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The Relationship Between Biophysical Skin Properties, Tactile Ability, and the Distance Adaptation-Aftereffect

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Abstract— **Interindividual differences in biophysical properties such as skin hydration and elasticity have been demonstrated to play a critical role in influencing various aspects of tactile perception. Here, we assess their role for interindividual variation of basic tactile abilities and the tactile distance adaptation aftereffect in a young adult sample. Tactile abilities were defined by tactile sensitivity in a monofilament detection task and spatial acuity in a grating orientation task. In the distance aftereffect, when a body area is repeatedly touched at two points separated by a given distance, subsequently presented smaller distances are perceived as smaller than on unadapted areas. Aftereffect magnitude describes the perceptual shift in a distance discrimination task following adaptation. We examine whether differences in skin hydration and elasticity at the finger pad are related to tactile abilities which in turn affect the magnitude of distance aftereffects. Results revealed that higher hydration and elasticity were related to increased tactile sensitivity and spatial acuity, but magnitude of distance aftereffects was independent from both skin properties and tactile abilities. While these results reemphasize the importance of healthy skin for tactile perception, they suggest individual differences in the magnitude of the distance aftereffect to be independent from peripheral skin properties.**

Keywords—skin properties, tactile perception, adaptation, aftereffect, sensitivity, skin hydration, skin elasticity

I. Introduction

Humans can collect tactile information through passive and active touch to assess the attributes of objects and materials. In this context, biophysical properties such as skin hydration and elasticity have been suggested to play a critical role in influencing various aspects of tactile perception performance [1–4]. Hydration is defined as the water content of the stratum corneum, the first layer of the epidermis, and elasticity generally describes the skins' ability to recover its' initial position after deformation. Performance parameters that are discussed to be affected by those properties are for example tactile sensitivity, which typically describes the ability to detect light pressure [3, 4], and spatial acuity, i.e. the spatial resolution of the tactile perception [2, 3]. Here, we aimed to strengthen the evidence for that relationship, with a particular focus on interindividual differences in the biophysical properties of hydration and elasticity of an otherwise homogenous young sample, and to assess how these differences affect more complex tactile perception by studying the tactile distance adaptation-aftereffect.

Regarding hydration, experimental manipulations such as moisturizer application were found to benefit perception: By softening the stratum corneum and thus increasing the contact area between object and skin, hydrating interventions were shown for instance to improve roughness perception [1] and spatial acuity, assessed in a gap detection task [2]. Similarly, higher water content of the stratum corneum due to single-time cream application was found to enhance tactile sensitivity, assessed in a suction pressure discrimination task [3]. Although one study found no substantial effects of single-time cream usage neither for sensitivity nor for spatial acuity [5], prolonged application of cosmetic oil with added aromatic compounds however increased elastic fiber length at the respective skin site, and in turn enhanced both spatial acuity, assessed in a grating orientation task, and tactile sensitivity, assessed in a monofilament detection task [4]. In line with these findings, interindividual differences in biophysical and related mechanical properties of the skin have been suggested to be tied to perceptual performance: Lower skin stiffness, measured as the compliance of the finger pad during a rigid body compression test, was found to be associated with better discrimination of compliant surfaces, as softer skin generated greater rates of change in contact area [6]. Similarly, skin conformance, i.e. a measure of how much the skin invades gaps in grating stimuli, was shown to partly account for differences in tactile spatial acuity in young subjects, again measured with a grating orientation task [7]. The decline in spatial acuity with aging however was suggested to be primarily caused by reduced afferent density rather than changes in skin properties [7]. This was highlighted by another more recent study, demonstrating that skin elasticity and hydration contribute to a lesser extent to the age-related changes in spatial acuity than afferent density

[8]. Overall, it becomes evident that there is a relationship between skin properties and basic tactile perception, most commonly assessed in the context of aging and moisturizing manipulations. By conducting a systematic assessment of interindividual naturally occurring differences in skin hydration and elasticity and their relation to basic perceptual parameters in young adults we aim to extend the existing literature.

