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RESEARCH NOTE

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Scopolamine increases prehensile force during object manipulation by reducing palmar sweating and decreasing skin friction

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Abstract The aim of this study was to determine whether relatively long-term changes in skin friction induced by a pharmacological blockade of sweat excretion would alter the grip forces applied to objects of a variety of different surface textures and frictions. Five men and three women were asked to lift the vertically mounted armature of a linear motor between the thumb and index finger and to hold it against an opposing force for 2 s. A 1.0-kHz tone indicated to the subject that the manipulandum had been correctly positioned between the upper and lower position limits. The linear motor generated a 2.5-N force tangential to the skin surface simulating an object weighing approximately 250 g. Three different polyamide plastic surfaces (either smooth or etched with 1.0 mm high Braille beads evenly spaced at 2- or 3-mm intervals) contacted the fingers in these experiments. Subjects lifted and held in a precision grip one of the three surfaces for blocks of ten consecutive trials, but the order of presentation of the three different textures was varied to offset the effect of expectancy. On a second block of ten trials the subjects were requested to release the object slowly to measure the ratio of the grip force normal to the grasped surface to the tangential load force at the moment of slip. This ratio or its inverse provided the coefficient of friction or the slip ratio for a particular subject and surface condition. Twelve hours prior to a second recording session all subjects placed transdermal patches of 1.5 mg scopolamine behind each ear to reduce palmar sweating by blocking the muscarinic receptors of exocrine sweat glands. The subjects were re-tested following procedures that were identical to the first session. Scopolamine significantly reduced the friction of the skin on the smooth and 2-mm beaded surfaces, but the friction of the 3-mm beaded texture was unaffected. Scopolamine also caused subjects to increase both the peak and static grip forces for all the textures including the 3-mm beaded surface, suggesting that for two of the three surfaces they were responding to the increased slipperiness of the skin due to reduced sweat production.

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Introduction

Although the importance of eccrine sweat secretion for controlling body temperature has been extensively researched (Sato 1977), the usefulness of sweating to increase the friction of the glabrous skin has received comparatively little attention. In the cat, Adams and Hunter (1969) established that sweat secretion increases the friction of the footpad by more than 50%, and in the raccoon Rassmusson and Turnbull (1986) found that wetting the glabrous skin produced large increases in the responsiveness of some slowly adapting mechanoreceptors.

Altering the friction of the skin has also been the subject of extensive study by the cosmetic industry, and these investigations have clearly demonstrated that moisture, and in particular sweat, can increase skin friction (Cussler et al. 1977; Highley et al. 1977; Wolfram 1983; Gerrard 1987; Buchholz et al. 1988). Gerrard (1987) found that water alone increased the friction of skin on smooth steel from 0.20 to 0.70. However, more importantly, friction against the skin has been shown to be a major determinant of the prehensile force needed in lifting and holding an object against the force of gravity (Johansson and Westling 1984a; Westling and Johansson 1984).

Johansson and Westling (1984b) also showed that washing and drying the hands caused a transient increase in the prehensile force used to handle a suede-covered object, presumably due to the removal of sweat from the skin. Skin friction decreased as an immediate consequence and was accompanied by an increase in grip force in order to prevent object slip. However, the extensive everyday experience of almost all individuals with the effects of hand washing raises the question of how much of this compensation was anticipated as opposed to feedback triggered during the manipulation of surfaces with unpredictable frictional properties. The present study sought to determine whether relatively long-term changes in the intrinsic properties of the skin produced by reducing sweat excretion would also stimulate compensatory grip force increases in object manipulation. An additional secondary objective was to test whether sweat reduction has the same effect over a range of different surface textures.

According to Sato (1977), the eccrine glands constitute the majority of glabrous skin sweat glands in the palm and fingers of the hand. Although it was initially believed that eccrine sweat glands were only supplied by cholinergic fibers, it has now been shown that some adrenergic innervation may also influence the sweating rate. Despite some disagreement among investigators, it is generally believed that about 90% of total sweat production is under cholinergic control (Shields et al. 1987). The present study was designed to examine whether reducing the natural rate of sweating by the administration of scopolamine, a muscarinic receptor antagonist, would decrease skin friction sufficiently to elicit compensatory increases in grip force during object manipulation.

