



An investigation of human palmar skin friction and the effects of materials, pinch force and moisture

BRYAN BUCHHOLZ , LINDA J. FREDERICK & THOMAS J. ARMSTRONG

To cite this article: BRYAN BUCHHOLZ , LINDA J. FREDERICK & THOMAS J. ARMSTRONG (1988) An investigation of human palmar skin friction and the effects of materials, pinch force and moisture, Ergonomics, 31:3, 317-325, DOI: [10.1080/00140138808966676](https://doi.org/10.1080/00140138808966676)

To link to this article: <https://doi.org/10.1080/00140138808966676>



Published online: 31 May 2007.



Submit your article to this journal [↗](#)



Article views: 168



View related articles [↗](#)



Citing articles: 80 View citing articles [↗](#)

An investigation of human palmar skin friction and the effects of materials, pinch force and moisture

BRYAN BUCHHOLZ, LINDA J. FREDERICK†
and THOMAS J. ARMSTRONG

The University of Michigan, Ann Arbor, Michigan, U.S.A.

Keywords: Friction; Skin; Handles.

A study was conducted to determine the friction characteristics for various materials against human palmar skin. Seven materials were tested using two pinch-force levels under both moist and dry conditions. Using a two-fingered pinch grip, subjects held a specially designed dynamometer covered with one of the test materials. They maintained a constant pinch force as load force was increased at a constant rate until the dynamometer slipped from their fingers. The load force at the slip point was then used to determine the coefficient of friction from Amonton's Law. The effects of subject, material, moisture, pinch force and the material-moisture and pinch force-moisture interactions were all significant. The coefficient of friction decreased with increased levels of pinch force for every material-moisture combination. The coefficient of friction for porous materials showed a significant increase when moisture was present. This information may be applicable in tool handle and work station surface design.

1. Introduction

Friction is an important factor in our ability to grasp and manipulate objects with the hand. Objects with low-friction surfaces have a greater tendency to slip out of the hand and require greater grip forces than objects with high friction (Armstrong 1985). Friction forces also produce deformation of skin which in turn stimulates nerve endings and provides tactile feedback (Taylor and Lederman 1975). Westling and Johansson (1984) concluded from their experiments that individuals sense the frictional condition between the surface of the object and the fingers and use this to adjust the amount of grip force applied. Thus friction is a very important factor in the design of handles, tools and controls.

Comaish and Bottoms (1971) estimated the coefficient of static friction for skin and polythene using Amonton's Law. They reported a coefficient as high as 2.2 for the palmar side and as low as 0.3 for the dorsal side of the hand. They attributed this difference to the high density of sweat glands and sweatiness of the palm. They also reported deviations from Amonton's Law at low contact forces (less than three newtons).

Taylor and Lederman (1975) measured coefficients of static friction between the finger tip and an aluminium tile also using Amonton's Law. They reported a coefficient of friction of 0.6, which dropped by at least 75% when the surfaces were covered with soap.

† Present address: Division of Biomedical and Behavioral Sciences, National Institute for Occupational Safety and Health, Cincinnati, Ohio, U.S.A.

Westling and Johansson (1984) measured the coefficient of friction for sandpaper (grade 320), suede and finely textured silk in contact with the skin for a pinch posture. They calculated average values for ten subjects using Amonton's Law. These were 1.21, 0.69 and 0.35 for sandpaper, suede and silk, respectively.

The purpose of this study was to investigate the friction characteristics of some common handle materials, under both the dry and the moist conditions that may be encountered in the workplace. The specific objectives of this study were:

- (1) To estimate the coefficient of friction for selected materials that are commonly used for handles, tools and controls.
- (2) To evaluate the effect of hand moisture on the coefficient of friction.
- (3) To evaluate Amonton's Law at two levels of pinch force, low and high.

2. Materials and methods

Friction measurements were based on the method described by Westling and Johansson (1984). Subjects were instructed to hold a specially designed pinch dynamometer using a pulp pinch and a constant force (Jacobson and Sperling 1976). Pinch force was displayed constantly in view of the subject. An external force, perpendicular to the pinch force, was increased at an approximate rate of 15 N/s until the dynamometer slipped from the subject's pinch. The coefficient of static friction was calculated as the normal force at which the dynamometer began to slip divided by two times the pinch force (Armstrong 1985).

