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Fingerprints are unlikely to increase the friction of primate fingerpads

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SUMMARY

It is generally assumed that fingerprints improve the grip of primates, but the efficiency of their ridging will depend on the type of frictional behaviour the skin exhibits. Ridges would be effective at increasing friction for hard materials, but in a rubbery material they would reduce friction because they would reduce contact area. In this study we investigated the frictional performance of human fingertips on dry acrylic glass using a modified universal mechanical testing machine, measuring friction at a range of normal loads while also measuring the contact area. Tests were carried out on different fingers, fingers at different angles and against different widths of acrylic sheet to separate the effects of normal force and contact area. The results showed that fingertips behaved more like rubbers than hard solids; their coefficients of friction fell at higher normal forces and friction was higher when fingers were held flatter against wider sheets and hence when contact area was greater. The shear stress was greater at higher pressures, suggesting the presence of a biofilm between the skin and the surface. Fingerprints reduced contact area by a factor of one-third compared with flat skin, however, which would have reduced the friction; this casts severe doubt on their supposed frictional function.

Key words: friction, fingerpads, fingerprints, rubbers, Amonton's law.

INTRODUCTION

It is generally accepted that the fingers of primates are adapted for grasping narrow branches (le Gros-Clark, 1936), an adaptation that also helps in fine manipulation of objects. To help improve grip they have evolved a unique suite of characteristics: their claws have been converted to nails; the tips of the digits are cushioned by soft pads; and the skin of the grasping areas exhibits a pattern of epidermal ridges which are orientated roughly at right angles to the forces to which they will be subjected; in the characteristic whorls and arches of fingerprints the ridges travel roughly parallel to the edges of the fingertip.

Fingerpads intuitively seem to be well designed mechanically to improve their grip. The skin is attached firmly to the bone around the edges of the nail bed, and the free edge of the nail helps prevent the skin from being pushed around the end of the finger (Farren et al., 2004). The skin is also attached directly to the bone *via* subcutaneous fibrous tissue (Cauna, 1954), which travels through fatty tissue that cushions the pad. The final adaptation is the presence of ridges on the fingerpad itself that make up our fingerprints. It has long been assumed that the ridges on the fingerpad improve grip by increasing friction (Jones and Lederman, 2006). This idea seems intuitively plausible and it is supported by observations of other gripping structures. Koalas, for instance, though unrelated to primates, also have fingerprints, while the prehensile tails of new world monkeys have gripping pads covered with 'tailprints' (Ankel-Simons, 2007).

Apart from the friction hypothesis, at least two other hypotheses have been put forward about why we have fingerprints. The first, which has received a great deal of attention from both sensory physiologists and engineers, is that fingerprints improve touch discrimination. Meissner's corpuscles are located in the ridges of the prints and it has been shown that this anatomical arrangement could result in the magnification of shear strains and the enhancement of touch sensitivity (Cauna, 1954; Maeno et al., 1998; Dandekar et al., 2003). Ridging could also increase the frequency content of sliding interactions, which could enhance the perception of textured surfaces (Smith et al., 2002). This sensory hypothesis has the disadvantage, however, that large areas of the palms of our hands and soles of our feet also have extensive ridging, despite not being used for touch discrimination, so this touch hypothesis cannot be the full answer.

The second hypothesis is that the ridging functions just like the tread of a car tyre or the grooves in the foot pads of tree frogs (Federle et al., 2006), facilitating the shedding of water between the pad and a wet surface, and so improving grip in wet conditions.

Despite the assumption that fingerprints increase the friction of skin, there is little evidence that they do. One would assume that the friction would be much greater at right angles to the prints than parallel to them. However, actual tests have shown only tiny differences in friction between directions. Buck and Bar (Buck and Bar, 1998) found no significant difference in friction on glass parallel to the finger (and hence at right angles to the ridges) and across them and differences of only 5%, 12% and 18% on plastic, wood and stone. The idea that fingerprints should increase friction is in fact largely based on the implicit assumption that fingerpads produce friction because of the jamming of asperities, as is the case for hard crystalline and amorphous materials such as metals, glass and hard plastics. These materials obey Amonton's law, so that the friction force, **F**, is given by the formula:

$$\mathbf{F} = \mu \mathbf{N} , \quad (1)$$

where μ is the coefficient of friction and **N** is the normal force. In such materials, friction is therefore directly proportional to the normal force, but is not significantly affected either by contact area or by the speed of movement. Adams and colleagues (Adams et al., 2007) found that this was indeed the case for dry forearm skin, but when tests have been performed at more than one normal force, the frictional behaviour of skin is usually very different.

