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Effect of hydration on the tactile and thermal sensitivity of the lip

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HIGHLIGHTS

- Hydration of the lip increases its sensitivity to light touch.
- Hydration of the lip does not alter its sensitivity to spatial stimuli.
- Changes in lip mechanics are proposed to underlie any hydration-related changes in lip sensitivity.

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ABSTRACT

The vermilion lip is a body site particularly susceptible to water loss. Therefore, the role of hydration in tactile perception at the lip was investigated. A series of measures of tactile performance and response were obtained from 22 female subjects, namely: (1) the subjective assessment of lip feel, (2) tactile sensitivity, (3) spatial acuity, (4) thermal sensitivity, and (5) the subjective assessment of thermal stimulation. These measures were obtained from lips in their natural (untreated) state, and lips that had been treated using a hydrating preparation. The preparation altered the subjective feel of the lips consistent with the treatment increasing lip hydration and compliance. Hydrated lips showed greater sensitivity to light touch, and there was a trend toward the lip's thermal sensitivity being altered consistent with the lip treatment having a physical cooling effect. Spatial acuity was unaltered by the state of lip hydration. The sensitivity changes on hydration were proposed to have mechanical basis.

1. Introduction

Of the many aspects of skin mechanics, one that is commonly altered in daily life is the state of hydration of the stratum corneum [1,2], which is thought to affect both thermal [3] and tactile sensations. Green has suggested that the oral tissues are more thermally sensitive, in part, due to their special state of hydration, conferring greater thermal conductivity than that observed on less well hydrated tissues. In contrast, other investigators have suggested that increasing hydration may decrease thermal sensitivity by increasing a property referred to as 'thermal inertia' [4].

Similar to thermal sensitivity, the existing literature does not provide a clear account as to whether hydration increases or decreases tactile sensitivity. In the earliest literature, Grossman [5] reported, based on his extensive experience studying orofacial tissues, that normally hydrated oral muscosa seemed to be more sensitive to touch than dried mucosa. However, experimental evidence suggested the opposite was true of extrafacial skin sites [6]. For example, Weinstein showed that a petrolatum barrier, presumably hydrating the skin, decreased sensitivity to light touch on the volar forearm.

More recent research has failed to resolve the uncertain effect of hydration on tactile sensitivity: Lévêque et al. [7] showed that hydrating dry cheek and forearm skin in aged individuals increased spatial acuity at those sites, a finding which the authors explained on the basis of mechanical differences in well-hydrated versus relatively dehydrated skin. In particular, well-hydrated skin was suggested to have increased compliance and to conform better to the test stimulus surfaces when pressed into the skin. The work of Lévêque et al. seems consistent with other research that has shown spatial acuity to be strongly correlated with skin compliance [8]. However, Vega-Bermudez and Johnson found that the loss in spatial acuity with aging was not related to the loss in skin compliance [also see Ref. 9].

Other investigators have found that hydration has a variable effect on tactile sensory function. For example, Verrillo et al. [10] found that with increasing hydration vibrotactile sensitivity at the thenar eminence was unaltered, but the perceived roughness of fine sandpapers at the fingerpad decreased. It is known that well hydrated skin has a higher friction coefficient than drier skin [11] and thus may slide less freely over touched stimulus surfaces. Therefore, Verrillo et al.'s (1998)

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finding of decreased perceived roughness could not be explained simply by a change in friction. All considered, it is likely that hydration has the effect of increasing sensitivity to some types of tactile stimulation, while decreasing sensitivity to others; and that the effects vary further with the site tested due to differences in the physical properties of the skin or its innervation.

Here, we report a study that sought to investigate the effect of lip hydration on tactile and thermal sensitivity on the vermilion. Hydration is an issue of particular importance for the lip because this body site is very susceptible to evaporative water loss through the skin [12]. If the lip's sensitivity is altered by variations in its state of hydration, the changing sensitivity may be of import in everyday behaviors that involve the lips. Normal lip hydration is necessary to maintain a healthy lip feel, and could be required for the maintenance of the lips' tactile-discriminative functions.

2. Methods

2.1. Subjects

Twenty-two female subjects (mean age 23 years, range 19–41 years) were recruited by advertisement in a local newspaper to participate in a study of lip sensation. Subjects agreed to refrain from using any cosmetic product or therapeutic treatment on the lips for 2 days prior to every scheduled testing session. The study was approved on ethical and safety grounds by the Biomedical Institutional Review Board (IRB) at the University of North Carolina at Chapel Hill.

2.2. Design

Each testing session consisted of two consecutive, identical series of sensory tests. Each series was conducted with the lip vermilion in an untreated (U) state or after the lip had been treated (T) with an agent known to moisturize the skin. Data were collected from 20 of the 22 subjects during three testing sessions defined as follows: No treatment prior to the first series, no treatment prior to the second series (UU); no treatment prior to the first series, treatment prior to the second series (UT); and treatment prior to the first series, treatment prior to the second series (TT). The other two subjects each participated in only one testing session. For the 20 subjects, the sessions were conducted on different days with the constraint that at least 2 days separated a UT or TT session and a UU session. Given this exception, the order in which subjects participated in UU, UT, and TT sessions was pseudo-randomized so that each type of session would be conducted about a third of the time on each of days 1, 2 and 3 of testing. Each session required 2 h to complete both series of sensory tests. All subject recruitment and testing were undertaken by one experimenter (A.M.).