Subjects were seated in a specially designed chair with an arm rest to support the right arm as shown in figure 1. Subjects sat with their upper arm approximately vertical

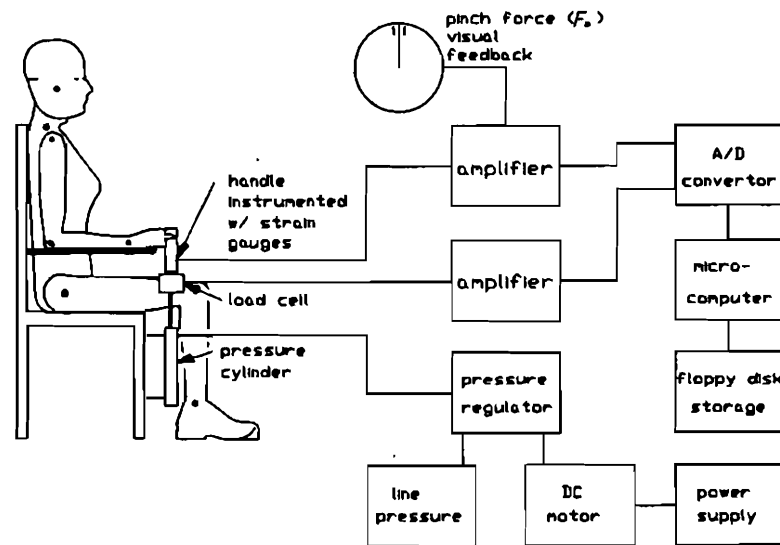


Figure 1. Experimental set-up. Subjects were seated in a specially designed chair with pinch force displayed constantly in their view. A pneumatic cylinder anchored to the chair was used to pull the dynamometer out of the subjects' hand. The pressure in the cylinder was varied by a regulator, which was controlled by a constant r/min motor and a 90-p.s.i. (620 kPa) air supply. Pinch force was measured via strain gauges mounted in the dynamometer. Load force was measured with a load cell. The strain gauge signals were amplified and collected at 50 Hz using a twelve-bit analog-to-digital (A/D) converter and general purpose A/D software implemented on a laboratory microcomputer.

and their forearm and hand approximately horizontal. A pneumatic cylinder anchored to the chair was used to pull the dynamometer out of the subject's hand. The pressure in the cylinder was varied by a regulator, which was controlled by a constant r/min motor and a 90-p.s.i. (620 kPa) air supply.

The fingers were extended beyond the arm rest so that the subject could pinch the dynamometer, using a two-finger pulp pinch (figure 2). The dynamometer was constructed with paddles that had the different materials mounted on them and were easily attached and removed. Pinch force, F_p , was measured via strain gauges mounted in the dynamometer. Load force, F_l , was measured via a 100 lb (445 N) load cell. The strain gauge signals were amplified and collected at 50 Hz using a twelve-bit analog-to-digital (A/D) converter and general purpose A/D software implemented on a laboratory microcomputer.

Subjects were instructed to maintain their pinch force at a constant level while the load force was increased at a constant rate until the paddles slipped from the fingers. The load force at slip, $F_{l(max)}$, was then used to determine the coefficient of static friction, μ , from the following relationship:

$$\mu = F_{l(max)} / 2F_p$$

Subjects washed their hands with soap and water prior to the start of each session. They were instructed to grasp the paddles between their thumb and index finger and to maintain a constant pinch force by watching a dial located in front of them. In between trials subjects dried their hands with paper towelling.

Several practice trials were allowed in order to familiarize the subject with the procedure. Because of the difficulty subjects had in maintaining the exact pinch-force level asked of them, trial acceptability was based on their ability to keep the pinch force stable (± 2.5 N) near the slip point, rather than the absolute magnitude of the pinch force. Pinch force stability was visually confirmed.

Seven materials, listed in table 1, were selected for study. Most of these are materials commonly encountered on the surface of handles, tools and controls, although they by no means provide an exhaustive list. Some of the materials were investigated because they represent a wide range of frictional properties or in order to compare them with the findings of previous investigators.