Materials and methods

This study was approved by the ethics committee of the medical faculty of the Université de Montréal and all subjects were unpaid volunteers who provided written consent to participate in the study. In the initial phase of this experiment, three women and five men (ages 21–51 years) were asked to grip and lift the vertically mounted armature of a linear motor over a distance of 2.5 cm, and to maintain this object within a narrow position window for a 2-s interval. The armature generated a 2.5-N opposing force which simulated an object weighing approximately 250 g. However, when the linear motor was inactivated, the armature actually weighed 674 g and had an inherent static friction of 0.44 N. Although the armature was not servo-controlled and had a significantly greater inertia than a 250 g weight, this was not thought to have influenced the grip forces greatly at the low rates of acceleration used by our subjects. The inherent friction of the armature was minimized by low-friction roller bearings, and the kinetic friction was probably not significantly less than the static friction and undoubtedly contributed some resistance which would have added to the force required to lift the object.

During lifting, the elbow and forearm rested on foam supports arranged to maximize the subject's comfort. The subjects were asked to use a key-pinch grip with the thumb and index finger of the preferred hand to grasp two identical circular disks atached to the motor armature and to lift the disks to a height of 2.5 ± 1.0 cm. An illustration of this apparatus has been published previously by Cadoret and Smith (1996). The correct position window was indicated to the subjects by both an amber light and a 1.0-kHz pure tone. The armature carrying the gripping disks was equipped with a position transducer, accurate to 0.1 mm, and two pre-calibrated load cells, one used to measure the horizontal grip force and the other to measure the vertical lifting force. The grip force was the sum of forces generated by the thumb and index finger together, which in this key-pinch grip is mostly generated by the combined activity of the first dorsal interosseous and adductor pollicis muscles. The voltages corresponding to the applied forces were digitized at 250 Hz and stored by a laboratory computer. The test surfaces in contact with the fingers were fitted with identical pairs of polyamide plastic surfaces. These plastic surfaces were either smooth or etched with Braille beads 1.0 mm high and evenly spaced at either 2.0- or 3.0-mm intervals measured from apex to apex.