2.3. Lip moisturization

Prior to the T series of sensory tests, the lower lip vermilion was treated with a lip moisturizing product known to have a rapid onset of action and duration of action exceeding that of the testing session, as measured using instrumental means [e.g., corneometry and allied techniques, 13,14]. To determine the amount of agent to be used on the lower vermilion, the total area of the red lips was grossly estimated using the formula $a = \pi \frac{hw}{4}$, where a is the area in cm^2; h is the height of the lips in cm, measured between upper to lower vermilion borders along the midline; and w is the width of the lips in cm, measured between left and right commissures. For areas of <7.4 cm^2, 0.01 ml of the agent was dispensed from a 1 ml syringe onto the experimenter's index fingerpad, covered with a latex finger cot. A larger volume of 0.02 ml was used for lip areas of >7.4 cm^2. Using three circular sweeps, the experimenter applied the agent to both the lower and upper vermilion. The subject was instructed to keep the lips together and to speak only when necessary during the subsequent series of sensory tests.

2.4. Sensory tests

During each series, the tests were administered in following order: Subjective assessment of lip feel; touch detection sensitivity; spatial acuity; thermal perception sensitivity; subjective assessment of suprathreshold thermal stimulation; subjective assessment of a textured surface. With the exception of the first, all tests evaluated sensation on the lower vermilion. Medio-laterally, the site for stimulus application was located half-way between the midline and the commissure of the lips on the subject's dominant side. Anteroposterially, it was located half-way between the vermilion border with the facial skin and muco-cutaneous junction with the labial mucosa.

2.4.1. Subjective assessment of how the lips feel

The subject was instructed to purse the lips a few times and rate the feel of the lips using a previously developed touch perception task [TPT, 15]. The TPT consists of a list of 40 adjectives, subdivided into 26 that describe sensory-related attributes (e.g., dry) and 14 that describe emotion-related attributes (e.g., exciting). The degree to which each attribute described the tactile experience was obtained from the subject using a five-point category scale. The categories were; 'none' (not descriptive), 'slightly descriptive', 'moderately descriptive', 'highly descriptive' and 'very highly descriptive'.

2.4.2. Touch detection sensitivity

The touch detection threshold was measured using nylon monofilaments that vary in the force applied to the skin. In preliminary testing, it was discovered that the instruments commercially available (viz., Touch Test Sensory Evaluators; Stoelting, 620 Wheat Lane, Wooddale, IL 60191) were not useful on the lower vermilion: The force delivered by the finest filament (ca 5 mg-wt.; filament marked '1.65') was often detected, and the force of the second finest filament (ca 23 mg-wt.; filament marked '2.36') was always detected. Given the need for greater resolution, sets of nine filament stimuli graded in force to blanket the range 3 to 32 mg-wt. were custom made. Specifically, lengths of monofilament line (RIO Powerflex; RIO Products, 5050S. Yellowstone Hwy., Idaho Falls, ID 83402; (208) 524-7760) were cut, one end of each was grasped by a small (14 cm long) straight mosquito hemostatic forcep, and the force in gm-wt. delivered by the opposite, free end of the filament was measured using a Ohaus Explorer Balance (Model E0RV70; P.O. Box 2033, Pine Brook, NJ 07058; (973) 377-9000). The free ends were re-cut and re-measured until the set of nine filaments was obtained. Using RIO Powerflex 0.7 kg/0.076 mm-diam-line, calibrated forces of 3, 4, 8, 12, 16, and 20 mg-wt. were achieved with filament lengths approximating 6, 5.6, 4.8, 4, 3.6 and 3.3 cm, respectively. Using RIO Powerflex 1.1 kg/0.102 mm-diam-line, calibrated forces of 24, 28 and 32 mg-wt. were achieved with filament lengths approximating 4.5, 4.3, and 4 cm. A total of 124 sets were made so that a new set of calibrated filaments could be used during each series of tests for each session for each subject. A few sets were recalibrated after use to confirm that the forces applied by the filaments had not changed.

Testing consisted of 40 trials. During each trial, a filament was applied to the skin during one time interval and no stimulus was applied during a second time interval. To the extent possible, the filaments were pressed into the skin creating a single buckle similar to that observed during the stimulus calibration procedure. Subjects identified the interval (first or second) during which the filament was delivered. Feedback as to correctness of response was given. The force delivered during the first trial was always 24 mg-wt. A computerized threshold-tracking program specified the random sequence of the interval for stimulus application, the monofilament to be used for each trial, and predicted the threshold force that would be detected in the correct interval on 75% of the trials (Harvey, 1986). The inverse of the threshold force provided a relative measure of the lip's touch detection sensitivity.

2.4.3. Spatial acuity

The threshold groove width at which the orientation of square-wave grating surfaces could be discriminated was measured using JVP Domes (Stoelting Co., 620 Wheat Lane, Wood Dale, Illinois 60191). Each dome-shaped piece of plastic was 19 mm in diameter and precision milled to provide alternating ridges and grooves of widths equal to 0.35, 0.5, 0.75, 1.0, 1.2, 1.5, 2.0 or 3.0 mm. Ridge width equaled groove width and the groove-spacing between ridges was uniform with no adjustment to account for the slight curvature-induced increase in the spatial period at the periphery of the dome. The eight dome stimuli were locally instrumented with spring-loaded tubes [16] to assist in the delivery of the same force for all domes and stimulus replications. Between series of tests, the domes were cleaned with SporGon (Decon Laboratories, Inc.) to maintain clinical asepsis.

Testing consisted of 40 trials. During each trial, a single dome was applied with its ridges either parallel or perpendicular to the lip vermilion. The dome was pressed normal to the skin and maintained in position for 3–4 s with approximately 50 g-wt. of force, Care was taken to avoid lateral movement, which could provide undesirable cues as to ridge orientation [see discussion in Ref. 17]. Subjects identified whether the orientation was parallel or perpendicular to the vermilion. Feedback as to correctness of response was given. The groove width used for the first trial was always 2 mm. A computerized threshold-tracking program specified the orientation at which the grating would be delivered during each trial, the dome (groove width) to be used for each trial, and predicted the threshold groove width for which grating orientation would be correctly discriminated by the subject on 75% of the trials (Harvey, 1986). The inverse of this threshold groove width provided a relative measure of spatial acuity.