Tests on moist forearm skin (Koudine et al., 2000; Li et al., 2006; Adams et al., 2007) suggest that its frictional behaviour is much more similar to that of rubbers; these tend to have much greater friction than hard solids, largely because their high compliance allows them to flow over and have a large area of contact with the opposing surface. Friction of rubber with flat, rigid substrates is due not to jamming of asperities but to adhesion, *via* van der Waal's forces of the long chain molecules of which rubbers are composed, to the substrate (Barquins and Roberts, 1986; Barquins, 1992; Barquins, 1993). These adhesive bonds can withstand a certain tangential stress. Hence the friction force is given by the equation:

$$\mathbf{F} = SA \,, \tag{2}$$

where A is the actual contact area and S is the adhesive shear strength between the rubber and the surface.

The ability of rubber to slide over other surfaces is due to the fact that the bonds are constantly being broken and reformed as the long chain molecules move about. As the rubber is moved over the surface, the chains can make jumps of between 10 and 50 Å (1–5 nm), relieving the stress and allowing relative movement of the two surfaces. The friction force seems to be due to internal friction within the rubber (Persson, 1998).

When a hemisphere of rubber is pushed sideways over a sheet of glass, the leading edge of the rubber detaches due to the resulting tensile forces and there is also lateral movement in the outer ring of material, the 'slip zone', where the normal pressure is least and where shear stresses are concentrated. Only in the central 'adhesion zone' does the rubber remain stationary. As the shear force is increased the adhesion zone gets smaller and eventually the whole rubber moves.

In rubbery friction, the concept of the coefficient of friction becomes meaningless. Careful experimentation has shown that the frictional force between a rubber and a rigid plate is proportional to the contact area between them (Barquins and Roberts, 1986). For a hemispherical piece of rubber sliding on a flat plate of glass (or hemispherical piece of glass on a flat bed of rubber) the area of contact is given by the expression:

$$A = \pi(9R\mathbf{N} / 16E)^{2/3} \,, \tag{3}$$

where R is the radius of the sphere, $\mathbf{N}$ is the normal force and E is the Young's modulus of the rubber (Hertz, 1881). Therefore the friction force, $\mathbf{F}$, is given by the expression (Barquins and Roberts, 1986):

$$\mathbf{F} = \pi S\,(9R\mathbf{N} / 16E)^{2/3} \,, \tag{4}$$

and, using conventional notation, the coefficient of friction, μ, is:

$$\mu = \pi S\,(9R / 16E)^{2/3}\,\mathbf{N}^{-1/3} \,. \tag{5}$$

Therefore the coefficient of friction will rise with the radius of curvature of the sphere and fall with both its stiffness and the applied load; large, soft rubber pads will have greater friction than small, hard ones, because they will deform to allow a greater area of contact with the surface.

Of course, skin does not exist in perfect hemispheres, but when hemispherical probes of glass, stainless steel or plastic are pushed across the moist skin of the human forearm (Koudine et al., 2000; Adams et al., 2007) the coefficient of friction is much greater than for dry skin and falls with the normal load approximately to the power of one-third, in just the way predicted by the rubber friction theory described above. These studies also showed that moisturising the skin counter-intuitively increased the friction coefficient, probably because moisturising the skin reduces the stiffness of the outer horny layer and increases the contact area. Finally, a fourth study (Li et al., 2006) showed that reciprocal movements of a circular probe of 15 cm diameter on forearm skin at intermediate loads and displacements results in the sort of annular pattern that has been observed in rubber; there were rub marks on an outer slip zone where there was relative movement, and pressure marks on an inner adhesion zone.

The limited research carried out on the friction of fingerpads suggests that these structures also show frictional behaviour that is more similar to that of rubbers than of hard solids. For instance when Cartmill (Cartmill, 1979) investigated the friction against slipping down smooth slopes in primates, he found that across a wide range of species the friction was much more closely proportional to the normal force to the power of two-thirds than to 1, so the coefficient of friction fell with normal force in the way predicted by rubbery theory. Of course, this trend could have been due to differences between the pads of animals of different sizes, so the evidence for rubbery behaviour is not strong, but more recent work by Andre and colleagues (Andre et al., 2008) on individual fingerpads also showed that the coefficient of friction fell at higher normal loads.

None of the above studies, however, have actually tested the rubbery friction model by directly measuring the contact area. If the rubbery model was correct, one would predict not only that the coefficient of friction should fall with the normal force but also that friction should rise in direct proportion with the contact area. In this study, therefore, we carried out a series of friction experiments that independently altered the normal force and contact area of fingerpads. As one of the effects of fingerprints is likely to be to reduce the contact area of the pads, this would test whether fingerprints do actually increase friction and shed further light on their possible functions.