We further aimed to investigate whether interindividual differences in these skin properties have implications for more complex tactile phenomena. Specifically, we investigate whether the expression of tactile aftereffects is affected by interindividual differences in skin properties. Adaptation-aftereffects describe the change in perception after prolonged exposure to the same stimulus. They exist in every sensory domain, with the largest reported variety of features in vision (see [9]). Numerous haptic aftereffects such as the tactile movement aftereffect or the softness aftereffect have been reported [10, 11]. Calzolari and colleagues showed that after adaptation to a tactile distance, participants perceive subsequent smaller distances as being smaller than on unadapted skin areas [12]. Distance as a basic somatosensory property is defined as the distance between two distal points simultaneously applied onto the skin. This distance aftereffect exhibits characteristics typical for low-level cortical adaptation aftereffects, namely orientation- and region-specificity, i.e. the aftereffect does not occur when application axis or area are not congruent between the adaptation and test phase. This supports the assumption that tactile distance perception mainly arises at early stages of somatosensory processing [13, 14]. As for every psychophysical measurement, there is interindividual variance for the strength of that aftereffect, i.e. individuals differ in the extent to which their subsequent perception is affected by the adaptation. While nearly all participants exhibit some degree of perceptual aftereffect, the extent of this effect varies considerably, with some individuals experiencing pronounced perceptual distortions, even for stimuli that would typically be easily distinguishable under no-adaptation conditions [12, 15]. In this study we examined whether interindividual differences in the magnitude of the tactile distance aftereffect can be explained by differences in skin properties and resulting differences in basic tactile perception. Distance perception here refers to very small stimuli at the finger pads in the order of millimeters [15].

Perceptual intensity of adaptation and test stimuli has been suggested to affect the magnitude of visual aftereffects. Multiple studies found for example that the visual motion aftereffect is influenced by both the physical stimulus strength as well as the subjective perceptual strength [16–18]. For instance, aftereffect magnitude was observed to increase with increasing adapting contrast and with decreasing test contrast [17]. Similarly, the magnitude of the high-level facial expression adaptation aftereffect was found to increase monotonically as a function of the intensity of adapting facial expressions [19]. Transferring this to the tactile domain, we suspected that tactile aftereffect magnitude might vary under conditions of differing sensory response intensity; such as those linked to specific skin characteristics shown in previous studies [1–4, 7]. In this analogy, enhanced contrast in visual adaptation stimuli would be the equivalent of heightened tactile acuity. While previous studies demonstrated that peripheral factors are not the origin and cause of tactile aftereffects, it is yet unclear whether they can have an additional impact on their expression, possibly explaining natural interindividual differences in e.g. the aftereffect magnitude. By employing this novel exploratory approach we aim to deepen our understanding of tactile aftereffect mechanisms.

We included both hydration and elasticity as parameters of skin properties as well as both tactile sensitivity and spatial acuity (subsumed under tactile ability in the following as in [20]). We investigated whether skin hydration and elasticity of the finger pad are related to the magnitude of a tactile distance adaptation aftereffect; mediated by resulting differences in tactile ability as assessed by tactile sensitivity to pressure and tactile spatial acuity. We expected higher sensitivity and acuity for more hydrated and more elastic skin. For the relationship between skin properties and aftereffect magnitude, we expected that more hydrated and elastic skin are associated with an increase of the sensory response to the adaptation and consequentially an increase of the resulting aftereffect.

II. Methods

A. Participants

Due to the very large effect sizes reported for the tactile distance aftereffect [12] and instances where certain skin properties have shown large effects on tactile precision [7], we expected medium-to-large effects for the relationship between skin properties and aftereffect magnitude. Based on that, we conducted an a priori sample size calculation for a power of 80%, an alpha of 5%, and an effect size f^2 of 0.25 (medium-to-large). Projected sample size was N = 34 for a linear regression (G*Power, [21]). We accordingly collected data from 34 right-handed students from Justus-Liebig University Giessen (19 female, age 18-30 years, mean: 23.38 years). None of them reported cutaneous impairments or sensory deficits. All participants were naïve to the purpose of the experiment, provided written informed consent, and received financial compensation (8€/hour). The experiment was approved by the local ethics committee LEK FB06 and conducted in accordance with the 2013 Declaration of Helsinki, except for preregistration.

B. Setup and Stimuli

For assessing tactile sensitivity, we used a calibrated set of 13 thin, polycarbonate rods with different diameters (Von Frey Filaments; Bioseb, USA). Application of a monofilament onto the surface of the skin with increasing pressure causes the rod to buckle and the monofilament bows out sidewards (buckling load). The ability of participants to detect the buckling of increasingly finer monofilaments (pressure threshold) was measured. The monofilament set comprised the buckling loads of 78, 59, 39, 20, 14, 10, 6, 4, 1.6, 0.7, 0.4, 0.2, 0.08 millinewton (mN). Intensity levels were chosen based on previous literature [5] and comprised values from a logarithmic scale of actual force and a linear scale of perceived intensity.

For assessing tactile acuity with a grating orientation task, we 3d-printed a set of 28 circular grating stimuli (printer: Stratasys Objet 30 Pro, resolution: 600 × 600 × 1600 dpi).

