve the desired ball flight. A smooth, dry ball produces the highest CoF, with the flat surface maximising contact and so the abundance of locally 'welded' asperity junctions. In wet conditions, it is impractical to apply an additive prior to passing; hence, the ball surface is designed with roughness to optimise CoF, with pimples being the most effective patterning [39]. Players have also trialled semi-permanent interventions including applying finger tape and wearing gloves, with Lewis et al. [40] reporting synthetic leather mitts provided the best handling performance, with a design optimised to interlock with the specific ball surface texture. Mitts with a more generic fabric, however, performed more consistently when considered across a range of ball textures. The use of gloves to increase friction with equipment is now commonplace in golf, with Sorbie et al. [41] reporting that players were able to generate significantly greater club head and ball speed. This translated to improved hitting distance and accuracy, though only for those shots using the longer clubs. Gloves are also used in wheelchair-based sports, as they enable the athlete to significantly increase their acceleration and agility [42].

The most problematic combination of environments involves wet sports equipment and wet skin, with both surfaces having surface coatings that may, depending on conditions, achieve hydrodynamic lubrication during dynamic events, leading to minimal friction [36]. For example, a rower's grip may fail and the oar may slip during the stroking action [43]. Whilst powdered chalk and Rosin offer opportunity to absorb excess moisture and so increase CoF, practical application is inherently constrained to certain sports and environments. Venice Turpentine does not influence friction in wet conditions, as it is insoluble and so unable to bond to skin. Whilst damp skin absorbs moisture and slightly swells, it still causes an overall reduction in friction when compared with dry skin, on a dry surface.

### 4.3 | Innovative Approaches

Some sporting interactions benefit from lower skin friction coefficients. The once-infamous cauliflower ear in rugby was, in some instances at least, caused by repeated abrasion against a neighbouring player during the scrummage [44]. Mitigating solutions include the use of tape to cover the ear, reducing friction and wear during repeated sliding and petroleum jelly to create a thick boundary lubricant layer. Indeed, the latter material has also been used surreptitiously, with players coating their legs to hinder an opponent's attempt to perform a successful tackle [45]. Rugby attire has also been designed to influence friction. For the 2011 Rugby World Cup, Scotland released an innovative shirt where the 'backs' had low friction material to help them slip out of tackles. The 'forwards' had higher friction, to aid scrum binding and ball carrying [46]. The lack of uptake indicates that this technology did not achieve the desired goals. Reducing skin friction has been more successful when considering innovation pitch constructs, with the latest generation artificial playing surfaces benefitting from rubber granules, designed to facilitate player sliding [47]. These are marked improvements on earlier versions, with the abrasive injuries synonymous with sand-based composition now, to the most part, a distant memory.

## 5 | CONCLUSION

Skin exhibits complex behaviour, with friction and wear characteristics differing across the human body, and across identical locations in different people. These variations hinder identifying the optimal balance–between sufficient friction to enhance performance, but not cause injury. Opportunities exist for further research to better understand the relationship between anatomy, physiology and skin tribology. Scope also remains to determine how populations can be appropriately represented in standardised, experimental testing. Only then will, scientists, engineers and clinicians be able to strike an appropriate balance between maximising skin friction for performance, and minimising injury risk.

