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Skin friction coefficient: changes induced by skin hydration and emollient application and correlation with perceived skin feel

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Synopsis

Greasiness, one of the parameters assessed by tactile impression or "feel" of the skin surface after use of an emollient, is correlated to instrumental measurement of SKIN FRICTION. In collaboration with sensory panels, we demonstrate that the changes in skin friction coefficient immediately after product use are inversely proportional to the subjective after-feel of "greasiness"; that is, the higher the increase in skin friction coefficient, the less greasy the product is perceived as being. The skin friction coefficient increases over baseline with SKIN HYDRATION, and a series of measurements of the coefficient with time reveals the duration of effect from the use of different MOISTURIZERS. For example, a "greasy" occlusive agent (petrolatum) produces an immediate decrease in skin friction, in agreement with its "slippery" properties; this is followed (1-3 hours) by an increase in friction coefficient, which indicates an increase in skin hydration.

INTRODUCTION

The frictional character of human skin *in vivo* can be assessed by determining the coefficient of sliding skin friction, or the "drag" experienced when a surface slides across the skin (1).

Measurements of skin surface friction, easily made with a portable friction meter (2), can reflect certain cosmetically induced changes (3,4). For example, the coefficient of friction increases with hydration of the stratum corneum (1,3,5-7), thus reflecting moisturization of the skin.

Materials which function as surface lubricants, in contrast, lower skin friction (1,3,6); a decrease in the coefficient of friction thereby indicates slipperiness, which usually is perceived by the consumer as "greasiness."

A combination effect can take place with the use of a "greasy" occlusive agent such as petrolatum. Initially, the coefficient of friction decreases due to the lubricant properties of the petrolatum, while later on the coefficient increases over baseline as a consequence of the increased skin moisturization induced by the occlusion.

Consumers usually rate "greasiness" as a negative attribute in emollient or cosmetic products. The perception of greasiness traditionally has been measured by sensory evaluation techniques. In this paper we describe the use of a portable friction meter to assess, quantitatively and *in vivo,* the changes in the friction coefficient of the skin following product use. We further demonstrate that these changes are inversely proportional to the subjective after-feel of greasiness, as determined in sensory panel studies.

Finally, we confirm that the skin coefficient of friction changes with the state of hydration of the skin; therefore, these measurements can be used to determine the duration of skin hydration following product application.

Because of its simplicity, objectivity, and time-saving features, this methodology is especially suited to the screening of large numbers of prototype formulations when the important after-feel perception of greasiness is of primary concern.

EXPERIMENTAL

METHODS AND MATERIALS

The coefficient of skin surface friction was measured with the Newcastle Friction Meter (Figure 1). This is a portable, hand-held instrument designed by Comaish, et al. (2) and consists of a spring-loaded Teflon® wheel driven by a battery-powered precision motor which develops high torque at low speed. The frictional resistance to rotation induced by the surface against which the wheel is pressed is registered on a meter directly calibrated to measure the friction coefficient. [Full specifications for this instrument have been published by the designers (2).]

The friction meter is so designed that the pressure against the skin (skin head loading) and the speed of the wheel rotating against the skin surface remain constant under all conditions of use. Hence, measurements of skin friction made at each test site on the subject's skin are reproducible.

The effects of different raw materials and products on the skin friction coefficient were compared by measuring the changes in treated vs. non-treated (control) sites as a function of time after treatment. Baseline measurements of the treated sites on the subjects' volar forearms were made before product application. Then the subjects applied *ad lib* small amounts of the test material (about 2 mg/cm^2 of skin) to each designated test site and spread it uniformly over the skin.

The distribution of treatments and treated sites was randomized for all subjects to avoid potential bias due to site variation. Water and a no treatment site were always used as controls. The skin friction coefficient was measured in triplicate at each site, immediately and then at various times after product application. The temperature in the room in which the tests were made was kept between 65–79°F and the relative humidity was recorded with a HUMI-CHEK® (Beckman Instruments, Cedar Grove, NJ 07009) electronic humidity indicator. No tests were performed if the humidity was below 15% or above 40%.