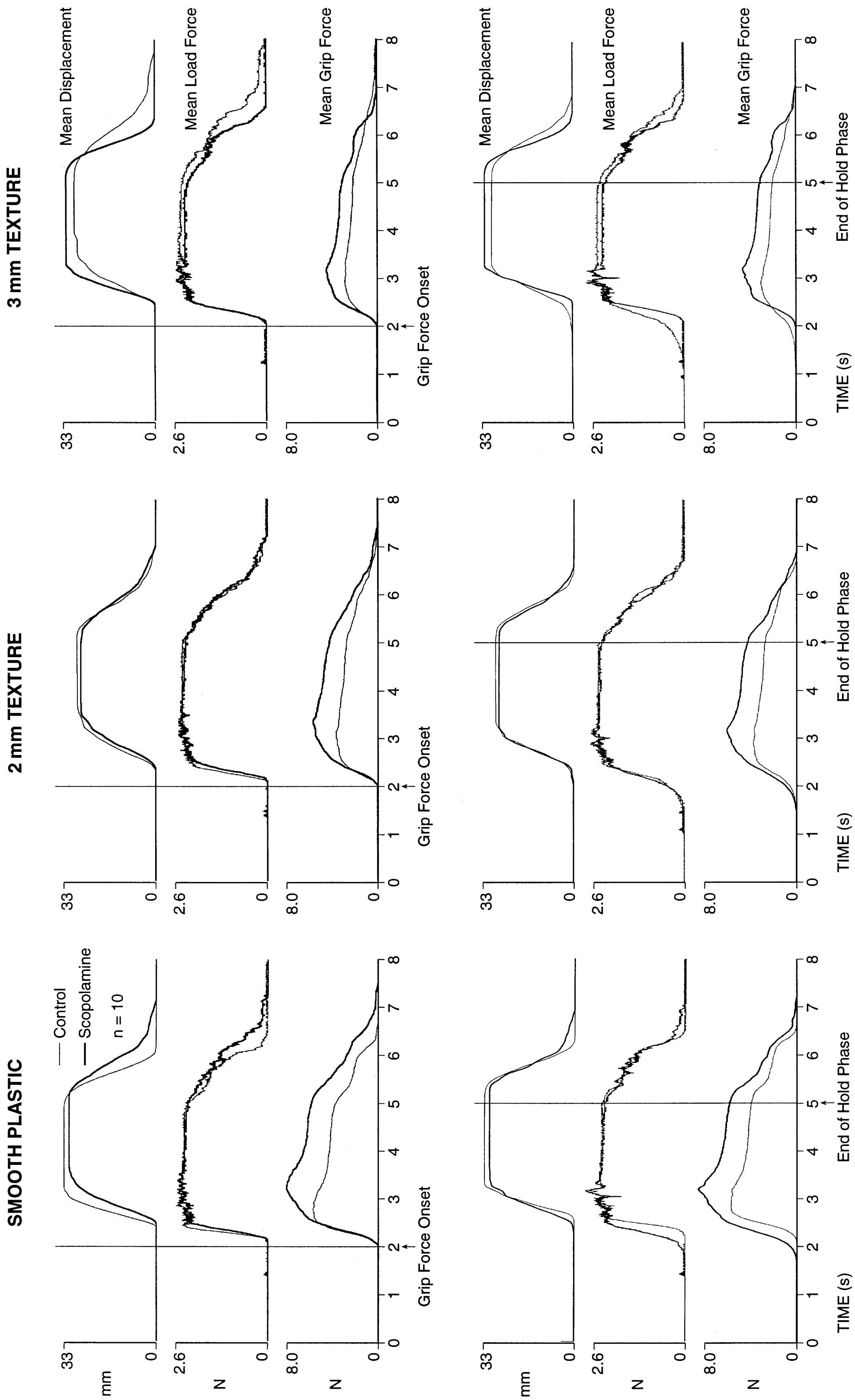
Subjects were asked to wash and dry their hands 15 min before starting the experiment. Adhesive surface electrodes to measure skin electrical conductance were placed on the palm of the non-working hand to estimate the sweat rate from electrical conductance (Thomas and Kawahata 1962; Yamamoto 1994). Ambient room temperature was maintained between 22 and 26°C with the relative humidity between 45% and 60%. All three textures were presented in blocks of ten trials and the textures were presented in varied order to offset the effect of expectancy. On separate blocks of ten trials the subjects were requested to release the test object slowly to determine the point at which the object slipped from the grip. The slip point was defined as the first detectable downward change in position even if the object's fall was subsequently arrested – as frequently occurred with the textured surfaces, which tended to stick and slip. The ratio of the tangential force generated by the motor to the grip force applied by the subject (i.e. normal to the object surface) at the point the object slipped from the fingers provided the coefficient of friction. Some practice was needed to enable subjects to release the object gradually.

Prior to the second test session, which was usually the following day, all subjects were requested to place transdermal patches of 1.5 mg scopolamine (Transderm V, Ciba-Geigy) behind each ear either before retiring for the night or 12 h prior to testing. This muscarinic cholinergic antagonist, generally prescribed for motion sickness, also blocks activity in exocrine glands (Brown 1993). Although some adrenergic sweating would have persisted, it was felt that scopolamine would eliminate the more significant cholinergic component. The second testing followed the same procedure as in the first.