2.4.4. Thermal perception sensitivity

The threshold change in temperature at which the subject first perceived warmth and first perceived cool was measured with a TSA II Neurosensory Analyzer (Medoc Advanced Medical Systems U.S., 1502 West Highway 54, Suite 404, Durham, North Carolina 27707). An intra-oral probe, the transducer end of which was 6 mm in diameter, was used to apply thermal stimuli to the test site on the lower vermilion. A single layer of cling film was stretched tightly across the end of the probe to maintain clinical asepsis. The film was replaced between subjects. Prior to testing, the temperature of the lower vermilion was estimated using a remote sensing infra-red thermometer held above the test site (SenseLab Tempett; Somedic Sales AB, Box 194, S-242 22 Horby, Sweden). This resting vermilion temperature defined the baseline temperature from which the thermal data were obtained. If needed, cotton rolls were placed in the labial vestibule to improve access to the vermilion.

A modification of the Marstock protocol was used to estimate the perception thresholds for warmth and cool [18,19]. The transducer probe was set to the baseline temperature and applied perpendicularly to the skin with consistent and comfortable pressure (the probe indented the vermilion skin 1–2 mm). After about 7 s, warming pulses were produced at 0.3 °C/s. Each was terminated by the participant's response to signify that the transducer began to feel warmer. The temperature returned to the baseline temperature and the next stimulus was initiated at a randomly chosen time between 4 and 6 s. Six stimuli were delivered. The highest and lowest response temperatures were eliminated consistent with standard practice [20]. The warmth perception threshold was calculated as the difference between the mean of the four remaining response temperatures and the baseline temperature. The inverse of this threshold elevation in temperature required for the perception of warmth provided a relative measure of warmth perception sensitivity.

The cool detection threshold was estimated in a similar manner. The stimulus temperature decreased at 0.3 °C/s until the participant signified that the transducer began to feel cool. The negative-signed changes in temperature were made positive in sign for presentation and all analyses.

2.4.5. Subjective assessment of suprathreshold thermal stimulation

2.4.5.1. Hedonic ratings. Hedonic ratings of suprathreshold thermal stimuli cooler than (22 and 28 °C) and warmer than (36 and 42 °C) the facial skin were obtained on the lower vermilion and on the mid-portion of the chin, using the TSA II thermal stimulator described above. The chin was included as a reference site as it was never treated with the moisturizing agent. For each stimulus, the probe was allowed to reach the desired temperature and was then placed in contact with the skin for 4 s. At the end of this period, the subject rated the pleasantness/unpleasantness of the thermal stimulation using an interval–ratio scale previous developed for the rating of oral stimuli [21].

2.4.5.2. Perceived intensity. The perceived relative intensities of thermal stimuli applied to the vermilion site as compared to the chin site were also obtained. On each trial, a thermal stimulus was first delivered to the chin. As for the hedonic ratings, the probe was brought to the desired temperature before being placed in contact with the skin for 4 s. Subsequently, the transducer was removed from the chin, and a thermal stimulus was delivered to the lower vermilion in a similar manner. The subject was instructed to rate the perceived intensity of the lip stimulus in comparison to perceived intensity of the chin stimulus using response scales developed for the study (Fig. 1). The two stimuli delivered on each trial were either both cooler (22 and 28 °C) than the facial skin or both warmer (36 and 42 °C). Data were thus collected for two pairs of cool stimuli and two pairs of warm stimuli. Additionally, some trials presented unequal temperatures to lip and chin, as a form of catch trial. Analysis of such trials is not reported here. When the two stimuli were cooler than the facial skin, the subjects used the relative cool intensity scale (Fig. 1A); when the two stimuli were warmer than the facial skin, the subjects used the relative warm intensity scale (Fig. 1B).

2.5. Subjective assessment of texture surface (artificial skin)

Using the TPT, the subject rated the tactile experience evoked by a rubber disk that was moved over the subject's lower vermilion by the experimenter. The surface of the rubber material was imprinted to resemble the surface of human skin (Beaulax, Tokyo, Japan). Because the surface could potentially remove any residual moisturizing agent from the lip, it was administered last in the series of tests.

2.6. Statistical analysis

2.6.1. Subjective assessment of how the lips feel

Difference values were obtained for each attribute of the touch lexicon for each subject, as the mean rating for untreated skin subtracted from the mean rating for treated skin. Means across subjects and 95% confidence intervals of the difference values were then calculated and plotted as a function of the mean value (e.g., Fig. 2). P-values of pair-wise tests for difference in means were not corrected for the number of tests here or elsewhere in the analyses.

2.6.2. Tactile and thermal sensitivity measures

The four threshold measures, namely those for touch detection, spatial acuity, warmth perception and cool perception, were log-transformed prior to analysis, consistent with the lognormal distribution of these measures [16,19].