MATERIALS AND METHODS

The set up

The frictional properties of the fingers of P.H.W. on dry acrylic glass sheet (Perspex®) were investigated using a universal testing machine (Instron model 4301, High Wycombe, Bucks, UK) fitted with a purpose-built attachment which could apply a constant normal force using gravity. An acrylic sheet was attached *via* a freely moving hinge to the 100 N load cell of the testing machine and allowed to hang vertically (Fig. 1). A lightweight bracket was screwed to the sheet and a stack of 50 g weights could be added to the end of this, so that as mass was added, a rotational moment would be set up, exerting a lateral force on the acrylic sheet. This lateral force was measured using a digital force gauge (MecMesin 200 N force gauge, 0.01 N accuracy, MecMesin, Slinfold, West Sussex, UK). This was placed behind the acrylic sheet and zeroed, the sheet was allowed to press upon it and the normal force was measured for each addition of 50 g, up to 600 g, giving normal forces from 0.03 to 1.64 N with intervals of 0.12 to 0.16 N.

Measuring friction

To measure the friction of a finger, it was held static in a vertical orientation behind the acrylic sheet by two copper rings screwed to a backboard. The acrylic sheet was then allowed to press on the fingerpad under the action of the weights and the testing machine was zeroed. The sheet was then raised at a speed of 100 mm min^{-1} (1.67×10^{-3} m s^{-1}) up to a displacement of 15 mm, pulling the acrylic distally along the finger. The force required was recorded using an interfacing computer, giving a graph of friction *vs* displacement. In each test there was an initial steep increase in force, which then

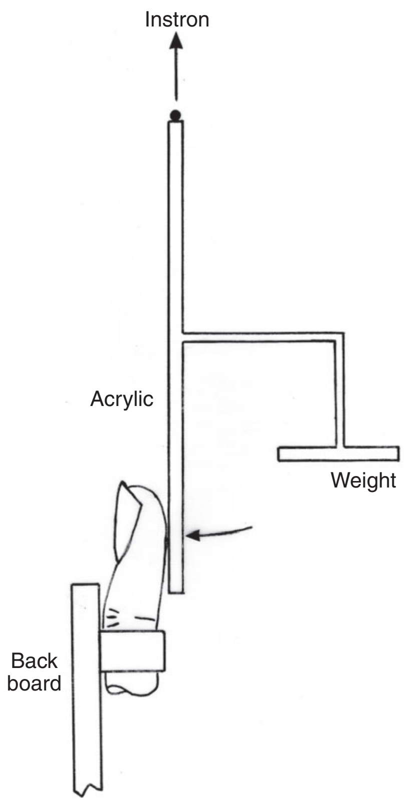

Fig. 1. Diagram showing the arrangement of the friction apparatus. The acrylic sheet, which is freely hinged to the load cell, is held against the fingerpad by the moment arm set up by the weights, and is then raised by the crosshead of the Instron testing machine, rubbing the sheet across the fingerpad.

levelled off after a displacement of around 3 mm to give the limiting frictional force. Because the finger would then be positioned slightly lower on the acrylic sheet, this would reduce the normal force applied by the weights, but as the initial distance to the hinge was 200 mm this would reduce the normal force by only around 1%. For each test, weights were added to the end of the bracket in 50 g increments, starting off with just the weight of the bracket itself and increasing to 600 g. In this way the effect of differences in normal force on the limiting frictional force could be examined.

Measuring contact area

Changing the normal force will alter the contact area of the fingerpads, both because the pad will become more flattened and because each print ridge might also become flattened. To calculate the overall area of the fingerpad in contact with the acrylic, and the area of print ridges in actual contact, prints of each fingerpad were taken at each different normal force. This was achieved by sticking a strip of plain paper onto one side of the acrylic while it was set up in the mechanical testing machine. The finger was pressed onto an ink stamp sponge to cover it with a thin layer of black ink, and placed behind the sheet as in the actual experiment. The paper strip was then moved along for each extra load addition, to produce a fingerprint for every load that was used on every fingerpad in each experiment.