Results

The grip and load forces and position traces were averaged for each subject over the ten trials and these parameters were compared before and after scopolamine administration for each of the three contact surfaces. Figure 1 shows the averaged traces from a single subject lifting the same resistive force with three different surface textures aligned on both grip onset and the signal indicating completion of the 2.0-s static holding. Typically, the grip forces measured during lifting and holding showed a peak at or near the end of the lifting phase and then declined to a slowly decaying value associated with stationary holding. In the traces aligned on grip onset in the upper part of Fig. 1, clear differences can be seen in the force peaks and rate of grip force application during the dynamic phase for each of the three textures. Alternatively the same traces aligned on the end of the steady holding phase in the lower portion of Fig. 1 more accu-

Fig. 1 A comparison of ten-trial averages of the grip and load force profiles and displacement traces for a single subject with and without scopolamine for three different surface textures. The traces in the *upper part* of the figure are aligned on grip force onset, whereas in the *lower part* the same traces are aligned on the end of the steady holding phase. For this particular subject the mean slip force for the smooth surface was 1.36 N under the control condition and 2.10 N with scopolamine. For the 2-mm surface the mean slip force was 1.37 N for the control condition and 1.65 N with scopolamine. For the 3-mm surface the mean slip force was 1.05 N for the control condition and 1.25 N with scopolamine ▶



SMOOTH PLASTIC
2 mm TEXTURE
3 mm TEXTURE
Control
Scopolamine
n = 10
Mean Displacement
Mean Load Force
Mean Grip Force
mm
N
33
0
2.6
8.0
Grip Force Onset
End of Hold Phase
TIME (s)
0
1
2
3
4
5
6
7
8

