Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 72 (2014) 611 – 617

Procedia Engineering

www.elsevier.com/locate/procedia

The 2014 conference of the International Sports Engineering Association

Skin friction at the interface between hands and sports equipment

R. Lewis[a]*, M.J. Carré[a], S.E. Tomlinson[a]

[a]*The University of Sheffield, Department of Mechanical Engineering, Mappin St., Sheffield, S1 3JD.*

Abstract

The friction between the finger pad/palm and items of sports equipment strongly influences how well an athlete is able to perform. It not only determines how well equipment can be gripped and manipulated, but also how the equipment feels to use and the perceived level of performance. In this paper various fundamental aspects of finger pad friction are reviewed, including the effects of applied force, skin moisture, material, surface texture etc., and the influence that they have on friction mechanisms such as adhesion, deformation, interlocking and hysteresis. A number of applied case studies are then outlined. The first is rugby balls and the effect the ball surface pimple pattern has on friction. Initially high speed video was used to establish how the hand interacts with a ball. Friction tests were then carried out with different hand conditions and pimple patterns and the link between friction and pass accuracy was explored. The second study relates to friction modifiers used in sports such as rock climbing and athletics. These can be affected by hand and environmental conditions so a focus was placed on tests with moist hands or wet surfaces. Finally Frisbee interactions were investigated. The impact of loss of feel as a result of wearing gloves was studied to see if any improvements in wet conditions with gloves were offset by the reduced feedback from the Frisbee interface. The fundamentals of skin tribology can play a key role in developing optimised sports equipment, gaps still exist, however, in the understanding and modelling of surface texture and how important feel/comfort are, which are both important for sports equipment design.

Selection and peer-review under responsibility of the Centre for Sports Engineering Research, Sheffield Hallam University

Keywords: Finger-pad friction; tribology; grip; sports equipment

* R. Lewis. Tel.: +44 (0) 114 2227838; fax:+44 (0) 114 2227890.
E-mail address: roger.lewis@sheffield.ac.uk

Selection and peer-review under responsibility of the Centre for Sports Engineering Research, Sheffield Hallam University
doi:10.1016/j.proeng.2014.06.064

1. Introduction

Finger friction is very important in many activities of daily living related to gripping, manipulating and feeling objects. The study, however, of the contact of a visco-elastic material with highly variable properties due to changes with temperature and moisture is extremely complex. This paper summarises previous work on fundamental understanding of finger-pad friction and outlines the effects of material, load, surface texture, moisture etc. and then describes some applied work to investigate finger-pad interfaces with rugby balls and the effects of grip enhancing agents used by athletes and some new work on Frisbees.

2. Assessing Finger Friction

The rig designed and developed for the testing outlined in later sections is shown in Figure 1a. It basically incorporates two load cells and a test-bed to hold the counterface material. The s-type load cells were carefully selected to be able to take account of effect due to eccentric loading. This was because as the finger slides on the counterface the position relative to the normal force load cell will change. Voltage measurements from the load cells were downloaded to a PC, where they were converted to force values using the load cell voltage/force relationships.

Test subjects washed their hands with soap prior to testing and dried them with paper towels. Before and in between tests, the counterface materials were cleaned with a solution of water and DEB Janitol Degreaser. All runs were carried out at a steady speed across the plate. The test subjects were asked to aim to move fingers/palms from one end to the other in the time it took to steadily count to five (Tomlinson et al., 2009a). The index finger from the dominant hand was always used and it was pulled towards the test subject. The test subjects were also asked to press harder/lighter to achieve the full range of normal forces required.

Moisture measurements of the finger-pads were taken using a Moistsense device (Moritex Europe). This device measures the moisture present at the surface using a capacitance measurement and converts it to a scale from 1 to 99 au (arbitrary units) based on measurements of 300 people. The measurement uncertainty as quoted by the manufacturers is ±2au.