Seven subjects, four males, three females, 23–41 years' old, were selected. The subjects were all students or otherwise affiliated with the University of Michigan and

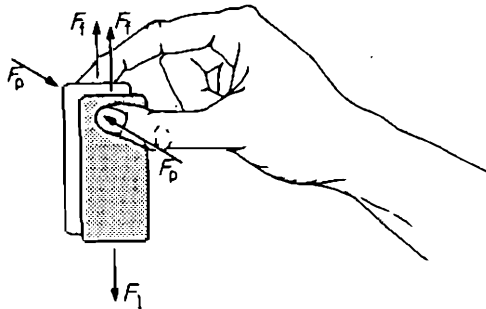


Figure 2. Pinch posture and free-body diagram of dynamometer used in the study. Subjects grasped the paddles of the dynamometer using a two-finger pulp pinch and constant force. Frictional force is generated on both surfaces of the dynamometer. It is assumed that the frictional forces are divided equally between the two surfaces.

Table 1. Description of materials used in the study.

Material	Description
Sandpaper	320 grit, aluminium oxide
Smooth vinyl	Steere vinyl rubber, SM1137 formulation
Textured vinyl	Steere vinyl rubber, SM1217 formulation, with 'suede-like cushion grip'
Adhesive tape	Johnson & Johnson sports tape, with cloth base
Suede	brushed leather
Aluminium	polished
Paper	20 bond computer paper

were of good health. Both males and females were included to estimate the variance of the adult population for future studies, although investigation of male-female differences was not an objective of this study.

Two pinch forces (19.6 and 39.2 N) were used. The larger pinch force (39.2 N) was selected because it was the maximum pinch force that subjects could easily maintain at a constant level. The lesser pinch force (19.6 N) was selected as a half-way point.

Because moisture from various sources is often encountered in an occupational setting, two levels of moisture, dry and moist, were investigated. Subjects moistened their fingers by dipping them in tap water briefly and shaking off the excess. The trial was performed within seconds of the finger moistening.

The order of presentation of the materials was randomized. Three trials were performed for each treatment combination. Half of the series of 28 treatment combinations was done with the fingers moist and half with them dry. The interval between trials was at least one minute. Total time for a session was approximately five hours divided into two or more periods.

Analysis of variance (ANOVA) was performed for this repeated-measures design to evaluate differences among subjects, materials, moisture, pinch force attempted and the two-factor and three-factor interactions. Scheffé multiple comparisons were employed to determine which factors had a significant effect. Since subjects did not maintain the exact level of pinch force requested of them, regression analysis was performed to investigate the effect of pinch force.

3. Results

Data from a typical trial are shown in figure 3. The load force always dropped off sharply at the slip point. Although most subjects were able to maintain a relatively constant pinch force, there was some variability in the pinch force just prior to slip. Therefore, the exerted pinch force during a 0.1 second interval immediately prior to slip was averaged to determine the pinch force (F_p) for all friction calculations.

An average pinch force of 22.1 ± 4.6 N was obtained for the low pinch-force condition (19.6 N) and 38.7 ± 6.4 N for the high pinch-force condition (39.2 N). On the average, subjects exerted 13% excess force for the low-force condition and their pinch force was 1% low for the high pinch-force trials.

Results from this study are shown in table 2. These data are the average for the seven subjects and the range of pinch forces that were used. Values are the mean plus-or-minus the standard deviation for the given trial group. The pooled coefficient of friction