Each print was then photographed under a microscope using Leica software. Files were transferred to ImageJ software. A scale was set on the software by measuring the actual prints to the nearest 0.5 mm and transferring this data into the program. The photographs were then altered to 8 bit black and white images, so that only the inked areas could be seen. By setting a threshold colour on the area measuring tool, the contact area could be accurately measured without measuring the total area inside the fingerpad perimeter, i.e. the troughs between the ridges were omitted. The total area of the pad in contact with the sheet was also determined by drawing round the print and measuring the area inside this perimeter. This allowed us to measure the effect of the fingerprints on the contact area.

The different tests

To investigate the effect of normal force and contact area on the limiting friction of the fingerpads, three separate sets of tests were carried out.

Different fingers

To investigate the friction of each of the fingerpads, each of the fingers of the right hand were investigated when the pads were held with the volar pad flat against the acrylic, giving the largest available contact area. Each test could be used to investigate the effect of both normal force and contact area on limiting friction. In addition, as each finger would have a different contact area, this experiment would also give some information on the effect of contact area on friction, independent of the normal force.

Different finger orientations

For the index finger, friction was measured when it was oriented in three different ways relative to the acrylic plate: flat against the plate; angled so that only the small tip region contacted the plate; and in an intermediate orientation. In this way we could examine the effect of contact area independently of the normal force, and using the same fingerpad so that the confounding variable of differing properties between fingerpads could be removed.

Different strip widths

A final series of tests also examined the way in which contact area affects friction, removing the confounding effects of using different fingerpads or different areas of the same pad, which might have different frictional properties. To do this we altered the area of the acrylic plate; the friction of the index finger was measured on the standard plate and also when it was touching vertically oriented acrylic strips 0.75 cm and 0.3 cm in width.

Analysis

For each series of tests on each fingerpad, the relationships between the three variables normal force, contact area and limiting friction were investigated by producing graphs of friction *vs* normal force (**F** *vs* **N**), contact area *vs* normal force (*A* *vs* **N**) and friction *vs* contact area (**F** *vs* *A*). Regression analysis was also performed on logged data to give the power relationship between each of the three variables. If the fingerpads behaved as rigid solids they would obey Amonton's law, so the slope of the graph of log**F** *vs* log**N** should be 1. Conversely, if the fingerpads behaved like rubber, the slope of the log**F** *vs* log*A* graph should be 1. Student's *t*-tests were performed in each case to determine whether the slope was significantly different from 1. Student's *t*-tests were also performed to determine whether the slope of the log**F** *vs* log**N** graph was significantly different from 2/3 as was found for tests of skin on hemispherical pads.

RESULTS

Different fingers

Each of the fingers had broadly similar frictional behaviour (Fig. 2). Friction rose with the normal applied force (Fig. 2A) but not linearly. In all cases, except for the middle finger, the slope of the

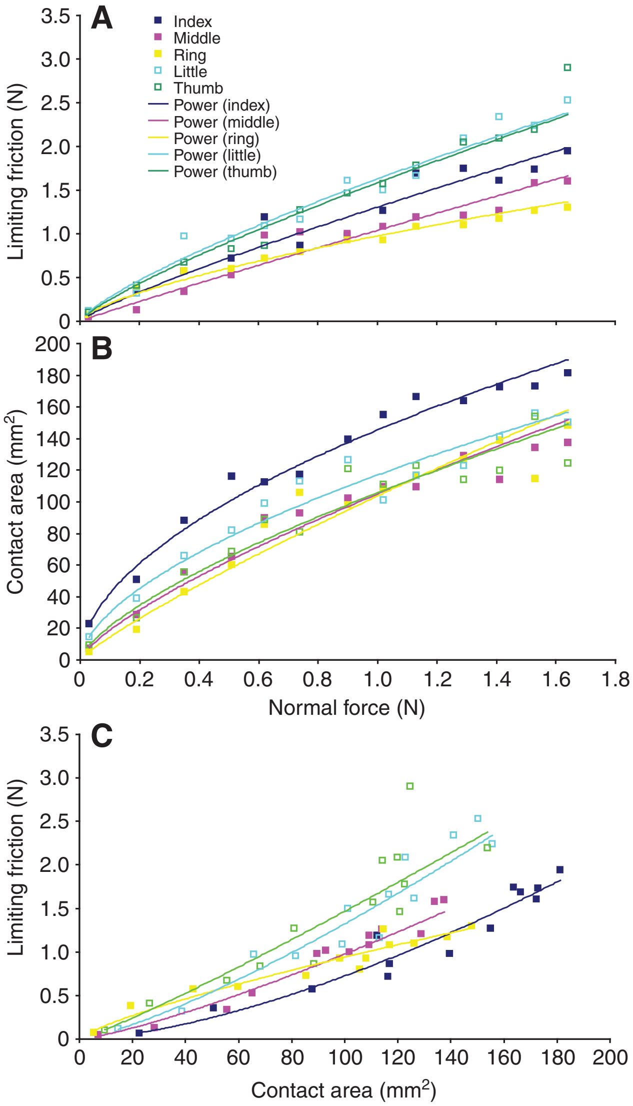

Fig. 2. Graph showing the relationship between (A) friction and normal force, (B) contact area and normal force and (C) friction and contact area, for all five fingers held flat against the acrylic sheet.