3. Fundamental Aspects of Finger-Pad Tribology

Many aspects of finger-pad tribology have been investigated. These have been summarised very well previously (Derler and Gerhardt, 2012; Tomlinson et al., 2007). As shown in Figure 1b, friction force for a finger-pad sliding over a surface can be seen to exhibit a two stage response as normal force is increased (Tomlinson et al., 2009). The threshold normal force is related to the point at which the contact area of the finger-pad can no longer increase. On relatively smooth surfaces the dominant friction mechanism is adhesion which is directly related to contact area, hence when the area stops increasing then so does the friction force. Different materials give a different friction response as seen in Figure 1c. For the same roughness, softer, more compliant materials are likely to provide higher friction as the finger will press into them more easily leading to a higher contact area. When surface texture is added, there is an initial decrease in friction force (see Figure 1d), this is due to the addition of larger asperities decreasing contact area and reducing adhesion effects (Hendriks and Franklin, 2010). As roughness increase, however, the asperities first start to interlock with the finger ridges and then deformation and hysteresis mechanisms start to dominate which leads to a friction increase (see Figure 1e) (Tomlinson et al. 2009a; Tomlinson et al., 2011). The effect of increasing finger moisture is quite interesting. As levels of moisture initially increases friction force actually increases (as shown in Figure 1f), this could be due to a number of mechanisms, but the most dominant is the reduction in the skin's modulus of elasticity which increases the contact area. As the moisture passes a critical level (in this case about 90AU), however, there is enough present to form a film and then friction decreases.

As can be seen in the discussion above, contact area is very important in dictating the levels of friction in a number of scenarios. Measuring nominal area of contact is relatively simple and can be achieved using ink printing methods or a change in area can be determined via electrical resistance measurements (Tomlinson, 2009). Skin imaging using Optical Coherence Tomography is currently being used to develop a technique for determining the actual contact area more accurately (Liu et al., 2013).