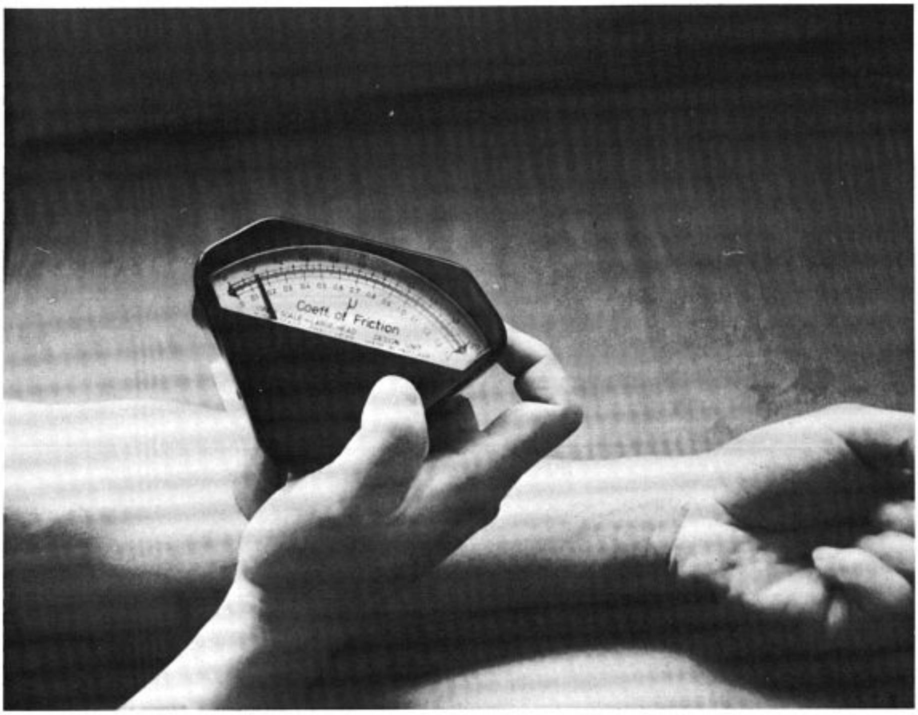

Figure 1. Newcastle friction meter being applied to the volar forearm.

SENSORY EVALUATION

All samples were evaluated on a blind basis by a group of trained judges (sensory panel) who routinely grade attributes of various topical products several times weekly. Perceived greasiness associated with the application of each product or sample was measured on a 6-point interval scale, from "not at all greasy" to "very greasy," after randomized applications of samples to the inside of the left or right volar forearm. The associated attributes of stickiness/tackiness and skin penetration (absorption) were also graded (Table I). Additionally, overall preference was elicited. Applications were randomized to eliminate test bias and standardized in the following manner: Equal amounts (0.2 cm^3) of each product were applied. Subjects applied products using the middle and index fingers of the appropriate hand to rub in a circular motion twenty (20) times. After cleansing their fingertips with facial tissue, subjects evaluated their tactile perceptions monadically (one sample at a time) by gently tapping and stroking the treated surface with their fingertips.

RESULTS AND DISCUSSION

SENSORY EVALUATION WITH LUBRICANT COSMETIC INGREDIENTS

Table II shows the mean scores obtained in blinded evaluation of petrolatum, heavy mineral oil, and glycerin (water served as a positive control). All of these commonly utilized cosmetic raw materials generated high greasiness scores. In comparison,

Table I
Rating Scales for Sensory Evaluations

	Greasiness	Stickiness/ Tackiness	Skin Penetration
0	Not at all greasy	Not at all sticky or tacky	Product disappears not at all
1	Very slightly greasy	Very slightly sticky or tacky	Product disappears very slowly
2	Slightly greasy	Slightly sticky or tacky	Disappears somewhat slowly
3	Moderately greasy	Moderately sticky or tacky	Disappears somewhat quickly
4	Considerably greasy	Considerably sticky or tacky	Disappears moderately quickly
5	Very greasy	Very sticky or tacky	Disappears very quickly

distilled water received a score of almost zero (0.05). Petrolatum was graded at the extreme high end of the greasiness scale, while glycerin and heavy mineral oil were designated one and two intervals lower, respectively. These materials also imparted a degree of tackiness which paralleled in general the feeling of greasiness. On the other hand, the sensory assessments of the rate of disappearance showed no correlation with the other two parameters evaluated.

SENSORY EVALUATION WITH COMMERCIAL MOISTURIZERS

Table III displays the mean scores obtained in the attribute ratings of six commercial moisturizers. Moisturizer A was perceived as being somewhat less greasy than C and significantly less greasy than moisturizers E and F. Also, A was perceived as being less tacky to the touch than E and disappearing more quickly than E and F. Moisturizer A was perceived as disappearing more quickly than C, while both were equally tacky to the touch. Also, moisturizer A was rated equal to B for greasiness and tackiness, but it disappeared significantly more quickly.