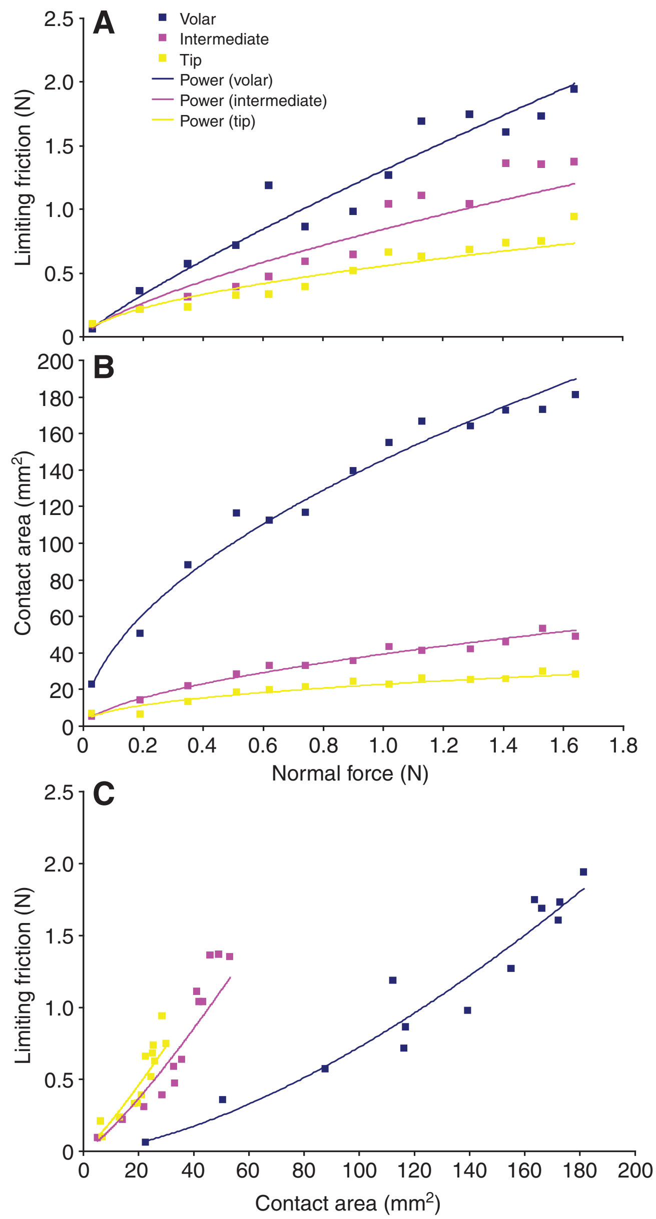

Fig. 3. Graph showing the relationship between (A) friction and normal force, (B) contact area and normal force and (C) friction and contact area, for the index finger when held with the volar surface flat, with only tip contact and at an intermediate orientation against the acrylic sheet.

regression line of log**F** *vs* log**N** (Table 1) was significantly lower than 1 (though higher than 2/3 except for the ring finger) so that the coefficient of friction fell from around 3 at 0.03 N normal force to around 1–1.5 at normal forces over 1 N.

However, the contact area increased even more slowly with normal force (Fig. 2B; Table 1), so that friction rose more rapidly as contact area increased (Fig. 2C; Table 1), with four out of the five fingers having the slope of the log**F** *vs* log*A* regression line significantly greater than 1, though it was significantly less than 1 for the ring finger.

There was some variability between fingerpads in the magnitude of friction, but there was no clear cut effect of pad area on friction. The index finger had the largest contact area but the thumb and little finger had the highest friction.

Different finger orientations

At the three orientations the index finger had fairly similar frictional behaviour (Fig. 3; Table 1). One again friction rose with the normal applied force (Fig. 3A) but not linearly. In all cases, the slope of the regression line of log**F** *vs* log**N** (Table 1) was significantly lower than 1, though higher than 2/3 for the flat volar pad, so that the coefficient of friction fell from 2–3 at 0.03 N normal force to around 0.5–1.2 at normal forces over 1 N. However, the contact area increased even more slowly with the normal force (Fig. 3B; Table 1), so that friction rose more rapidly as contact area increased (Fig. 3C; Table 1), with the slope of the log**F** *vs* log*A* regression line being greater than 1 for all three orientations, though not significantly so for the tip and intermediate orientations.