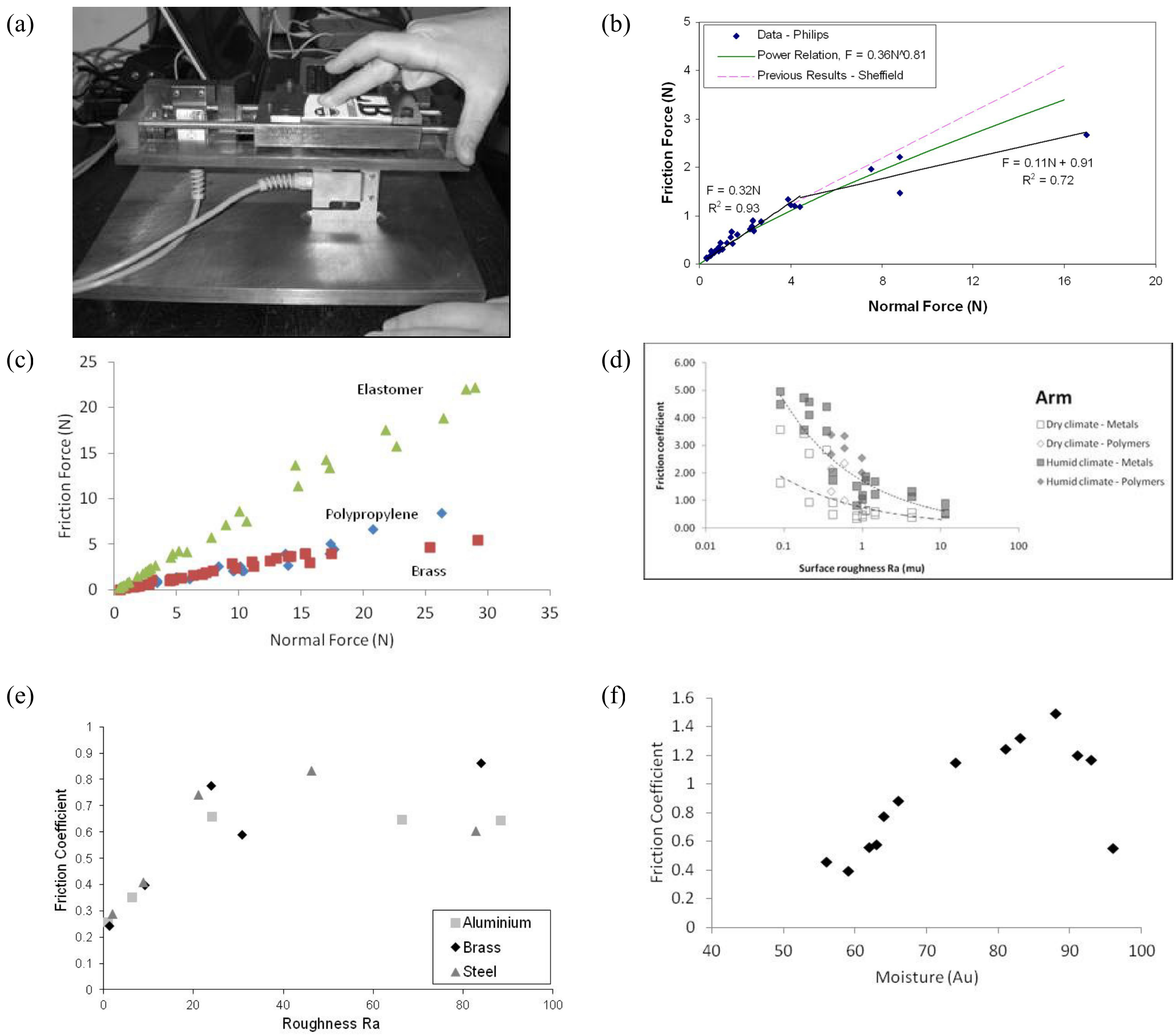

Fig. 1. (a) finger friction test apparatus; (b) two part friction force relationship; (c) friction force for different materials; (d) effects of low roughness (Hendriks and Franklin, 2010); (e) effects of higher roughness (Tomlinson et al. 2009a) and (f) moisture effects (Tomlinson et al. 2011).

4. Case Studies

4.1. Rugby Balls

Good grip of the ball is essential for players to perform the required actions during a game of rugby. There are many ways in which the hands contact the ball. This can be in the form of passing the ball, catching the ball, line outs or when running with the ball. High friction is obviously needed for catching and holding the ball. When passing, the ball is generally spun about its long axis. To enable this, a certain level of friction is required. Handling errors are often seen in professional rugby games and even more so in amateur rugby so ball manufacturers are working constantly to provide extra grip to overcome the problems that occur, not all of which are related to player ability.

Manufacturers have developed different materials containing varying levels of natural rubber and have experimented with different pimple patterns on the surface to improve handling.

The work carried out on rugby balls involved three phases: high speed video analysis of ball catching; a laboratory study of finger-pad friction against various ball pimple patterns and measurements of friction tied up with target scores.

The high speed video analysis (Tomlinson et al., 2009b) showed that when the ball is caught, the palm initially cushions the ball. There is then a fluctuating movement of the fingers over the surface of the ball (imperceptible to the naked eye in real time). It also showed that the fingers move over the surface of the ball when the ball is thrown, confirming that the dynamic friction is a good measure of how easily a ball can be handled.

Friction tests were carried out across a number of ball materials and in various conditions (Lewis et al, 2012). Here two patterns are presented (see Figure 2a and b) for two different conditions (wet and dry) to highlight the effect of the pimple spread. The results shown in Figure 3 indicate that the closely packed pimples work well in the dry as they present a relatively large contact area, but in the wet a film is more likely to form reducing friction. More widely spaced pimples give slightly lower dry friction, but performance is maintained in the wet as the pimples can break through a water film.