Moisturizer B was found to be significantly less greasy, less tacky, and it disappeared more quickly than product D.

The evaluations of greasiness by the sensory panel were, in general, very consistent. In the two instances in which moisturizer B was assessed, it was rated with essentially the same score (1.0 and 1.2). When moisturizer A was tested repeatedly, almost identical scores (0.7–0.8) were obtained in three out of the four cells. However, in the fourth test

Table II
Attribute Ratings of Some Lubricant Cosmetic Ingredients[1]

Sensory Attributes	Petrolatum	Glycerin	Heavy Mineral Oil	Distilled Water
Disappears	0.4	2.1	2.2	1.5
Skin feels sticky/tacky	3.5	2.5	1.2	0.8
Skin feels greasy	4.9	3.9	3.0	0.05

[1]Mean values of 20 subjects

Table III
Attribute Rating of Moisturizing Formulations[1]

Sensory Attribute	A vs B		A vs C		A vs E		A vs F		B vs D	
Product disappears[2]	2.8[4]	1.9	3.2[4]	2.2	3.0[4]	2.3	2.2[4]	1.5	3.2	2.7
Skin feels tacky/sticky[3]	1.1	1.1	1.4	1.4	1.5	2.0	2.1	2.2	1.1[4]	2.0
Skin feels greasy[3]	0.8	1.0	0.7[4]	1.3	0.8[4]	2.9	1.8[4]	4.2	1.2[4]	2.8
Overall preference	10/20	10/20	10/20	9/20	14/20	5/20	18/20	2/20	16/20	4/20

[1] Mean values of 20 subjects

[2] Rating scale:
0—not at all
1—very slowly
2—somewhat slowly
3—somewhat quickly
4—moderately quickly
5—very quickly

[3] Rating scale:
0—not at all
1—very slight
2—slight
3—moderate
4—considerable
4—very much so

[4] $p \leq .05$

(A vs. F), a rather different value (1.8) was assigned to A. The other product in this cell, F, received a very high score of 4.2 ("Considerable" to "Very much so"). It is possible that the high level of greasiness perceived for F, distorted the rating of A, bringing it up from "very slight" to the "slight" level.

Preference data elicited as part of the above evaluations, and also included in Table III, suggest that, in this type of products the perceived greasiness of a product affects its preference. When two products are given similar greasiness scores (as in the first two cells), overall preference scores are distributed evenly. But as the magnitude of the difference in greasiness scores grows, preference for the less greasy product becomes more pronounced.

EFFECTS OF WATER APPLICATION ON SKIN FRICTION

The effects of water on skin surface friction were measured as a function of time after application. Results (Figure 2) are expressed as percent change over baseline values. In all the subjects tested, there was a sharp increase in the coefficient of friction immediately after water application. However, this effect was short-lived and the skin returned to its baseline state within 10 min.

This immediate, pronounced increase in friction coefficient upon skin hydration has been observed by other investigators (1,3,5–7). Highley *et al.* (7) observed two frictional peaks after water application, and proposed that the initial increase in friction reflects the surface tension of the water layer interposed between the surface of the wheel and the skin, while the second peak, which occurs 10 min later, reflects an increase in the adhesiveness of the stratum corneum brought about by hydration of the surface cell layers. In our studies, we observed only one frictional increase following water application. We used approximately 2 mg of water per cm^2 of skin, while Highley *et al.* applied almost 8 mg/cm^2. It seems likely that, due to the smaller dosage employed in this study, there was not enough liquid to form a continuous layer between the wheel of the instrument and the skin and, therefore, we could not detect the effects of the surface tension of the liquid. Instead, we measured directly changes in coefficient of friction that possibly reflect the increased adhesiveness induced by rapidly hydrating the stratum corneum.