The magnitude of friction differed greatly depending on the pad orientation. Friction was much greater for the pad held flat and least for the fingertip (Fig. 3A). The flat pad also had greater contact area (Fig. 3B) but it produced less friction per unit of contact area (Fig. 3C).

Table 1. The exponents (means ± s.e.m.) of the power relationships between the normal force, the limiting friction and the contact area of fingerpads at different orientations and on Perspex pads of different widths

Finger	Friction *vs* normal	Area *vs* normal	Friction *vs* area
Index flat	↑*** 0.850±0.038 ↓**	0.538±0.020 ↓***	1.554±0.094 ↑***
Middle flat	↑*** 0.949±0.062 n.s.	0.745±0.029 ↓***	1.269±0.076 ↑**
Ring flat	n.s. 0.683±0.024 ↓***	0.853±0.041 ↓**	0.777±0.050 ↓***
Little flat	↑* 0.773±0.040 ↓***	0.591±0.027 ↓***	1.290±0.074 ↑**
Thumb	↑*** 0.807±0.026 ↓***	0.694±0.035 ↓***	1.121±0.083 n.s.
Index intermediate	n.s. 0.717±0.057 ↓***	0.580±0.017 ↓***	1.219±0.113 n.s.
Index tip	n.s. 0.561±0.048 ↓***	0.428±0.055 ↓***	1.140±0.157 n.s.
Index on 0.75 cm	↑** 0.808±0.033 ↓***	0.425±0.025 ↓***	1.823±0.144 ↑***
Index on 0.3 cm	↑** 0.819±0.042 ↓***	0.205±0.024 ↓***	3.470±0.453 ↑***

The statistical tests (*t*-tests) show whether the exponents are significantly different from the value of 1 (right-hand side of the exponent) and 2/3 (left-hand side of the exponent): n.s., not significant; *, $P<0.05$; **, $P<0.01$; ***, $P<0.001$.

Different strip widths

Against the three different widths of acrylic the index finger had fairly similar frictional behaviour (Fig. 4; Table 1). Once again, friction rose with the normal applied force (Fig. 4A) but not linearly. In all cases, the slope of the regression line of log**F** *vs* log**N** (Table 1) was significantly lower than 1, though higher than 2/3, so that the coefficient of friction fell from 2–3 at 0.03 N normal force to around 0.8–1.2 at normal forces over 1 N. However, the contact area increased even more slowly with the normal force (Fig. 4B; Table 1), so that friction rose more rapidly as contact area increased (Fig. 4C; Table 1), with the slope of the log**F** *vs* log*A* regression line being significantly greater than 1 for all three widths.

The magnitude of friction differed greatly depending on the acrylic width. Friction was greatest for the two wider plates and least for the 0.3 cm wide one (Fig. 4A). The wider plates also resulted in greater contact area (Fig. 4B) but less friction per unit of contact area (Fig. 4C).

Effect of fingerprints on contact area

In all tests, the contact area of the fingerpad, measured with ink, was markedly less than the area within the perimeter of the contacting area, because no contact occurred between the troughs of the pads and the acrylic glass. The relative contact area did not consistently change with the normal force, or between fingers, orientations or widths; for the nine situations examined the actual contact area was only 66.7±8.0% of the total perimeter area.

DISCUSSION

The results of the tests showed conclusively that the friction of the fingerpad did not obey Amonton's law; the friction coefficient fell significantly at higher normal forces. This was true for all fingers bar the ring finger and at all orientations and against all widths of acrylic. The friction was also higher when there was a greater contact area: fingers held flatter against the acrylic pad or held against a wider strip of acrylic. Therefore the pad could not have been behaving like a hard material.

In contrast, friction did increase with contact area, suggesting that the pads might be showing rubbery behaviour, but three findings suggest that fingers were not behaving quite as classical rubber friction theory would suggest. First, friction rose with normal force to a power usually greater than the 2/3 value found for the friction of rubber hemispheres. Of course, however, fingerpads are not hemispherical and have a complex pattern of ridges so there is no real reason to expect the 2/3 value. Second, friction rose with contact area to greater than 1, the value predicted for rubbers. Third, when contact was limited to smaller areas, both by inclining the fingertip and by using a narrower acrylic plate, the friction per unit area of contact was higher. The results therefore do not fully support either model of friction.