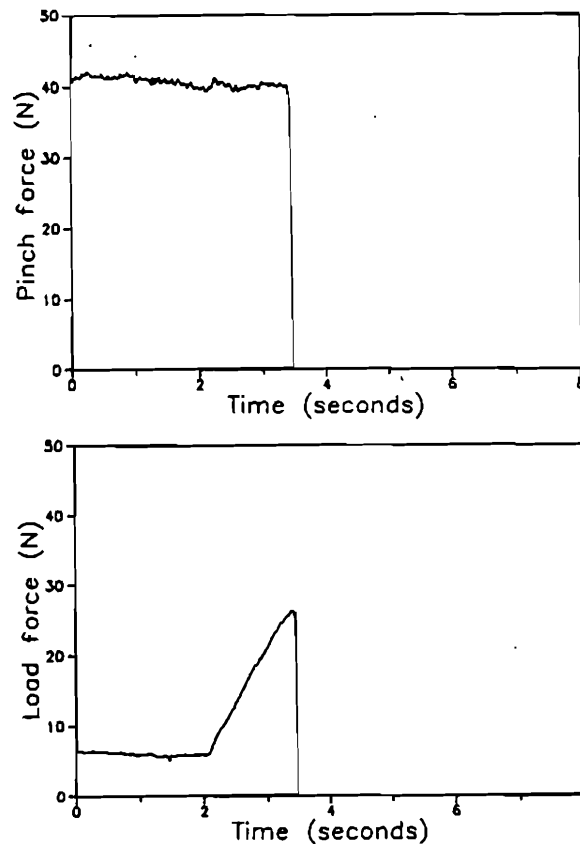


Figure 3. Data from a typical trial. Although most subjects were able to maintain a relatively constant pinch force, there was variability in the pinch force just prior to slip. Load force was ramped up at 15 N/s. The load force always dropped off sharply at the slip point.

was 0.49, while values for individual treatments ranged from a low of 0.27 for dry paper to a high of 0.66 for dry sandpaper, moist adhesive tape and moist suede. Standard deviations ranged from 0.06 for dry suede to 0.21 for moist smooth vinyl.

An analysis of variance (ANOVA) was performed on the data. The effects of material, moistness, pinch force, subject and the material-moistness interaction were all significant at $p < 0.01$. The pinch force-moisture interaction was significant at $p < 0.05$. Scheffé multiple comparisons were employed to determine significant main effects and interactions.

Material differences, as seen in table 2, are large. They accounted for 27.9% of the total variation. Material differences varied from -45% to +35% of the average friction coefficient for all materials and conditions.

The effect of moisture was dependent upon the material. The effects of moisture and the material-moisture interaction accounted for 7.2% and 15.9% of the total variability, respectively. Table 2 shows the coefficients of friction, averaged for the different pinch forces used, and the effect of moisture. The coefficient of friction for adhesive tape, suede and paper showed statistically significant increases ($p < 0.001$, Scheffé multiple comparisons) when some moisture was present between the material surface and the skin. These represent increases of 61%, 68% and 59%, respectively.

Table 2. Effect of moisture on the coefficient of friction for various materials against human palmar skin.

Material	Dry	Moist	Difference
Sandpaper (Grade 320)	0.66 ± 0.11	0.57 ± 0.07	-0.08 (-13%)
Smooth vinyl	0.56 ± 0.15	0.49 ± 0.21	-0.07 (-12%)
Textured vinyl	0.50 ± 0.12	0.49 ± 0.10	-0.01 (-2%)
Adhesive tape	0.41 ± 0.10	0.66 ± 0.14	+0.25 (+61%)*
Suede	0.39 ± 0.06	0.66 ± 0.11	+0.27 (+68%)*
Aluminium	0.33 ± 0.09	0.42 ± 0.14	+0.08 (+25%)
Paper	0.27 ± 0.09	0.42 ± 0.07	+0.16 (+59%)*

*** Significant at $p < 0.001$ (Scheffé multiple comparisons).

Table 3. Effect of pinch force on the coefficient of friction of various materials against human palmar skin.