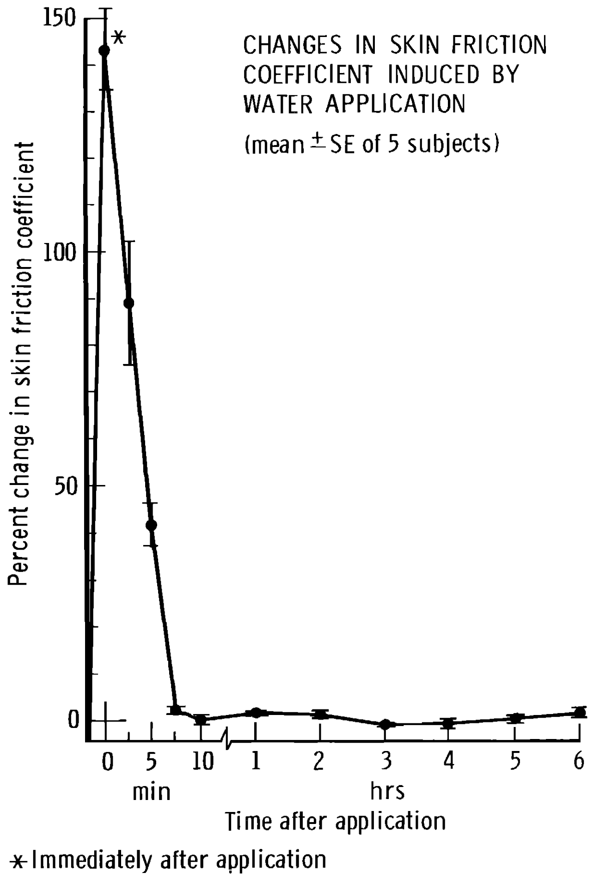

Figure 2. Changes in skin friction coefficient induced by water. Amount applied: approx. 2 mg/cm^2. Each point is the Mean ± SE of five subjects measured in triplicate.

This surface phenomenon can also be explained by other changes in the physical-chemical state of the stratum corneum. The water absorbed by the stratum corneum can increase the size and surface characteristics of its cells. This could bring about an increase in the contact area between the probe and the skin cells and lead to an increase in friction coefficient. As water is lost through evaporation, the stratum corneum returns to its original state and this is associated with a return of the friction coefficient to baseline value.

EFFECT OF VISCOUS LUBRICANTS ON SKIN SURFACE FRICTION

Viscous lubricants such as petrolatum, heavy mineral oil, and glycerin may hydrate the skin surface by reducing the rate of transepidermal moisture loss; this brings about a subsequent increase in friction coefficient induced by the slow and prolonged hydrating effect. However, the initial lubricating effects of the materials would be expected to result in a reduction in friction. Accordingly, when petrolatum, heavy mineral oil, and glycerin were tested, they decreased the friction coefficient immedi-

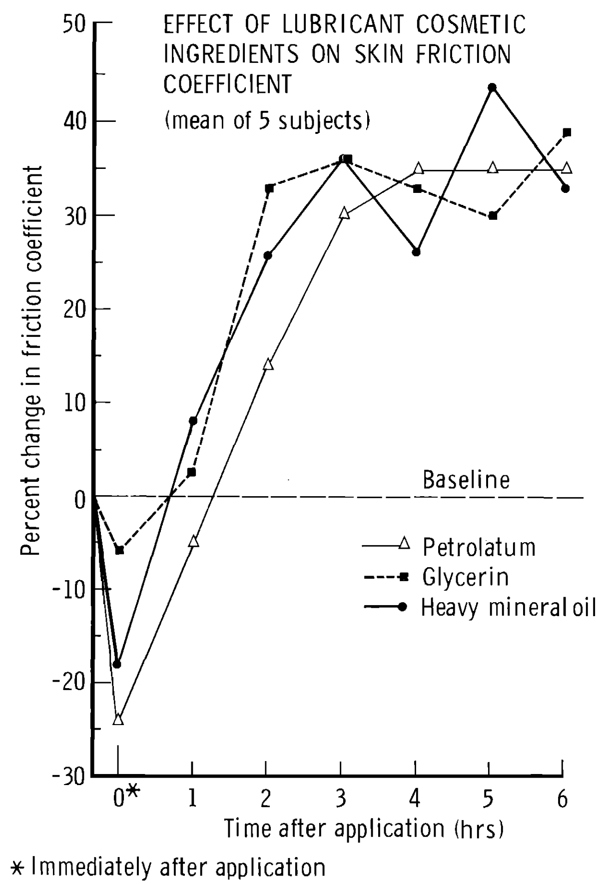

Figure 3. Effect of lubricant cosmetic ingredients on skin friction coefficient. Amount applied of each material: approx. 2 mg/cm^2. Each point is the mean of five subjects measured in triplicate.

ately after application (Figure 3). As the materials were absorbed into the skin surface layers and the hydrating effects overcame the diminishing lubricating effect, a gradual increase in friction coefficient was observed.