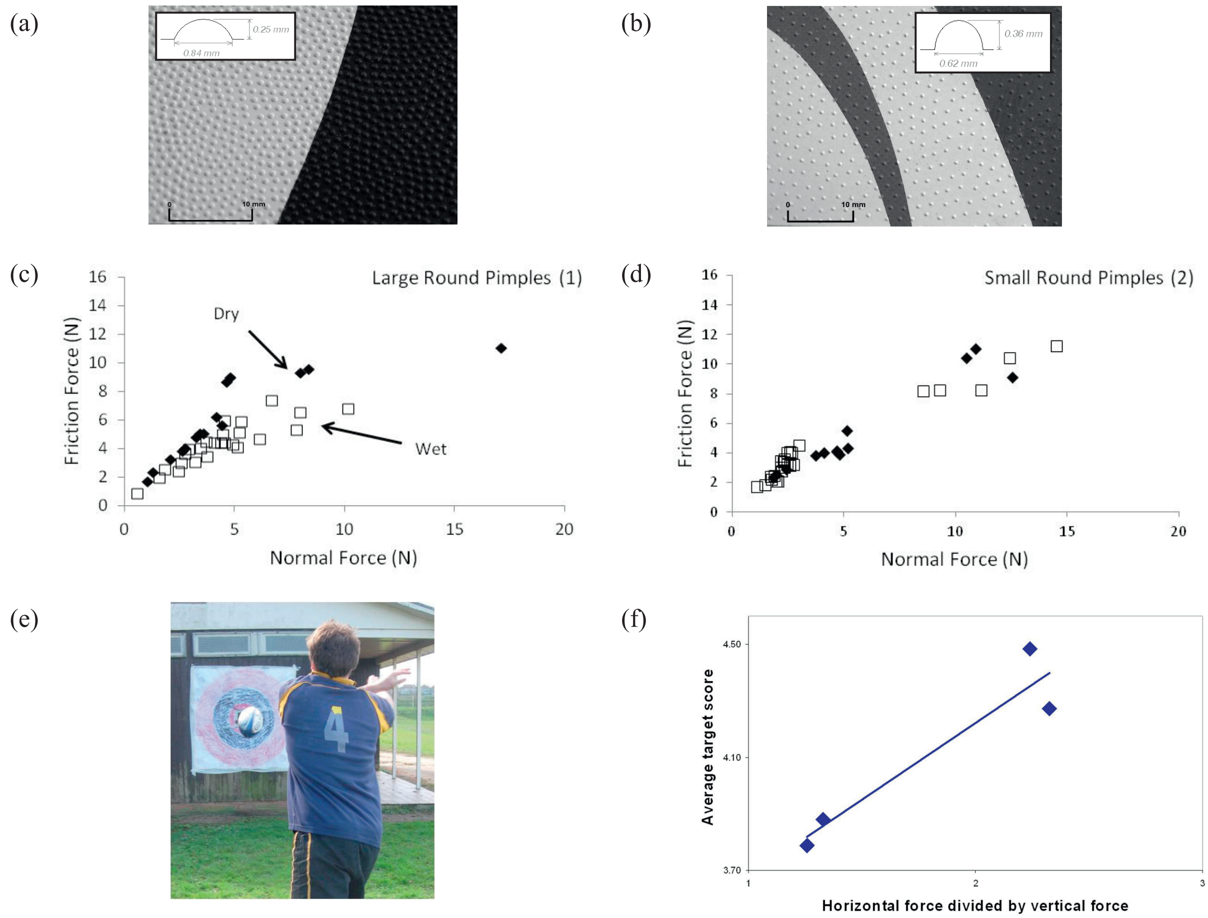

Fig. 2. (a) Ball 1 surface, 0.58 Mppm^2 (Mega pimples per square metre); (b) Ball 2 surface, 0.21Mppm^2; (c) Ball 1 friction data; (d) Ball 2 friction (e) Target scoring; (f) target score versus friction (Lewis et al., 2012; Tomlinson et al., 2009b).

4.2. Friction Modifiers

The performances of four grip enhancing agents used routinely in sports such as weightlifiting, javelin and climbing, Powdered and Liquid Chalk, Rosin and Venice Turpentine, were assessed compared against an agent-free finger (Carré et al., 2012). The effectiveness of the agents was measured in dry, damp and wet conditions, to simulate the different environments in which the agents are used. The tests were first done on a polished steel surface and then the Powdered and Liquid Chalk, and agent-free finger were tested on sandstone.