Material	Moisture	Regression	R ²
Sandpaper	Dry	$\mu = 0.780 + (-4.08 \times 10^{-3})F_p$ [N]	0.13*
	Moist	$\mu = 0.758 + (-6.43 \times 10^{-3})F_p$ [N]	0.41***
Smooth vinyl	Dry	$\mu = 0.696 + (-4.59 \times 10^{-3})F_p$ [N]	0.08
	Moist	$\mu = 0.810 + (-10.4 \times 10^{-3})F_p$ [N]	0.31***
Textured vinyl	Dry	$\mu = 0.599 + (-3.22 \times 10^{-3})F_p$ [N]	0.08
	Moist	$\mu = 0.655 + (-5.62 \times 10^{-3})F_p$ [N]	0.25***
Adhesive tape	Dry	$\mu = 0.532 + (-3.91 \times 10^{-3})F_p$ [N]	0.13*
	Moist	$\mu = 0.863 + (-6.97 \times 10^{-3})F_p$ [N]	0.27***
Suede	Dry	$\mu = 0.469 + (-2.36 \times 10^{-3})F_p$ [N]	0.23***
	Moist	$\mu = 0.877 + (-7.70 \times 10^{-3})F_p$ [N]	0.48***
Aluminium	Dry	$\mu = 0.430 + (-3.20 \times 10^{-3})F_p$ [N]	0.10*
	Moist	$\mu = 0.689 + (-8.88 \times 10^{-3})F_p$ [N]	0.43***
Paper	Dry	$\mu = 0.345 + (-2.41 \times 10^{-3})F_p$ [N]	0.09
	Moist	$\mu = 0.570 + (-4.45 \times 10^{-3})F_p$ [N]	0.43***

* Significant at $p < 0.05$ (regression ANOVA).

*** Significant at $p < 0.001$ (regression ANOVA).

Differences in the pinch force attempted accounted for 7.7% of the total variation. For every material-moisture combination the coefficient of friction decreased with increased pinch force. Regression analyses were performed on each of these trial conditions, using the actual pinch force exerted at slip (F_p) as the independent variable. These regressions are shown in table 3. The decrease in coefficient of friction ranged from a minimum of 0.002 per Newton increase in pinch force, for dry suede and dry paper, to a maximum of 0.01 per Newton increase in pinch force, for moist smooth vinyl. For the range of pinch forces examined in this study, these effects correspond to decreases in the coefficient of friction of 0.04 (12.6%) to 0.20 (52.7%), respectively. The regressions for all of the moist materials and for one dry material (suede) were significant at $p < 0.001$. The regressions for sandpaper, aluminium and adhesive tape, all dry, were significant at $p < 0.05$. The pinch-force-attempted-moisture interaction accounted for less than 1% of the total variation.

Subject effects were significant. The coefficient of friction averaged for all treatments varied among subjects from a low of 0.43 to a high of 0.54. These are variations of -11.7% and 9.9% from the pooled mean, respectively. Subject differences accounted for less than 5% of the total variation in these data. These effects were much smaller than the effects of material or the combined effects of material and moisture. Subject effects were similar in magnitude to pinch-force effects.

4. Discussion

The effect of moisture was dependent upon the material. The only statistically significant differences were for adhesive tape, suede and paper. For these materials, the presence of moisture resulted in an increase in the coefficient of friction. This is probably because all of these materials are porous in nature, none of the other materials could be characterized in this manner. Moore (1972) states that the increase in friction for permeable materials is due to a 'softening effect'. Permeable materials soften in the presence of lubricants, i.e. their pressure hardness (load force/area of contact) decreases, and this is caused by an increase in the true area of contact (Rubenstein 1961). It is doubtful that the coefficient of friction would continue to increase under very wet conditions (as opposed to moist conditions, as used in this study) because then the coefficient of friction would be determined by complete lubrication. In this case, friction is determined solely by the viscous nature of water rather than by the frictional properties of the materials (Bowden and Tabor 1967).

A decrease in coefficient of friction was found with increasing pinch force, for all material-moisture combinations. This is consistent with the findings of Comaish and Bottoms (1971). Overall, this effect was small, accounting for only 7.7% of total experimental variation. In the present study, the coefficient of friction declined between by 0.002 and 0.01 per Newton increase in pinch force, depending on trial conditions. The effect was largest for the moist materials. The decrease in coefficient of friction per Newton increase in pinch force was between 158% and 326% greater for the moist material than for the same material dry.

The reason the magnitude of this effect was small is probably because the pinch (normal) forces used in this study were relatively large, from 9 to 55 N. While this covers most of the working range of the hand, Comaish and Bottoms (1971) found that normal force had the greatest effect on the coefficient of friction when normal forces below 3 N were used. They attributed these effects to the visco-elastic nature of skin which causes the true area of contact to be disproportionately large at low normal forces (Bowden and Tabor 1967). This would account for the larger effect found for the moist materials in the present study. Increasing the hydration of the skin and material would increase their viscous properties and decrease the elastic effects.