EFFECTS OF MOISTURIZING FORMULATIONS AND SURFACE LUBRICANTS ON SKIN FRICTION

We then compared the changes in friction coefficient induced by different products, immediately after application and for six hours thereafter, with the perceived sensory skin feel. The changes in skin friction coefficient induced by the six moisturizing formulations tested can be grouped into three main categories (Figure 4). Products A, B, and C, which were perceived by the sensory panel as essentially nongreasy, induced similarly high increases in friction coefficient immediately after application, reflecting a prompt hydration effect (Figure 4-a). These increases were the highest among the six products tested and, although somewhat lower than those induced by water, they were significantly longer lasting. The effect of water treatment lasted only 10 to 15 min, while those observed with products A, B, and C persisted for the six hours of the

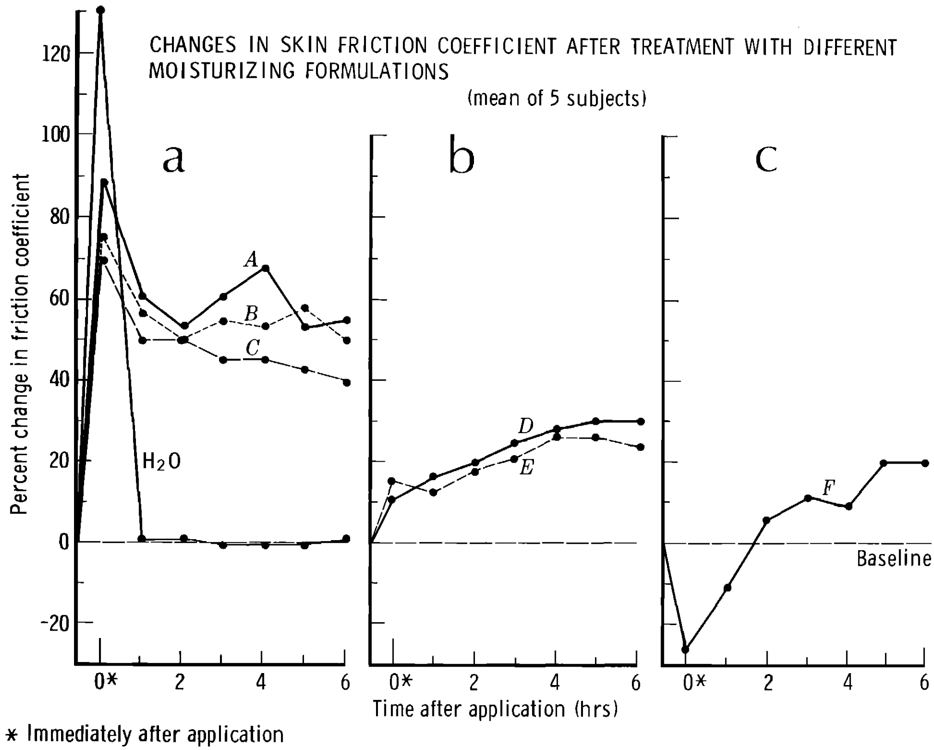

Figure 4. Changes in skin friction coefficient after treatment with different moisturizing formulations. A, B, C, D, E, and F are six commercial moisturizing products. Amount applied of each product: approx. 2 mg/cm^2. Each point is the mean of five subjects measured in triplicate.

duration of the test, indicating the prolonged hydration induced by the products. The large increases in friction coefficient observed with these products indicate that the skin surface can generate an appreciable drag; thus, it will be non-slippery and the product will be perceived as non-greasy. These conclusions are well substantiated by the results from the sensory evaluation.

Products D and E, which were perceived by the sensory panel as moderately greasy, resulted in a second type of instrumental response (Figure 4-b). They induced a moderate increase in friction coefficient immediately after product application and this increase continued for the six hour period tested.

This moderate increase in skin friction early after product application can be interpreted as the composite effect of an immediate hydration produced by the aqueous vehicle and some degree of slipperiness, related to the nature of the residue, which possibly produces some occlusive effects. As the occluded skin surface becomes more hydrated, this process overcomes the lubricant effect of the treatment and a steady increase in friction coefficient is observed.

Product F was perceived in sensory evaluation as considerably greasy and it exemplifies a last type of products which induce an immediate *decrease* in friction coefficient due to the slipperiness (or greasiness) of the product (Figure 4-c). The subsequent steady increase in friction coefficient reflects the slow hydrating effects of a product which acts mainly by occlusion.