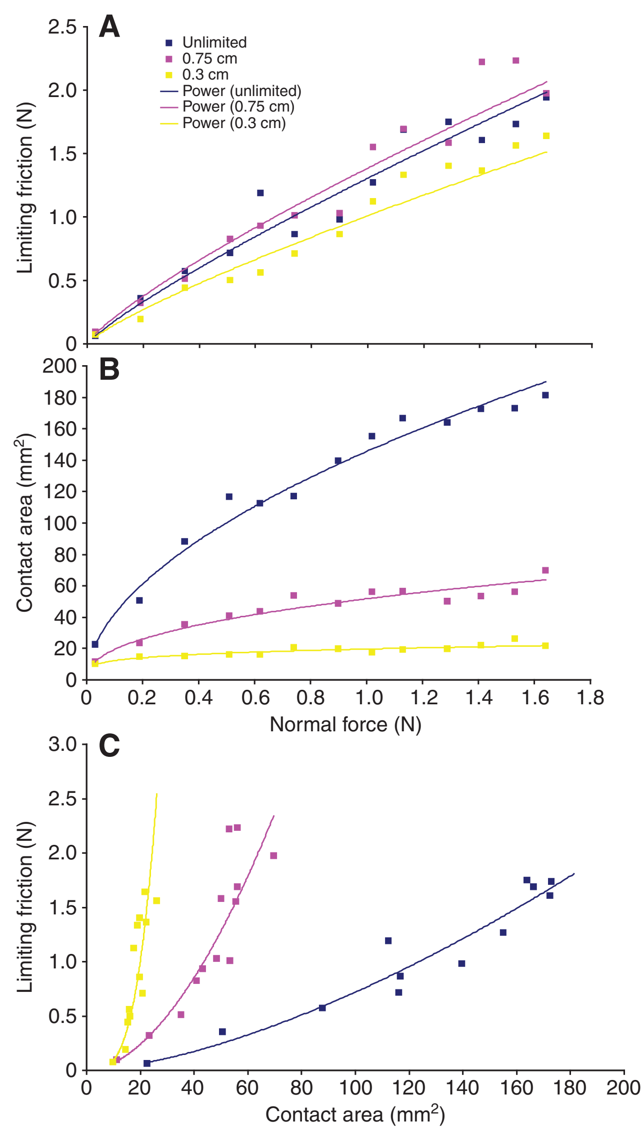

Fig. 4. Graph showing the relationship between (A) friction and normal force, (B) contact area and normal force and (C) friction and contact area, for the index finger when held against an acrylic sheet and against strips 0.75 cm and 0.3 cm wide.

There are two factors that might make the rubbery model more feasible. First, in our tests, the measurement of contact area using ink was probably rather inaccurate. It would almost certainly have overestimated the contact area because the thickness of the ink film would mean that minor folds within each ridge would be filled in, overestimating true contact area especially at low normal forces. Therefore the actual increase in contact area with normal force would probably have been more linear than we measured. The overestimation of contact area would have been greatest for the flat fingertip, as it was subjected to the least pressure. In contrast, the inclined fingertips and the fingers held against the narrower acrylic sheets would have a greater pressure and so a greater proportion of each ridge would probably have been in actual contact with the acrylic. The relationship of friction to contact area would therefore be more similar in these cases. However, until a more accurate way of measuring contact area is devised, and before the fine scale deformations of the ridges themselves is examined, there is no way of properly testing the rubber model.

A second factor is that Adams and colleagues (Adams et al., 2007) suggested that for a rubbery material, friction can be greater at higher contact pressures due to the presence of a thin liquid film, such as water or grease. In such a case the interfacial shear strength, S, is given by the formula:

$$S = S_0 + \alpha p \,, \tag{6}$$

where α is a pressure coefficient and pressure p=$\mathbf{N}/A$. The results of a plot of shear stress $\mathbf{F}/A$ against contact pressure $\mathbf{N}/A$ is shown for the index finger against different widths in Fig. 5. It can be seen that the points do approximately follow a straight line as predicted by Adams and colleagues, with values from regression analysis for S_0 and α of 0.004 MPa and 0.986, respectively. These values are very similar to those found by Adams and colleagues for the skin of the forearm on glass (S_0=0.0048 MPa; α=0.8).