The presence of any treatment effects was ascertained via mixed-model ANOVAs with subjects as a random effect. Each model included factors for the type of session (i.e., whether the session consisted of UU, UT or TT series), the order of the within-session series (i.e., whether

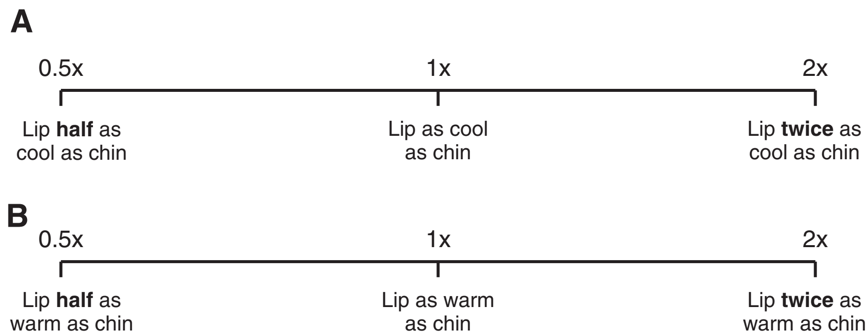

Fig. 1. Response scales for the rating of relative thermal intensity. A) is the scale used for rating cool stimulus pairs, B) for rating warm stimulus pairs.

the series was first or second within the session) and the treatment (i.e., untreated or treated lips). Touch detection and spatial acuity data were analyzed in separate models. Both warm and cool thermal thresholds were entered in a single model, which included an indicator variable for the type of threshold, and an interaction between threshold type and treatment.

2.6.3. Hedonic and thermal intensity ratings

Hedonic ratings of suprathreshold thermal stimuli were treated similarly to the threshold measures, except that the statistical model included an additional factor of stimulus temperature and the interaction between stimulus temperature and treatment. A separate analysis, including both lip and chin data, but omitting the treatment factor, was used to ascertain if there were differences between these two facial sites in the hedonic value of different temperature stimuli.

Only the intensity ratings for equal-temperature stimuli on chin and lip were analyzed, as noted in the Methods: The unequal-temperature stimuli were considered to be a form of catch trial such that subjects did not always experience equal temperatures on the two sites on every trial. The mixed-model analysis of this data included factors for series order, session type, treatment, stimulus temperature and an interaction between treatment and stimulus temperature.

2.6.4. Subjective assessment of textured surface

Finally, the emotional and sensory response to the texture moved over the lips was analyzed using the same procedure used for the subjective assessment of how the lips felt.

3. Results

3.1. Subjective assessment of lip feel and textured surface

Fig. 2 shows the changes in mean responses for the 26 sensory-related attributes after treatment, for assessment of lip feel and for assessment of the textured surface. Inspection of the figure and the 95% confidence intervals plotted therein indicates that lip treatment altered lip feel (Fig. 2, solid line) for many of the ratings of sensory attributes, with especially large increases in smoothness, slipperiness and greasiness, and particularly large decreases in roughness and dryness. There were no significant changes in the attributes of warm or cool, although subjects interestingly reported that the lip was less 'hot'. In contrast, the feel of the textured (artificial skin) surface as it moved across the vermilion was changed relatively modestly by lip treatment (Fig. 2, broken line).

With similar format to the plot of the sensory-related attributes, Fig. 3 shows the changes in mean responses for the 14 emotion-related

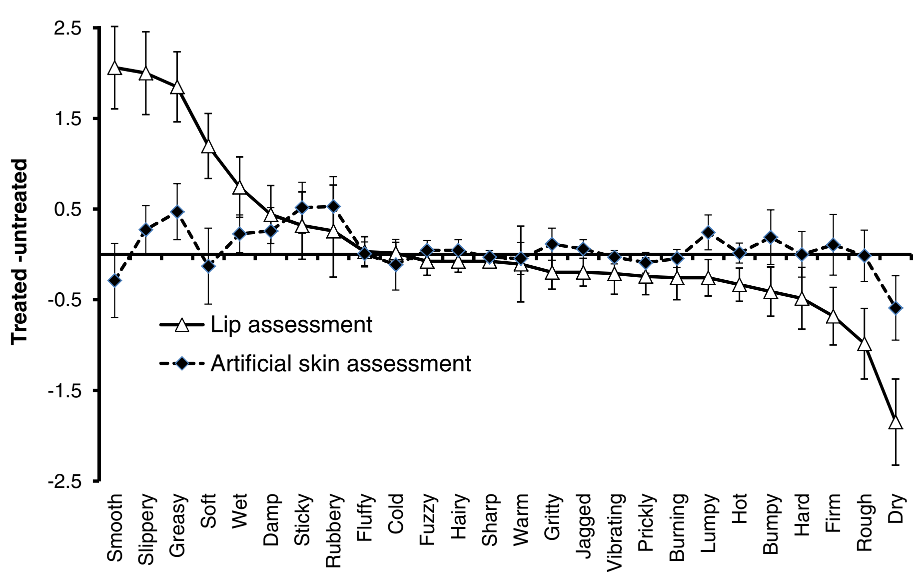

Fig. 2. Mean differences of ratings given to 26 sensory-related attributes, for treated versus untreated lip vermilion. Lip assessment (solid line) was for to the upper and lower lips being moved against each other. Artificial skin assessment (broken line) was for a textured, rubber surface moved over the lips by the experimenter. Error bars show 95% confidence intervals.