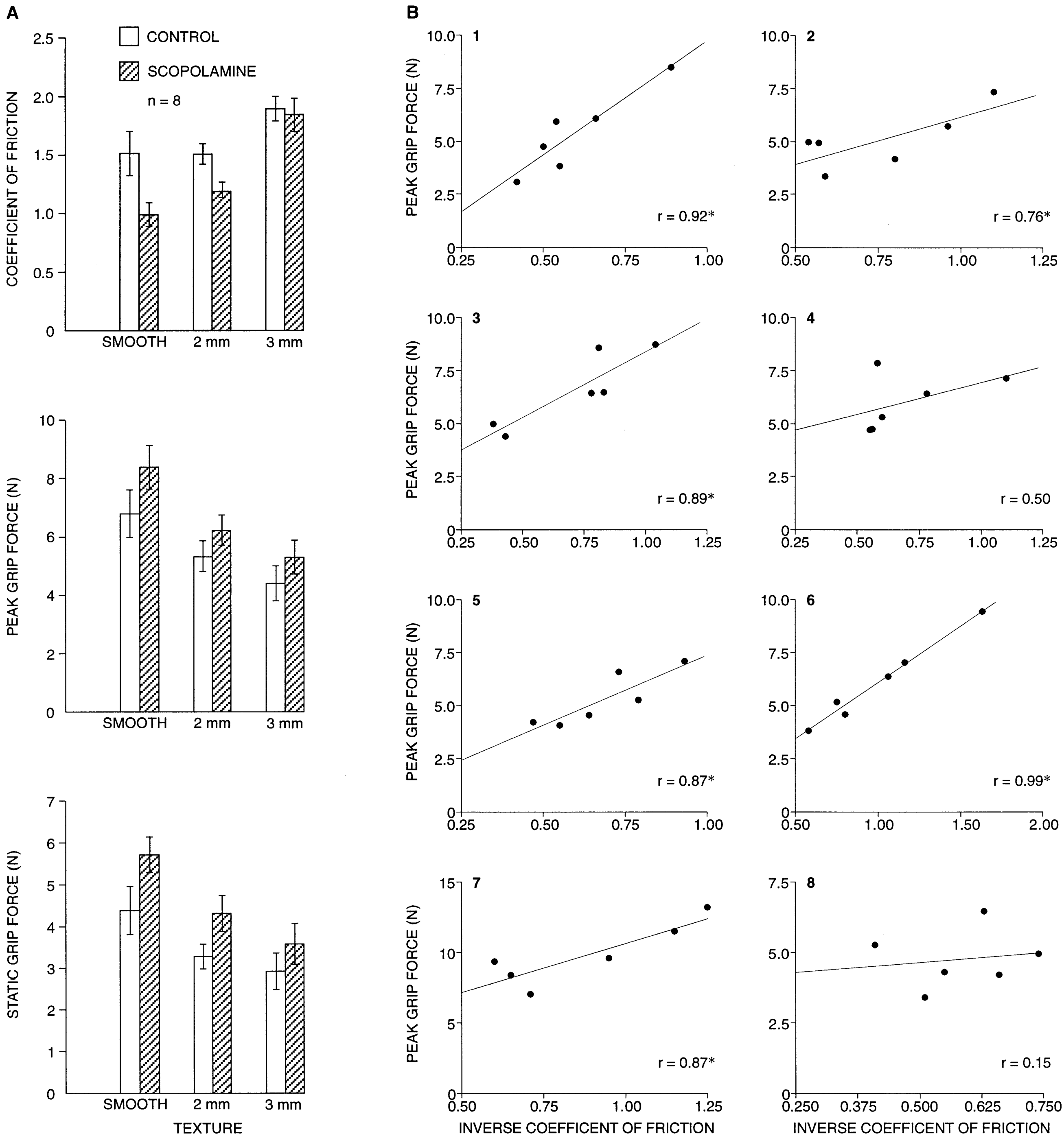


Fig. 2 **A** *Top*: Average coefficients of friction for three surfaces with and without scopolamine. Only the smooth and 2-mm surfaces were significantly different. *Middle* and *bottom*: Differences in peak grip force during lifting and static holding forces with and without scopolamine. Significant differences between the scopolamine and control conditions were only observed for the smooth and 2-mm beaded surfaces. **B** Individual correlations between peak grip force and the three textures with and without scopolamine for all eight subjects

rately illustrate the differences in static grip force measured over the 500 ms preceding object release. The mean peak grip forces were compared with and without scopolamine. The static grip force was measured over the last 500 ms of the static phase and then averaged again over the ten trials. For the subject shown in Fig. 1, the scopolamine increased both the peak grip force as well as the mean static grip force used to hold the object stationary for all three surfaces. The rate of change in the grip force appears to have been identical in the two conditions for all three surfaces. Since the final grip force was higher after scopolamine one might have expected the grip force rate to be greater as well.

The electrical resistance of the skin provided an independent measure of the reduction in palmar sweating. Although the absolute skin resistance varied widely between subjects, a paired *t*-test comparing skin resistance before and after scopolamine administration indicated a small but statistically significant increase (t 2.468, df 7, $P < 0.05$) within 1 min of electrode placement on the skin. This observation confirms the well-known inhibition of eccrine glands, including sweat glands, by scopolamine.

For each subject, the peak grip force during lifting and the mean holding force measured over the 500 ms prior to the release were averaged and subjected to statistical analysis. The upper part of Fig. 2A shows the average coefficient of friction for the three surfaces for all subjects calculated from the ten lift-and-release trials before and after scopolamine. The middle histogram of Fig. 2A illustrates the ten-trial mean peak grip force for all subjects gripping each of the three surface textures under normal conditions and after scopolamine administration. A two-way analysis of variance indicated that the scopolamine significantly ($P < 0.001$) increased the mean peak grip force. A separate two-way analysis of variance on the mean static grip force, shown in the bottom portion of Fig. 2A, indicated a similar increase in the holding force due to scopolamine. The same analyses of variance showed a significant effect of surface texture ($P < 0.03$) as well as a significant interaction between surface texture and the scopolamine treatment ($P < 0.001$). Paradoxically, for the 3-mm beaded surface, scopolamine increased the grip force without producing a measurable change in skin friction (Fig. 2A).