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## REFERENCES

1. Veijgen, N.K.: Skin friction: a novel approach to measuring in vivo human skin. Thesis - University of Twente (2013)
2. Comaish, S., Bottoms, E.: The skin and friction: deviations from Amonton's laws, and the effects of hydration and lubrication. Br. J. Dermatol. 84(1) (1971)
3. Basler, R.S.W., et al.: Immediate steps for treating abrasions. Physician Sportsmed. 29(4) (2001)
4. van den Eijnde, W.A.J., et al.: Understanding the acute skin injury mechanism caused by player-surface contact during soccer. Orthop. J. Sports Med. 2(5) (2014)
5. Basler, R.S.W., et al.: Athletic skin injuries. Physician Sportsmed, 32(5) (2004)
6. Schwartz, C.J.: Friction, human body: skin. In: Encyclopaedia of tribology, pp. 1386–1393. Springer US, Boston (2013)
7. Verhelst, R., et al.: Temperature development during sliding on different types of artificial turf for hockey. International Conference on Latest Advances in High-Tech Textiles and Textile-Based Materials. 90–5 (2009)
8. Agrawal, A., Raibagkar, S.C., Vora, H.J.: Friction burns: epidemiology and prevention. Ann. Burns and Fire Disasters. 21(1), 3–6 (2008)
9. Lewis, R., Carré, M.J., Tomlinson, S.E.: Skin friction at the interface between hands and sports equipment. Procedia Engineering. 72, pp. 611–617. Elsevier Ltd (2014)
10. Kwiatkowska, M., et al.: Friction and deformation behaviour of human skin. Wear, 267(5–8) (2009)
11. Subhi, K.A., et al.: The adhesion and hysteresis effect in friction skin with artificial materials
12. Joodaki, H., Panzer, M.B.: Skin mechanical properties and modelling: a review. Proc IME H J Eng Med, 232(4) (2018)
13. Derler, S., Gerhardt, L.C.: Tribology of skin: review and analysis of experimental results for the friction coefficient of human skin. Tribol Lett. 45(1), 1–27 (2012)
14. Leyva-Mendivil, M.F, et al.: Skin microstructure is a key contributor to its friction behaviour. Tribol Lett. 65(1), 12 (2017)
15. Mayo Clinic, F.: Basement membrane. [Internet]. Mayo Foundation for medical education and research. 2021 May 26. https://www.mayoclinic.org/diseases-conditions/epidermolysis-bullosa/multimedia/basement-membrane-zone/img-20005890
16. Clancy, N.T., et al.: A new device for assessing changes in skin viscoelasticity using indentation and optical measurement. Skin Res. Technol. 16(2), 210–228 (2010)
17. Seehra, G.P., Silver, F.H.: Viscoelastic properties of acid- and alkaline-treated human dermis: a correlation between total surface charge and elastic modulus. Skin Res. Technol. 12(3) (2006)
18. Liu, X., et al.: Feasibility of using optical coherence tomography to study the influence of skin structure on finger friction. Tribology international. 63, pp. 34–44. Elsevier Ltd (2013)
19. Adams, M.J., Briscoe, B.J., Johnson, S.A.: Friction and lubrication of human skin. Tribol Lett. 26(3), 239–253 (2007)
20. Liu, J., Zhang, Q., Liu, X.: Understanding handling performance of rugby balls under wet conditions: analysis of finger-ball friction. Int J Perform Anal Sport, 20(5) (2020)
21. André, T., Lefèvre, P., Thonnard, J.L.: A continuous measure of fingertip friction during precision grip. J Neurosci Methods. 179(2), 224–229 (2009)
22. Tomlinson, S.E., et al.: Understanding the friction mechanisms between the human finger and flat contacting surfaces in moist conditions. Tribol Lett. 41(1), 283–294 (2011)
23. Derler, S., Rossi, R.M., Rotaru, G.M.: Understanding the variation of friction coefficients of human skin as a function of skin hydration and interfacial water films. Proc. IME J. J. Eng. Tribol. 229(3), 285–293 (2015)
24. Maiti, R., et al.: Morphological parametric mapping of 21 skin sites throughout the body using optical coherence tomography. J. Mech. Behav. Biomed. Mater. 102 (2020)
25. Boyle, C.J., et al.: Morphology and composition play distinct and complementary roles in the tolerance of plantar skin to mechanical load. Sci. Adv. 5(10), 1–14 (2019)
26. Liu, X., et al.: The contributions of skin structural properties to the friction of human finger-pads. Proc. IME J. J. Eng. Tribol. 229(3), 294–311 (2015)
27. Korbeld, K.T., et al.: Effects of sebum properties on skin friction: investigation using a bench test. Biosurface and Biotribology. 6(2), 43–47 (2020)
28. Sivamani, R.K., et al.: Friction coefficient of skin in real-time. Skin Res Technol. 9(3), 227–234 (2003)
29. Shrestha, R., Krishan, K., Kanchan, T. Abrasion. [Internet]. StatPearls - Treasure Island. 2021 May 26. Springer Netherlands (2020). https://www.ncbi.nlm.nih.gov/books/NBK554465/
30. Why Do Boxers Use Vaseline?. Just-Athletic. [Internet]. 2021 May 26. https://just-athletics.com/why-do-boxers-use-vaseline/
31. adidas: adidas climacool. adidas UK. [Internet]. 2021 May 26. https://www.adidas.co.uk/climacool
32. Nike: What is Nike dri-FIT?. Nike Help. [Internet]. 2021 May 26. https://www.nike.com/gb/help/a/nike-dri-fit
33. Brown, N., et al.: An investigation into breast support and sports bra use in female runners of the 2012 London Marathon. J Sports Sci. 32(9), 801–809 (2014)
34. Brennan, F.H.: Managing blisters in competitive athletes. Curr. Sports Med. Rep. 1(6), 319–322 (2002)
35. Lenehan, K.A., Twomey, D.M.: Abrasion testing on synthetic turf: a modified device. Proc. Inst. Mech. Eng. P. J. Sports Eng. Technol. 230(4), 280–284 (2016)
36. Hurtado, M.M., et al.: Tribological behaviour of skin equivalents and ex-vivo human skin against the material components of artificial turf in sliding contact. Tribol. Int. 102, 103–113 (2016)
37. Carré, M.J., et al.: An assessment of the performance of grip enhancing agents used in sports applications. Proc. IME J. J. Eng. Tribol. 226(7), 616–625 (2012)
38. Yamaguchi, T., et al.: Effects of Rosin powder application on the frictional behaviour between a finger pad and baseball. Front. Sports Acti. Living, 2 (2020)
39. Tomlinson, S.E., et al.: Understanding the effect of finger-ball friction on the handling performance of rugby balls. Sports Eng. 11(3), 109–118 (2009)
40. Lewis, R., et al.: Effect of surface texture, moisture and wear on handling of rugby balls. Tribol Int. 63, 196–203 (2013)

41. Sorbie, G.G., et al.: Commercial golf glove effects on golf performance and forearm muscle activity. Res Sports Med. 25(4), 451–461 (2017)
42. Lutgendorf, M., et al.: Effect of glove type on wheelchair rugby sports performance. Sports Technol, 2(3, 4) (2009)
43. Karlson, K.A.: Rowing injuries. Physician Sportsmed. 28(4), 40–50 (2000)
44. Gardner, S.S.: Cauliflower ear: symptoms, causes, and treatments. [Internet]. WebMD. 2021 May 26. (2020). https://www.webmd.com/skin-problems-and-treatments/cauliflower-ear-symptoms-causes-treatments
45. LoveRugbyLeague: NRL ban James Graham using Vaseline. LoveRugbyLeague. [Internet]. 2021 May 26. https://www.loverugbyleague.com/post/nrl-ban-james-graham-using-vaseline/
46. ScottishRugbyBlog: The new Scotland rugby kit 2011. Scottish Rugby Blog. [Internet]. 2021 May 26. https://www.scottishrugbyblog.co.uk/2011/06/the-new-scotland-2011-rugby-kit/
47. Tay, S.P.: New strategies towards the next generation of skin-friendly artificial turf surfaces. Thesis - Nanyang Technological University (2016)

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