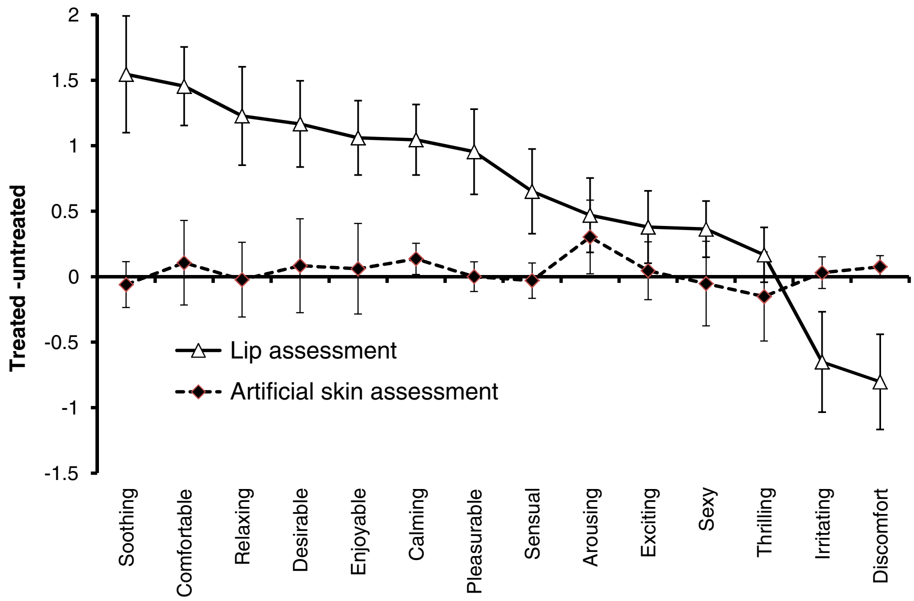

Fig. 3. Mean differences of ratings given to 14 emotion-related attributes for treated versus untreated lip vermilion. Key as for Fig. 2.

attributes. Treated lips were assessed with significantly greater positive affect than untreated lips, except for the 'thrilling' attribute. Furthermore, negative affect was reduced for the treated lips; 'irritating' and 'discomfort' ratings were lower, on average, for the treated as opposed to untreated lips. As for the sensory attributes, the perception of the textured surface as it moved across the lips was altered minimally by the lip treatment (Fig. 3, broken line).

3.1.1. Touch detection sensitivity

After accounting for significant variation in the thresholds attributed to the order of the within-session series of test ($F_{1,98} = 6.35$, $p = .0134$; first series geometric mean = 5.92 mg, second series mean = 4.41 mg), treated lips were found to be significantly more sensitive to light touch than untreated lips ($F_{1,98} = 7.87$, $p = .0061$; treated = 3.87 mg, untreated = 6.74 mg; see shaded bars in Fig. 4A). The series order effect likely represents an effect of practice that occurred within the experimental session. In respect of this, observe that in Fig. 4A, regardless of the type of session, a reduction in thresholds was seen in the second series of tests compared to the first.

3.1.2. Spatial acuity

Thresholds varied among the types of session ($F_{2,98} = 6.90$, $p = .0016$; see Fig. 4B), with lower thresholds being observed for sessions during which the treatment was applied before one or both series of tests (geometric mean UU = 1.27 mm, UT = 0.82 mm, TT = 0.95 mm). However, threshold values were not significantly altered by the treatment ($F_{1,98} = 0.88$, $p = .3497$), and did not differ significantly across the two series of tests conducted in the same session ($F_{1,98} = 2.61$, $p = .1095$).

3.1.3. Thermal perception sensitivity

3.1.3.1. Resting temperature of the lower vermilion. Skin temperature averaged 31.5 °C (range among subjects 30.1–34.3 °C) for the untreated lip and 31.6 °C (range among subjects 30.0–35.0 °C) for the treated lip. The temperature did not vary in a consistent manner with any of the experimental conditions, including whether or not the lip was treated. However, temperature differences during testing of the lip in the treated versus untreated states were observed for individual subjects.

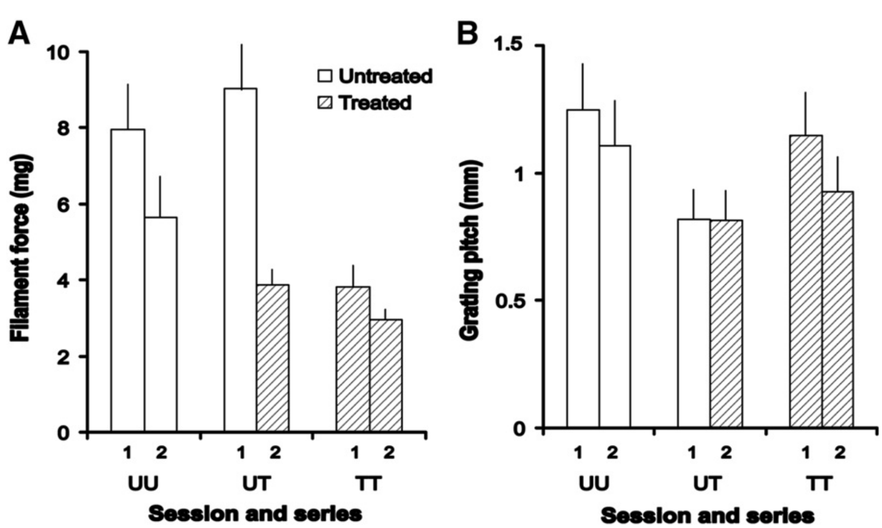

Fig. 4. Geometric mean threshold values for the two experimental series within each type of experimental session for A) contact detection, and B) grating orientation discrimination. Errors bars show + 1 SE.

Among subjects, the treated lip was from 1.3 °C cooler than the untreated lip to 1.8 °C warmer than the untreated lip.

3.1.3.2. Effect of changes in baseline temperature on warm and cool perception thresholds. To determine whether differences in the perception thresholds observed in individual subjects after lip hydration were related to the change in the temperature of the vermilion, we plotted the change in threshold (treated–untreated lip) versus the change in skin temperature (treated–untreated lip). Fig. 5A makes evident that 19% of the variability in the treatment effect on the warm perception threshold could be attributed to differences in the baseline lip temperature from which the thresholds were measured ($F_{1,20}$ = 4.63, p = .0438). Subjects who had decidedly cooler skin during the treatment measurement period exhibited the greatest elevations in the warm threshold. The y-intercept (0.35 °C) of the line describing the linear relationship is significantly >0.0 (t = 2.38, p = .0274). Thus, this analysis supported the suggestion that the treatment produced an elevation in the warm threshold, on average.