As shown in Figure 3, the tests on the steel showed that in a dry condition only the Venice Turpentine significantly increased the coefficient of friction, compared to no application of agent, with the Rosin and Powdered Chalk actually decreasing the coefficient of friction. It is thought that the reduction in the coefficient of friction is caused by the solid particles acting as a lubricant between the two surfaces. When the fingers were wet only the granular powder-based agents increased the coefficient of friction. This is because the Venice Turpentine cannot adhere well to a wet finger; and therefore is not as effective. When the surface is wet there is very little difference between the agents, due to the water separating the finger surface from the steel.

The tests on the sandstone showed no real difference between the lubricants or the different conditions, except for the dry, chalk-free finger, which had a decreased coefficient of friction due to the lubricating properties of the sandstone particles.

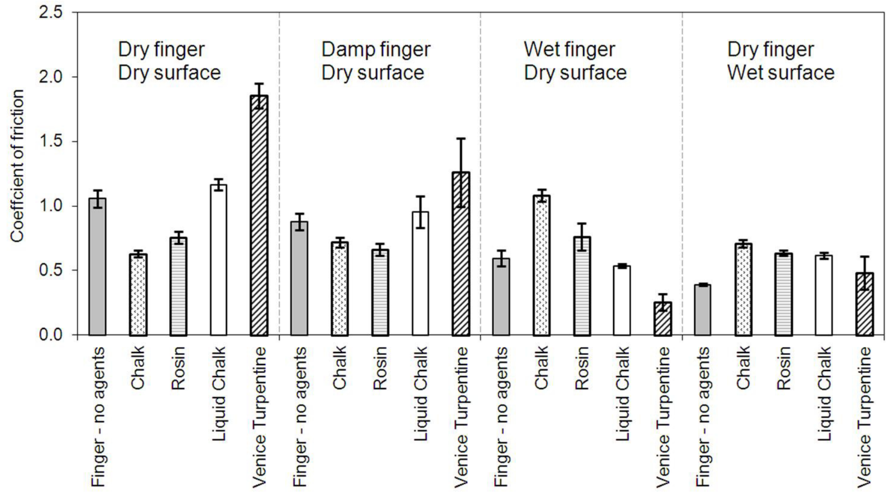

Fig. 3. coefficient of friction data for grip enhancing agents on steel under differing conditions (Carré et al., 2012).

4.3. Frisbees

Ultimate Frisbee is a fast moving sport that involves passing the Frisbee from player to player about with the aim of getting it into a target zone. The approach taken to analyse the hand/Frisbee contact was similar to that for the rugby balls. Initially high speed video techniques were used to study the interactions during catching and passing movements. Then friction testing was carried out in a range of conditions, this time including the wear of a glove which is permitted as long as the index and middle fingers are not covered at the end (as shown in Figure 4a). The friction testing was also tied up with target scoring (see Figure 4b) as well as two point sensitivity discrimination tests to see what effect gloves had on feel during the interactions.

Friction data shows that with gloves friction is increased (Figure 4c), but accuracy decreases (Figure 4d). The results of the two-point discrimination test showed that sensitivity was reduced with gloves, so it is thought that reduced sensitivity in feel outweighs advantages of the higher friction. Performance in the wet is not as affected by wearing gloves, this could be due to improved insulation or the fact that the glove material absorbs water.