The other major result of these tests is that whatever the pressure on the fingerpad, the presence of fingerprints reduces the contact area by a factor of approximately one-third. These results force us to re-evaluate the role of fingerprints. As the fingers behave in a rubbery fashion with friction rising with contact area, fingerprints should result in a reduction of friction. Certainly compared with the tests of other authors fingerpads do not have exceptionally good frictional properties. Koudine and colleagues (Koudine et al., 2000) found coefficients of friction of moist forearm skin on glass of 3.5 at 0.02 N, 1.2 at 0.2 N and 1.0 at 1 N, very similar to our fingerpads, while the corresponding values for forearm skin on glass found by Adams and colleagues (Adams et al., 2007) were also similar: 2 at 0.03 N, 1.5 at 0.2 N and 1.1 at 1 N. No corresponding values were obtained for acrylic glass, but Adams and colleagues found values of friction for forearm skin on polypropylene that were approximately double ours for fingerpads on acrylic. Unfortunately, neither group gives details of the actual contact area.

So why do we have fingerprints? One possibility is that they increase friction on rougher surfaces compared with flat skin, because the ridges project into the depressions of such surfaces and provide a higher contact area. Experiments on materials of contrasting known roughness are needed to test this possibility.

A second possibility is that they facilitate runoff of water like the tread of a car tyre or grooves in the feet of tree frogs (Federle et al., 2006), so that they improve grip on wet surfaces. Though there is evidence that friction falls on fingers coated with high levels of moisture (Andre et al., 2008) it is possible that it falls less quickly on fingertips than on flatter skin. Once more, suitable experiments could test this idea.

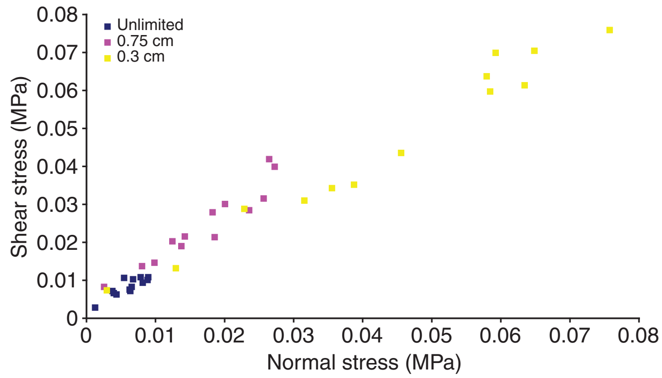

Fig. 5. Graph showing the relationship between the limiting shear stress on the index finger and the normal pressure when held against an acrylic sheet and against acrylic strips 0.75 cm and 0.3 cm wide.

A third possibility is that fingerprints have quite a different function than mere maximisation of friction. Fingerprints are just one part of the complex design of the contact areas of our fingerpads, and of the other contact areas of our hands and feet. The pads themselves, with subcutaneous cushions of fat, are soft and act rather like a water bed (Serina et al., 1998), helping to maximise contact area even at low normal forces. This allows friction to be high even at low applied forces. Of course, this might result in our fingers getting stuck onto objects even when we try to release them. By having fingerprints, the contact area and friction might rise more linearly as we increase our gripping force.

Another aspect of the flexible ‘water bed’ design is that though it allows a large contact area, the skin itself is relatively strong, which will reduce wear. A further advantage may be that the large contact area will minimise the shear stresses on the skin around the perimeter of contact, stresses that on smooth skin so readily cause friction marks (Li et al., 2006) and can result in blistering as the epidermis and dermis are sheared apart and separated. In this context, fingerprints might have the added advantage that they allow the skin to stretch more at right angles to the ridges and make it more compliant than parallel to the ridges (Wang and Hayward, 2006). This should enable the skin of our fingerpads to deform extensively when stressed in shear without being damaged, and hence be more resistant to blistering. There is some indication from the correlation analysis of Levesque and Hayward (Levesque and Hayward, 2003) that such large deformations indeed occur, but further investigation of the movements of fingerpad skin in contact areas is needed to verify this. As the troughs of the prints are reinforced and connected directly to the bone beneath, the arrangement will further inhibit blistering. Readers will probably themselves be familiar with the sites where blisters form; they are common on areas of skin which are subject to rubbing but which are not covered by prints: the heels of our feet and tops of our toes subjected to rubbing by new shoes; areas of our hands subjected to rubbing in unfamiliar mechanical tasks such as gardening or DIY; and pressured areas in the bed-bound. They only rarely seem to occur on the fingerpads or other ridges areas.

Clearly a great many more experiments must be carried out on different surfaces under different conditions, and using more sophisticated methods before we can truly understand the design of fingerpads and understand why we have fingerprints. However, this initial study is enough to show that fingerpads might have quite a different function than just to increase friction.

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