Similar to warmth perception, Fig. 5B shows that 23% of the variability in the treatment effect on the cool perception threshold could be attributed to differences in the baseline skin temperature from which the thresholds were measured ($F_{1,20}$ = 5.95, p = .0242). Subjects who had decidedly cooler skin exhibited the greatest reductions in the cool threshold. In this case, the y-intercept (−0.10 °C) was not significantly different than 0.0 (t = 1.15, p = .2624). Thus, this analysis did not support the suggestion that the treatment produced a decrease in the cool threshold, on average.

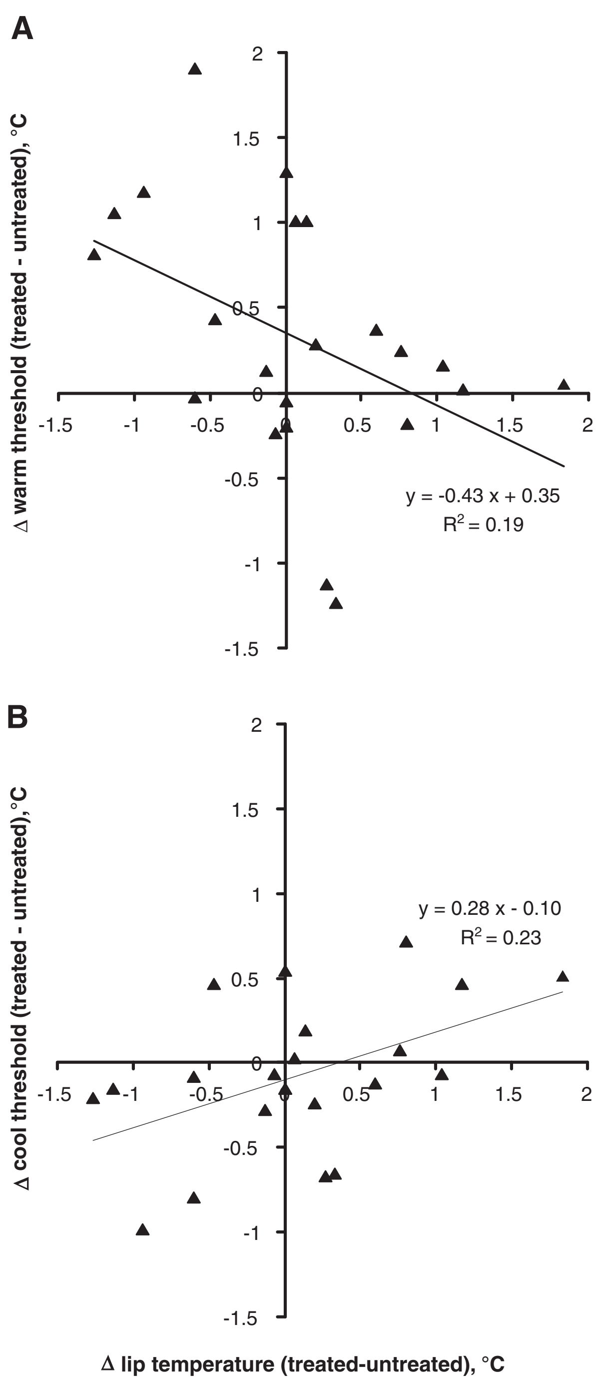

Fig. 5. Scatter plots of A) the mean change in warm perception thresholds, B) mean change in cool perception thresholds, plotted against the mean change in baseline vermilion lip temperature, for each of the 22 subjects.

3.1.4. Subjective assessment of suprathreshold thermal stimulation

3.1.4.1. Hedonic ratings. An analysis of the lip data indicated that the hedonic ratings of thermal stimuli presented to the lip varied according to stimulus temperature ($F_{3,464}$ = 4.87, p = .0024), but treatment had no effect on the ratings ($F_{1,464}$ = 0.14, p = .7074). A separate analysis including both lip and chin data confirmed that ratings varied according to stimulus temperature ($F_{3,960}$ = 14.92, p < .0001), and further, found that ratings obtained on the lip were greater overall that those obtained on the chin ($F_{1,960}$ = 5.56, p = .0185), indicating that the thermal stimuli overall were slightly more pleasant on the lip than on the chin. Fig. 6 shows the hedonic ratings for each stimulus temperature, plotted separately for lip and chin, where it may clearly be seen that the 36 °C stimulus, one slightly above the baseline temperature of the lip, was the most pleasant. All stimuli were found affectively positive on the lip, whereas the 22 °C stimulus on the chin was judged with negative affect. Observe also that the hedonic value of the thermal stimuli was not great, with the greatest affective response approximating only 'slightly pleasant'.

3.1.4.2. Perceived intensity. The relative intensity of a thermal stimulus placed against the vermilion was approximately the same as that temperature stimulus placed against the chin, except for the 22 °C stimulus, which was felt to be more intensely cool on the lip than on the chin ($F_{3,464}$ = 22.40, p < .0001; mean relative intensity = −0.43, with reference to Fig. 1A where −1 denotes the lip feeling half as cool as the chin and 0 denotes equal perceived intensity). Treatment of the lip did not alter ratings of thermal intensity, although there were nonsignificant trends in the data whereby the 22 °C stimulus felt cooler after lip treatment and the 42 °C felt less warm. The directions of these trends are consistent with the treatment-related trends in the cool and warm perception thresholds, respectively, reported above (Fig. 5).