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These were constructed following the same principle as the well-established JVP domes, which have been widely used for assessing sensory capacity in grating orientation discrimination to qualify the tactile threshold for the spatial resolution [22]. For our purpose, we implemented smaller steps sizes between stimulus intensities. Each grating stimulus consists of a circular, convex grating surface (2 cm diameter, curvature: 0.29 cm^{-1}), mounted on top of a cylindrical handle (height: 3 cm). The set comprises 28 stimuli with equidistant groove and bar widths equal to 0.3 mm-3 mm (step size: 0.1 mm).

For the tactile distance aftereffect-paradigm, we 3d-printed a set of four stimuli (printer: Formlabs Form 3, XY-resolution of 25 microns, layer thickness of 25 - 300 microns). All stimuli consisted of 25 mm × 20 mm × 20 mm cubes. The test stimuli had two spikes on top (diameter: 1mm at their tip, height: 8 mm) with 5/6/7 mm distance to each other (between their inner edges), with the larger, 7 mm one also serving as the distance adaptation stimulus. The single-point adaptation stimulus had only one spike of the same diameter on top. A pilot experiment ensured adequate difficulty levels that allowed for proper psychometric fitting.

C. *Procedure*

Testing of participants involved first measuring skin hydration and elasticity, followed by psychophysical testing of tactile sensitivity, spatial acuity, and the distance aftereffect (in this specific order). All testing was carried out at the index finger pad of the left hand and participants were blindfolded and wore noise-cancelling headphones throughout the testing (as in [15]). We selected the index finger due to its highest sensitivity as demonstrated in two-point discrimination tasks [22]. The hand was chosen arbitrarily, as both homologous fingers exhibit equivalent sensitivity [23]. Total duration of one session was ca. 1.5 hours, comprising ca. 5 minutes for skin measurements, 20 minutes for assessing tactile ability, and 60 minutes for the adaptation aftereffect paradigm.

Skin properties were assessed with different probes from Courage & Khazaka Electronic GmbH (Cologne, Germany). Finger hydration was measured with a Corneometer CM 825 in arbitrary units (a.u.), based on bioelectric impedance to provide measurements of the skin conductance (reciprocal of resistance). Each individual moisture value is an average of five repeated measurements (as in [8, 20]) across the left index finger pad. Location of measurement was the center of the finger pad, as well as the point 5 mm above, below, left and right to the center, identified by measuring the whole distal phalanx with a caliper (Burg Wächter Precise PS 7215). Finger elasticity was measured at the same locations with a Cutometer MPA 580 by measuring the vertical deformation of the skin when pulled into a 2 mm diameter probe with an optical sensor. Each of the five measurements consisted of a suction cycle of 2 s using a constant negative pressure of 450 mbar, followed by a 2 s period when the pressure was switched off (relaxation phase), allowing the skin to return to its original shape. We used the elastic recovery parameter (R5, also called net elasticity) computed by the Software MPA CTplus (Version 1.1.5.0) to represent finger elasticity in the current study (as in e.g. [20]). This value contrasts the elastic part of the suction phase against the immediate recovery during relaxation phase; higher values here indicate higher elastic properties. As for hydration, each individual elasticity value is again an average of five repeated measurements.

To assess tactile sensitivity, we ran an adaptive staircase procedure similar to the one used in [5] and [24]. After a familiarization phase with the monofilament of the highest force level (78 mN), testing began with the 39 mN monofilament, which the experimenter applied three times at different sites of the finger pad and the participant verbally responded "yes" as soon as they felt a stimulation. If they gave three correct responses, the monofilament level decreased by two levels (i.e., to 14 mN). If all stimulations were felt again, the monofilament level increased by one level to the adjacent higher force level (20 mN). The procedure continued in this step-wise order (descending two levels, ascending one level) until an incorrect detection within one series was given (miss). If the participant missed one detection during the series of the three applications, the adjacent higher force level was tested. The procedure was terminated when two errors within one series were made and the monofilament above was noted as the tactile detection threshold. Exact time of stimulation within one series was unknown. We ran this staircase twice, gathering two threshold values that were averaged afterwards, to achieve a more reliable estimate.