Paper had the lowest dry friction coefficient of all the materials tested. It increased significantly in the presence of moisture, but all the materials except aluminium had a significantly higher moist coefficient.

Not surprisingly, sandpaper had the highest dry coefficient of friction. This high value may not be totally from shear forces, rather, some normal forces may be transferred through the sides of the grains of sand, depending upon their size. The specific grit size (grade 320) used in this study was chosen in order to compare the results with those of previous investigators. In a related study, Westling and Johansson (1984) reported a coefficient of 1.21 for sandpaper (grade 320) and 0.68 for suede. These values are almost twice those found for the same dry materials in the present study: 0.66

and 0.39, respectively. It is possible they did not include the effect of both surfaces (subjects also used a two-fingered pulp pinch) in their calculations. Also, this result could be due to the very low grip forces used in their study. It is doubtful, however, that this latter factor could account for the magnitude of the differences.

The dry coefficient of friction for bare aluminium was not significantly different from that for adhesive tape, suede or paper. Under moist conditions, however, both adhesive tape and suede had a coefficient of friction similar to dry sandpaper. When moist, aluminium had a significantly lower coefficient of friction than sandpaper, vinyl rubber, adhesive tape or suede under the same conditions. This has implications for the choice of tool handle coverings. Because the palm is very rarely sweat free (Comaish and Bottoms 1971), a material with a high coefficient when moist is desirable as a surface material for tool handles, to reduce grip-force requirements. On the other hand, aluminium is probably a good choice when low friction is needed between the hand and an object.

While a high coefficient of friction is desirable to lower grip force requirements, a compromise must be reached to limit injuries from abrasion (Pheasant and O'Neill 1975). Sandpaper, even a very fine grade such as used in the present study, is too abrasive to be used to cover tool handles. When moist, suede and adhesive tape also had a high coefficient of friction. These materials are not likely to be as abrasive as sandpaper. Adhesive tape would be an easy way to increase the frictional properties of a bare metal tool handle. Tapes similar to cloth-based adhesive tape are available for this purpose and used by some workers in industrial applications.

The coefficients of friction for the smooth and textured vinyl were not significantly different. Thus, it cannot be assumed that the small surface ripples on the textured vinyl rubber used in this study will increase its frictional properties. Vinyl rubber has desirable properties when high friction is required. The dry coefficient of friction for vinyl rubber was the second highest of the materials tested. The coefficient for moist vinyl was not significantly different from the dry material. Sleeves made of vinyl rubber are commonly used to cover tool handles.

5. Summary

The presence of moisture resulted in an increase in the coefficient of friction for the porous materials in this study. A decrease in the friction coefficient was found with increasing pinch force. This effect was most pronounced for the moist materials. Overall, sandpaper had the highest dry coefficient, while paper had the lowest. Aluminium had a relatively low friction coefficient and would be desirable for situations where low hand friction is desired. Adhesive tape and suede had large frictional properties when moisture was present. These would be good handle materials for reducing grip-force requirements in workplaces where there is a lot of moisture, such as meat processing plants, or for operators whose hands sweat often. Vinyl rubber appears to have good characteristics when high friction is desired, in both dry and moist conditions.

Acknowledgement

This research was supported by the US National Aeronautics and Space Administration (NASA training grant number NGT-23-005-802 in conjunction with the NASA Center of Excellence in Man-Systems Research at the University of Michigan) and by gifts from private industry.