4. Discussion

4.1. Subjective assessment of lip feel and textured surface

Treatment of the vermilion led to marked changes in subjects' reports of the sensory and emotional perceptual attributes of the touch lexicon. The greatest sensory changes were increases in smoothness, slipperiness and greasiness and decreases in dryness and roughness. The emotional changes were notably positive, indicating that the overall sensory changes elicited by treatment were desirable.

Previous research investigating the perception of treated and untreated skin, has found positive relationships between ratings of skin pleasantness and perceived smoothness and softness of the skin, and a negative relationship between skin pleasantness and perceived stickiness [22]. Further, it is generally the case that smooth, soft stimuli are

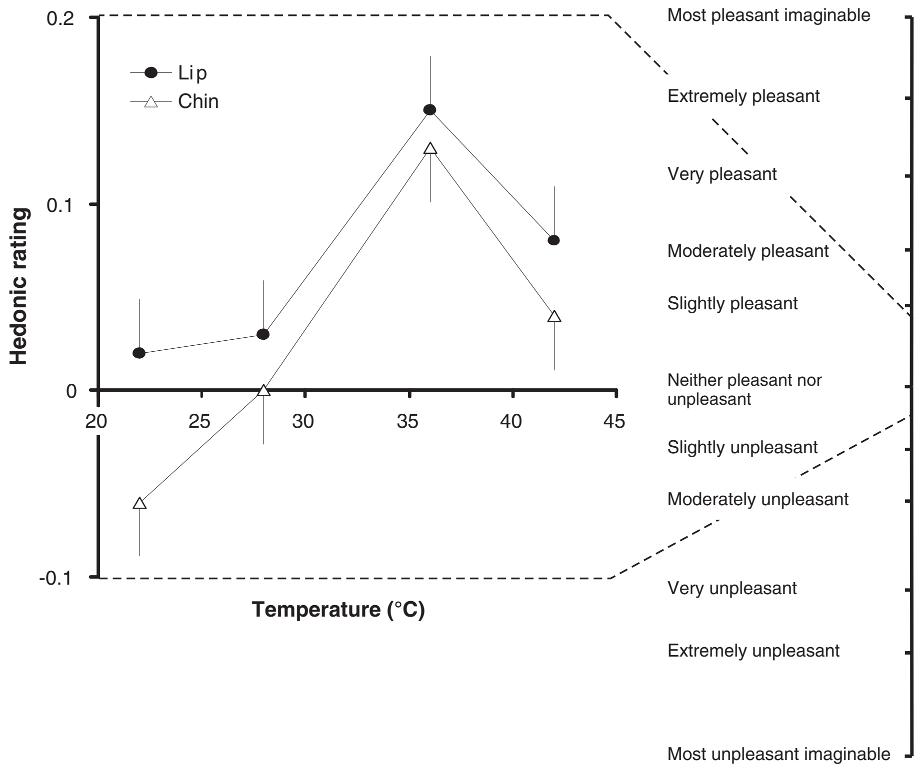

Fig. 6. Mean hedonic ratings given to four different temperature stimuli presented to either vermilion lip or chin. Error bars show +1 SE.

rated especially pleasant when moved across the skin [23,24]. The results of the study we report here are therefore consistent with prior work on touch hedonics. The increases in softness and smoothness (and other desirable sensory attributes) after hydration were clearly more important than changes in stickiness (and other undesirable sensory attributes) in determining positive changes in affect, for increasing stickiness has been shown to decrease positive affect [22].

Unlike the subjective assessment of lip feel, treatment of the vermilion led to relatively modest changes in the sensory and emotional assessment of the textured surface moved across the lips. Moreover, unlike for lip feel, negative sensory attributes were emphasized by the treatment, including rubbery, sticky, greasy and lumpy. The nature and magnitude of these changes may be related to the insignificance of the textured surface used as the stimulus, or to the nature of the touch event itself. That is, the assessment of the texture involved passive touch, as opposed to the active touch used during the assessment of lip feel. In this regard, it is known that the precise manner in which tactile stimulation is provided is important in the assessment of various stimulus properties [22,25,26].

4.1.1. Sensory thresholds

We found that the treated vermilion was considerably more sensitive to light touch than the untreated vermilion. The mean thresholds of 6.7 mg before treatment, and 3.9 mg after treatment are lower than those reported by other researchers for the lower vermilion, using commercially available stimulus instruments [e.g., 18.2 mg, 27]. This attests to the utility of our custom monofilaments, fabricated to blanket the anticipated range of force thresholds for the vermilion, unlike the commercially available instruments. Methodological differences in how the threshold was defined may also have contributed to between-study differences in the absolute threshold values. Nevertheless, the data obtained in this study underscore the need to re-evaluate tactile sensitivity on perioral and facial sites using instruments that are more sensitive than those used in most previous studies and that are calibrated in easily interpreted units of measurement.

In contrast to the thresholds for light touch, no consistent change in spatial acuity was observed in response to lip treatment. The mean grating threshold we found (0.99 mm) is consistent with prior research from our laboratory which has used a similar, albeit not identical, definition of threshold performance [82% correct grating pitch of 0.86–0.92 mm, 16]. These values are somewhat higher than the 75% correct threshold values of 0.51 mm reported by van Boven and Johnson, [28], and 0.48 mm by Sathian and Zangaladze [29]. Wohlert [30] reported values in the range of 0.48–0.75 mm for performances just above chance, which seems more comparable to the performance level we found. Direct comparisons between studies are rendered difficult by varying definitions of threshold and substantial differences in the way the task was carried out.