Thus, we found that, following the application of an emollient formulation, frequent measurements of the skin friction coefficient for a protracted period of time can provide an insight into the mechanism and duration of the formulation's moisturizing action.

CORRELATION BETWEEN SENSORY EVALUATION AND SKIN FRICTION

Lubricant raw materials such as petrolatum, heavy mineral oil, and glycerin, which were perceived as greasy in sensory evaluation, induced a substantial initial decrease in friction coefficient, thus supporting the correlation between skin friction and subjective afterfeel of greasiness.

On the three sensory attributes evaluated on the various commercial moisturizers and

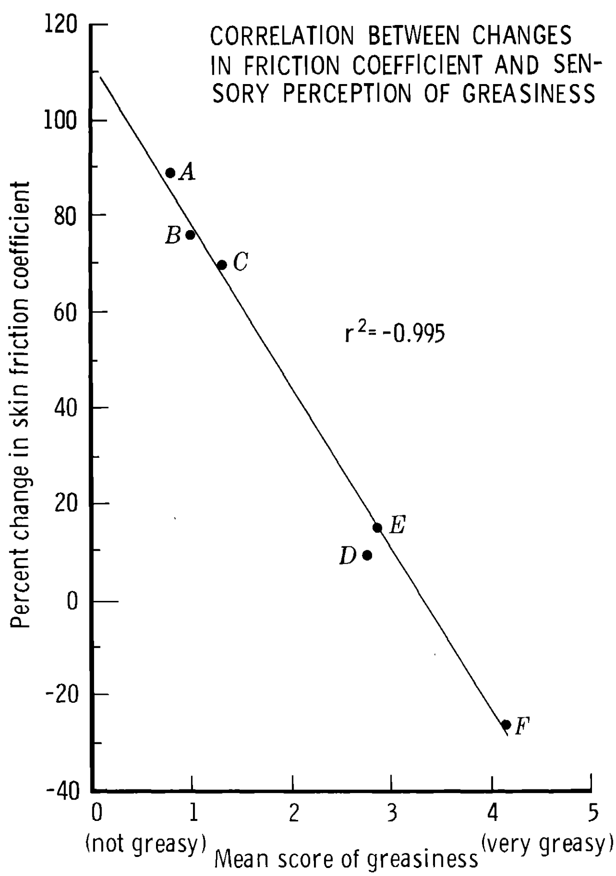

Figure 5. Correlation between changes in friction coefficient and sensory perception of greasiness. A, B, C, D, E, and F are the same commercial products used in Fig. 4. The % change in skin friction coefficient is that observed immediately after application, while greasiness scores are taken from Table 3. r^2 is the correlation coefficient obtained by regression analysis and the line is the best fit.

surface lubricant cosmetic ingredients, only "greasiness" was found to correlate well with the immediate changes measured in skin friction coefficient, with a correlation coefficient of −0.995 (Figure 5). It is clear that the initial increase in skin friction coefficient is inversely proportional to the sensory perception of greasiness; i.e., the higher the skin friction measured, the lower the greasiness rating obtained by tactile perception.

Although the other sensory attributes evaluated (tackiness/stickiness and rate of product disappearance) did not correlate well with skin friction measurements, the sensory attributes measured do appear to interact with each other. For example, in general, the quicker that a product disappears, the less tacky and the less greasy it is perceived as being. But foremost, an overall preference is observed for those products which are perceived as less greasy.

SUMMARY

Changes in skin surface friction observed immediately after the use of different products, are inversely related to their perceived greasiness. Further, friction measurements made over an extended period of time (up to 6 hours) permit the assessment of the duration of hydration effects. Thus, measurement of friction coefficient can facilitate the screening of a large number of prototype formulations for the afterfeel attribute of greasiness, and for their moisturizing properties. Such measurement further permits the classification of emollient moisturizers into different categories according to their sensory and functional attributes. Some moisturizing products are perceived as non-greasy and, like water, increase friction coefficient immediately after application, but their hydration effects persist for a longer period of time. Other moisturizers are perceived as slightly or moderately greasy; they induce a small or moderate increase in friction coefficient immediately after application, and this increase continues for a period of time thereafter because of their sustained hydrating effects. Finally, viscous lubricating emollients like petrolatum, heavy mineral oil, and glycerin can have a composite effect: they reduce the skin friction coefficient when applied, while eventually resulting in a delayed increase in friction due to the slow hydration induced by their potentially occlusive properties.

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