References

- ARMSTRONG, T. J., 1985, Mechanical considerations of skin in work. *American Journal of Industrial Medicine*, **8**, 463-472.
- BOWDEN, F. P., and TABOR, D., 1967, *Friction and Lubrication* (Methuen, London).
- COMAISH, S., and BOTTOMS, E., 1971, The skin and friction: deviations from Amonton's laws and the effects of hydration and lubrication. *British Journal of Dermatology*, **84**, 37-43.
- JACOBSON, C., and SPERLING, L., 1976, Classification of the hand-grip: a preliminary study. *Journal of Occupational Medicine*, **18**, 395-398.
- MOORE, D. F., 1972, *The Friction and Lubrication of Elastomers* (Pergamon, Oxford).
- PHEASANT, S., and O'NEILL, D., 1975, Performance in gripping and turning—a study in hand/handle effectiveness. *Applied Ergonomics*, **6**, 205-208.
- RUBENSTEIN, C., 1961, Lubrication of polymers. *Journal of Applied Physics*, **32**, 1445-1450.
- TAYLOR, M. M., and LEDERMAN, S. J., 1975, Tactile roughness of grooved surfaces: a model and the effect of friction. *Perception and Psychophysics*, **17**, 23-36.
- WESTLING, G., and JOHANSSON, R. S., 1984, Factors influencing the force control during precision grip. *Experimental Brain Research*, **53**, 277-284.

Manuscript received 12 May 1987.

Manuscript accepted 25 September 1987.

On a réalisé une étude pour déterminer les caractéristiques tribologiques de divers matériaux frottant contre la peau palmaire. Sept matériaux ont été testés sous deux niveaux de force de pince, en conditions humide et sèche. Les sujets devaient retenir en pince avec deux doigts un dynamomètre spécialement conçu, recouvert du matériau à tester. Ils devaient maintenir une force de pince constante durant l'accroissement à vitesse constante de la charge jusqu'à ce que le dynamomètre leur échappe des doigts. La charge atteinte à ce moment-là était ensuite utilisée pour calculer le coefficient de friction, à partir de la loi d'Amonton. Les effets des sujets, des matériaux, de la mouillure, de la force de pince, ainsi que les interactions, matériaux-mouillure et force de pince-mouillure, étaient tous significatifs. Le coefficient de friction diminuait en fonction des niveaux croissants de la force de pince pour chaque combinaison matériaux-mouillure. Le coefficient de friction pour les matériaux poreux a augmenté significativement dans la condition de mouillure. Ces résultats peuvent servir lors de la conception de manches d'outils ou des plates-formes de travail.

Zur Ermittlung der Reibung zwischen verschiedenen Materialien und der Haut der Hand wurde eine Studie durchgeführt. Sieben Materialien wurden bei zwei Greifkräften unter feuchten bzw. trockenen Bedingungen getestet. Die Versuchspersonen hielten im Zweifingergriff ein spezielles Dynamometer, welches mit einem der Testmaterialien versehen war. Sie behielten eine konstante Greifkraft bei, während das Gewicht mit konstanter Rate gesteigert wurde, bis das Dynamometer aus den Fingern glitt. Das Gewicht zum Zeitpunkt des Entgleitens wurde zur Berechnung des Reibungskoeffizienten nach Amonton verwendet. Die Auswirkungen von Versuchsperson, Material, Feuchtigkeit, Greifkraft und der Material-Feuchtigkeit, bzw. Greifkraft-Feuchtigkeit-Wechselwirkungen waren durchweg signifikant. Der Reibungskoeffizient nahm mit zunehmender Greifkraft für jede Material-Feuchtigkeitskombination ab. Der Reibungskoeffizient zeigte bei porösen Materialien eine signifikante Zunahme bei vorliegender Feuchtigkeit. Die Ergebnisse sind anwendbar bei der Gestaltung von Werkzeuggriffen und Arbeitsstations-Oberflächen.

手掌皮膚に対する種々の材料の摩擦特性を測定する研究を実施した。数種類の材料を湿潤と乾燥の両条件下で2レベルの挟み力を使用して試験した。被験者は試験材料の一つで被われた特別設計の力量計を指2本で挟んだ。被験者は力量計が指から滑って外れるまで負荷力が一定速度で増えるにつれて一定の挟み力を維持した。滑り時点での負荷力を使用してアモントン法則に従って摩擦係数を決定した。被験者、材料、水分、挟み力の影響、材料-水分相互作用、挟み力-水分相互作用はすべて有意であった。摩擦係数はどの材料-水分組合せでも挟み力のレベルが上がると下がった。多孔質材料の摩擦係数は水分があると大幅に増えた。この情報は工具取手とワークステーション表面の設計に適用可能に思える。