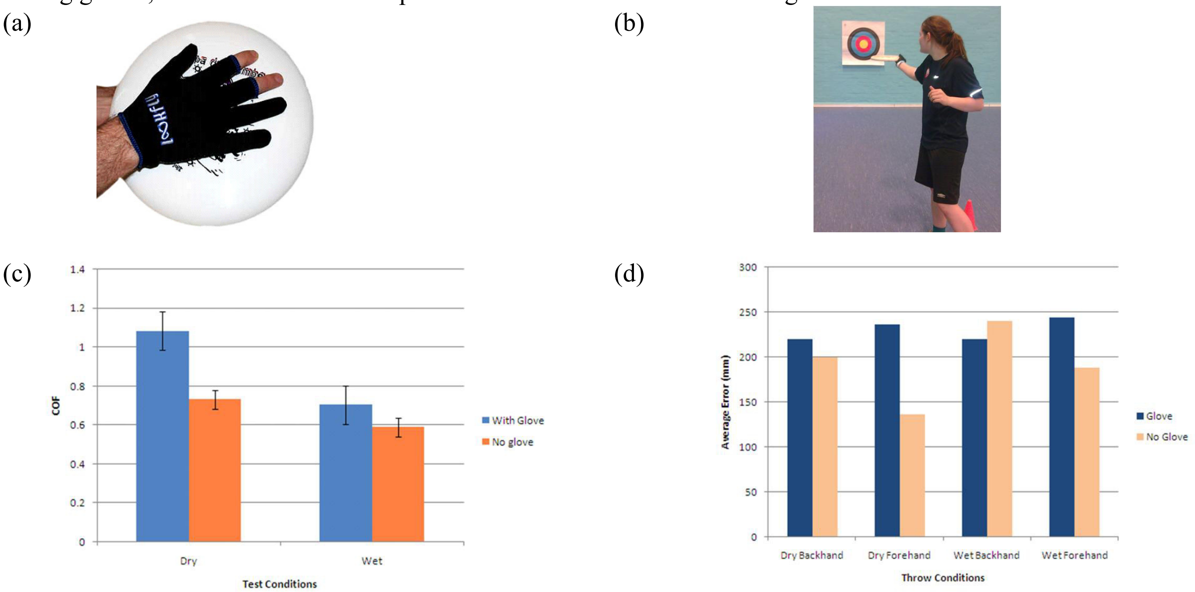

Fig. 4. (a) Frisbee and glove; (b) target testing; (c) friction in wet and dry, with and without a glove; (d) target results.

5. Conclusions

A good understanding of the fundamentals of finger-pad tribology has been obtained in the work reviewed here, and in the many studies carried out by other researchers, that can now hopefully be used to inform design of sports equipment to help optimize its performance. In many cases development of features to aid grip has been quite arbitrary and as such has led to undesired outcomes such as reduced grip or restricted dexterity etc. There is still a lot to do, however, particularly in the area of surface texture and materials, both of which will be high priorities for sports equipment manufacturers.

The applied case studies show examples of how knowledge and test methodologies from the fundamental studies can be used with high speed video techniques and score testing to understand equipment performance and highlight how it is influenced by, for example, hand/product friction and where feel/comfort fits in.

References

Carré, M.J., Tomlinson, S.E., Collins, J.W., Lewis, R., 2012. An Assessment of the Performance of Grip Enhancing Agents used in Sports Applications. Proc. IMechE Part J: Journal of Engineering Tribology 226, 616-625.

Derler, S., Gerhardt, L.-C., 2012. Tribology of Skin: Review and Analysis of Experimental Results for the Friction Coefficient of Human Skin. Tribology Letters 45, 1-27.

Hendriks C.P., Franklin, S.E., 2010. Influence of Surface Roughness, Material and Climate Conditions on the Friction of Human Skin. Tribology Letters 37, 361-373.

Lewis, R., Carré, M.J., Abu Bakar, A., Tomlinson, S.E., 2012. Effect of Surface Texture, Moisture and Wear on Handling of Rugby Balls, Tribology International 63, 196-203.

Liu, X., Lewis, R., Carré, M.J., Matcher, S.J., 2012. Feasibility of using Optical Coherence Tomography to Study the Influence of Skin Structure on Finger Friction. Tribology International 63, 34-44.

Tomlinson, S.E., 2009. Understanding the Friction between Human Fingers and Contacting Surfaces. PhD thesis, University of Sheffield, UK.

Tomlinson, S.E., Lewis, R., Carré, M.J., 2007. Review of the Frictional Properties of the Finger-Object Contact when Gripping. Proc. IMechE Part J: Engineering Tribology 221, 841-850.

Tomlinson, S.E., Lewis, R., Carré, M.J. 2009a. The Effect of Normal Force and Roughness on Friction in Human Finger Contact. Wear 267, 1311-1318.

Tomlinson, S.E., Lewis, R., Carré, M.J., 2009b, Understanding the Effect of Finger-Ball Friction on the Handling Performance of Rugby Balls. Journal of Sports Engineering 11, 109-118.