Separate correlation coefficients were calculated in order to demonstrate the relationship between friction and peak grip force for each subject individually in order to avoid the spurious effect of pooling data across subjects. That is, the analysis consisted of calculating the correlation coefficient between the mean peak dynamic force averaged over ten trials and the inverse or reciprocal coefficient of friction, sometimes called the slip ratio, for the six conditions (three surface textures, with and without scopolamine) for each of the eight subjects (shown in Fig. 2B). The slip ratio was used instead of the coefficient of friction to linearize the relationship between friction and grip force. These correlations were statistically significant ($P < 0.05$) for six of the eight subjects and ranged from 0.15 (not significant) to 0.99 with a mean value of 0.75 averaged from the individual subject values. Whereas for one subject the relationship between grip force and surface friction just failed to achieve statistical significance (r 0.50, $P > 0.05$), no relationship whatsoever was found in the other subject (r 0.15). The correlations between the mean static grip force measured over the 500 ms prior to object release and the mean inverse coefficients of friction ranged from 0.14 to 0.94 and were statistically significant for the same six subjects. Both sets of correlations are slightly lower than those found in a previous study by Cadoret and Smith (1996), probably because a narrower range of friction was used in the current study.

Discussion

The results indicated that reducing the spontaneous sweat gland activity of the hand by the transdermal absorption of the muscarinic antagonist scopolamine, significantly decreased the friction of the fingers against a smooth plastic surface and one of two beaded textures. Despite wide individual differences, the galvanic skin resistance provided an independent measure of palmar sweating and indicated that scopolamine was effective in reducing sweat excretion. The reduced friction for two of three surfaces was accompanied by a compensatory increase in the grip force needed to lift and hold the object against an opposing force. Although one subject showed no relationship between grip force and friction, this particular subject had the smallest change in skin-surface friction with the scopolamine. In general, these results add further support to the suggestion that skin mechanoreceptors can signal both increases and decreases in the friction due to changes in skin moisture and trigger appropriate grip force adjustments (Johansson and Westling 1984; Cadoret and Smith 1996).

Admittedly the testing order was not varied in this study, leaving open the possibility that a practice effect may have influenced the grip force adaptations. Predictable loads and repeated visual cues are known to contribute to anticipatory programming of grasping and lifting (Johansson and Westling 1988; Gordon et al. 1991). However, practice by itself without changes in friction would be most likely to decrease the grip force in an economy of effort which would have countered the effect of scopolamine reported here.

Although it is perhaps more commonly believed that sweat or moisture *reduces* the coefficient of friction of the skin on grasped objects, this is not supported by the results of either this or previous investigations. For textures which have very small surface areas in contact with the skin, or where there is sufficient moisture to form a lubricating boundary layer between the skin and the surface, the coefficient of friction will be reduced (Comaish and Bottoms 1971; Highley et al. 1977; Nacht et al. 1981). However, most studies of moisture on the skin indicate that hydration of the cells of the stratum corneum substantially increases skin adhesiveness to most surfaces (Cussler et al. 1977; Highley et al 1977; Wolfram 1983; Gerrard 1987; Buchholz et al. 1988). The data from the present study suggest that, in general, subjects are able to detect and compensate for losses in skin friction due to changes in the intrinsic mechanical properties of the skin itself. This observation may nevertheless only be valid for surfaces having low to moderate friction against the skin and may not apply to surfaces such as the 3-mm beaded texture with higher coefficients of friction.

The failure to find a significant reduction in the friction for the 3-mm beaded surface with reduced palmar sweating (Fig. 2A) was not entirely surprising, although the increased grip force with scopolamine was unexpected. Cadoret and Smith, (1996) had demonstrated that simply adding enough moisture to the skin was sufficient to abolish the differences in friction between the smooth and the 3-mm beaded surfaces (see their Fig. 2A). However, despite the absence of any significant change in the measured friction, the subjects paradoxically responded to the effect of scopolamine by increasing the dynamic and static grip forces on the 3-mm surface (Fig. 2A). It appears that although sweat reduction might explain the grip force changes for the smooth and 2-mm surfaces, it cannot explain the increased force on the 3-mm beaded surface. Moreover, so far as we are aware, scopolamine has no direct effect on cutaneous mechanoreceptors and its effect on tactile sensation is thought to be exclusively through the perception of friction.

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