Our results for light touch detection and spatial acuity may be contrasted with those of Lévêque et al. [7]. These investigators found improved spatial acuity in their aged subject population after hydration of the skin overlying the cheek, and decreased responsiveness of cutaneous afferents in the peroneal nerve to constant force stimulation after hydration of the afferents' receptive fields. Lévêque et al. proposed that increased skin compliance post-hydration led to less, but more spatially distinct, neuronal activity, explaining the improved spatial acuity of hydrated skin. Tactile detection thresholds and receptor activation thresholds were not reported.

Assuming that the skin of the vermilion behaves similarly to that of the cheek and leg, it follows from Lévêque et al. (2000) that hydration might be accompanied by increased thresholds (decreased sensitivity) to the detection of light touch. The opposite result was obtained in the present study and spatial acuity, unlike in Lévêque et al. (2000), was not improved by hydration. The subjects' assessment of lip feel (viz., touch lexicon) suggested that the vermilion became more compliant after the treatment, as evidenced by higher ratings of softness, and lower ratings of hardness and firmness, although explicit measurements of skin compliance were not made.

Attempts to reconcile our and Lévêque et al.'s results with the body of literature concerning skin morphology, tactile thresholds and neural responses do not provide a clear answer as to whether changes in skin compliance are associated with changes in sensitivity to light touch. In contrast to Lévêque et al., other human microneurography studies have found indirect evidence to suggest an increase in stimulus-evoked afferent activity with increasing skin compliance. For example, Edin et al. (1995) found that the indentation thresholds for afferents in the inferior alveolar nerve supplying the lower lip and chin were lower on average than those for radial nerve supplying the back of the hand, which in turn were lower than those for median nerve supplying the palm. The low indentation thresholds for the facial afferents were likely facilitated by the receptors' location in highly compliant perioral skin. It is known that forearm skin is less stiff and more elastic than palmar skin, and that a fixed force indents the forearm skin to a greater depth than that of the palm [31] — perhaps explaining the differences in the thresholds of afferents supplying these two different sites. Similar biophysical measurements have been made for other body sites [32], although the vermilion has not been explicitly studied.

Verrillo et al.'s [10] finding that vibrotactile indentation thresholds are unaltered by skin hydration bears indirectly on the role of skin compliance and neural responsivity. With a fixed indentation force, rather than controlled indentation as used by Verrillo et al., one might expect a decrease in the threshold, given that a greater skin indentation would occur post-hydration if skin compliance had increased. However, some investigators have failed to find clear changes in skin mechanical properties after changes in skin hydration [33].

It may be that the findings of neither Lévêque et al. (2000) for the cheek and leg nor Verrillo et al. (1998) for the palm strictly apply to the findings of the current study for the transitional epithelium of the vermilion. Contrasted to these body sites, the vermilion is innervated differently and more densely with an estimated 10–20 corpuscular receptors per mm^2 of epithelium [34]. These corpuscles are thought to be the end terminals of sensitive rapidly adaptive mechanoreceptors. The mechanisms by which mechanical energy is transferred to and represented in this dense sheet of corpuscles is not known, but intuitively could be different than that of a sheet of less dense receptors, as the cheek. That spatial acuity did not improve post-hydration suggests that the mechanism by which mechanical information is represented in the receptor sheet of the cheek, as proposed Lévêque et al. (2000), may not apply to the vermilion.

4.1.2. Thermal response

Consistent trends were found in both the threshold and intensity rating data for both increases and decreases in temperature to suggest that the lip's temperature sensibility was altered to mimic the situation expected if the vermilion had been cooled by the treatment. Specifically, it is established that when the skin is cooled, temperature increments are detected less readily but temperature decrements are detected more readily [35]. In the present study, the warm thresholds increased significantly and the cool thresholds decreased (albeit not significantly) after treatment. Additionally, subjects rated the 22 °C stimulus with greater cool intensity and the 42 °C stimulus with lesser warm intensity when the lip was hydrated. However, this result must be tempered by the fact that the temperature measurements of the vermilion indicated that the lip on average had not been cooled by the treatment used in the present study. The treatment may have increased the temperature of some subjects' lips and decreased the temperature of others: Other studies have found that hydrating agents can either warm or cool the skin [36]. For example, an emollient, such as petrolatum, that provides a thermal (e.g., lipid) barrier can insulate the skin, and thus increase the temperature under the barrier. Skin warming can also be produced by the addition of rubefacients that increase blood flow [37]. In contrast, a humectant with volatile ingredients (e.g., water) can promote evaporative cooling. For example, Lehmuskallio et al. [38] found minimal thermal insulation and a significant decrease in facial skin temperature, by 0.6 °C, for hydrating crèmes investigated in cool environmental conditions (15 °C, with a 3 m/s breeze). A significant cooling effect has also been observed for a high water content emollient, using an in vitro permeable skin model [39].

Consistent with the absence of a change in lip temperature in the present study with lip hydration, on average, the subjects reported no change on the warm or cold attributes of the TPT during assessment of lip feel, on average. However, lower ratings were given to the hot attribute. Such discrepancies between reported thermal changes and actual changes in skin temperature have been observed in other studies. For example, Lehmuskallio et al. [38] found that petrolatum in particular could lead to a feeling of skin warmth that was unrelated to measured thermal change on application of the treatment. It is unclear why in the present study the subjects elected to report 'less hot' rather than 'less warm' or 'more cold'.

5. Conclusions

The present study demonstrates that hydration of the lips significantly increases tactile sensitivity. In addition, changes in subjects' threshold and suprathreshold responses to thermal (especially warm) stimulation were strongly suggested. Mechanical changes in the skin were hypothesized to underlie the tactile threshold changes, although the precise nature of these mechanical changes, and their effects upon the responses of tactile receptors remain uncertain. The trends in the thermal thresholds and subjective responses were consistent with those expected for skin cooling, although temperature measurements did not indicate that the lip, on average, had been cooled by the hydrating agent.

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