To assess spatial acuity, we conducted a modified staircase procedure adapted from a protocol by Wang and colleagues [25]. Before the test session, participants received a familiarization phase during which the 3 mm stimulus was visually presented to them and instructions were given verbally in combination with three example trials. Participants had to report whether the grating was oriented horizontally or vertically and received verbal feedback. A short practice session followed: In 20 practice trials, using again the 3 mm grating, participants had to achieve an accuracy of 75% in order to not be excluded from further testing (as participants with thresholds of >3 mm would not be able to properly perform the adaptation aftereffect-task). No participant was excluded. Afterwards, the test session started, and the staircase began with the 3 mm grating. On each trial, grating orientation was randomized and had to be verbally reported by the participant. If the participant gave two consecutive correct answers, the next lower grating width would be used; if the participant gave one incorrect answer, the next greater grating width would be used. The session was completed when twelve transition points were identified. A transition point is defined as the stimulation changing from decreasing widths to increasing widths and vice versa. The average of the grating widths at the last eight transition points was used to determine the threshold, corresponding to the intensity producing approximately 71% correct responses [26, 27].

The adaptation-aftereffect experiment included a 10-minute break between the two main blocks that constituted the two conditions (distance adaptation and control), and a 5-minute break within each block. The order of conditions was randomized and counterbalanced between participants. Each trial consisted of an adaptation and a test phase. During adaptation, participants were touched multiple times across the finger pad of the left index finger with either the two-point (7 mm distance) or the single-point stimulus (control), in separate conditions (Fig. 1). Single applications of the adaptation stimulus were evenly distributed across the area with distinct space between consecutive applications as the aim was to adapt to the abstract property of distance (i.e., the spatial relation between two tactile events) rather than adapting exact locations on the skin. The adaptation per trial was conducted for 10 seconds in a typical trial. However, in the first trial of each condition block and after each break, we implemented an intensive 60 second adaptation phase. The adaptation durations were the same as in [12, 28, 29]. After the 10 (or 60) secs adaptation, two test stimuli were applied sequentially, one to each index finger pad with a one second interstimulus interval. Application of test stimuli started randomly and equally often on the left and the right hand. Participants had to judge if they perceived the first or the second stimulus to be larger and give their answer verbally without time restriction. The test stimuli of 5, 6, 7 mm were presented in 5 possible combinations: right index finger/ left index finger (RF/LF): 5/7, 5/6, 6/6, 6/5, 7/5, forming the RF/LF ratios 0.714, 0.833, 1, 1.2 and 1.4. The total trial number was 120 (5 pairs x 2 conditions × 12 repetitions per pair).

D. *Analysis*

Regarding the adaptation-aftereffect paradigm, we first computed for each participant the proportion of trials in which they judged the RF stimulus to be larger (note however, that the actual task of the participant was to indicate whether the first or second stimulus felt larger); separately for each RF/LF ratio and both adaptation conditions. For statistical analyses and fitting the data, we used common logarithms of the five RF/LF ratios to produce a symmetrical distribution from the point of actual equality (x = 1). For intuitive interpretation, we converted the mean of the logarithms back into ratios to report means. For each of the three adaptation conditions separately, we fitted cumulative Gaussian distributions (two free parameters: μ [alpha] and σ [beta]) as functions of the logarithmic RF/LF ratios to the individual participants' data, using a Maximum Likelihood criterion. For that, we used the Palamedes Toolbox [30]. The points of subjective equality (PSEs) were defined as the estimated RF/LF stimulus ratios at which subjects were equally likely to judge either the LF or the RF stimulus as larger. As an indicator of the perceptual bias, we use the difference between the PSE and the point of objective equality = 1. PSE values smaller than 1 indicate a tendency to perceive a distance applied to the adapted finger as smaller than it objectively is. PSE values larger than 1 indicate the opposite. To derive a value representing the "pure" aftereffect magnitude, we subtract for each participant the average PSE of the control condition, serving as a baseline, from the average PSE of the distance condition. Thus, the diffPSE is free from any systematic bias due to mere stimulation or hand preferences. For inferential statistics, a one-way repeated measures Analysis of Variance (ANOVA) on log PSEs was conducted to check for main effect of the "adaptation condition" (two levels: distance adaptation and control). Additionally, two one-sample t-tests against log 1 (= zero) were conducted to further assess the PSE-shift. Eight simple linear regressions were used to assess the relationship between skin properties, tactile abilities and aftereffect magnitude. We test whether there is a relationship between hydration and tactile sensitivity, expecting higher sensitivity for higher levels of hydration. Likewise, we test whether higher elasticity is related to higher sensitivity. We further test whether higher hydration and elasticity are also related to higher spatial acuity. Regarding the aftereffect magnitude, we check whether there is a relationship with hydration and elasticity, expecting higher aftereffects magnitudes for higher hydration and elasticity. We further test whether higher sensitivity and/or spatial acuity is related to higher aftereffect magnitude. Given that we test a set of predefined well-justified hypotheses, alpha-levels will not be adjusted [31, 32].

III. Results

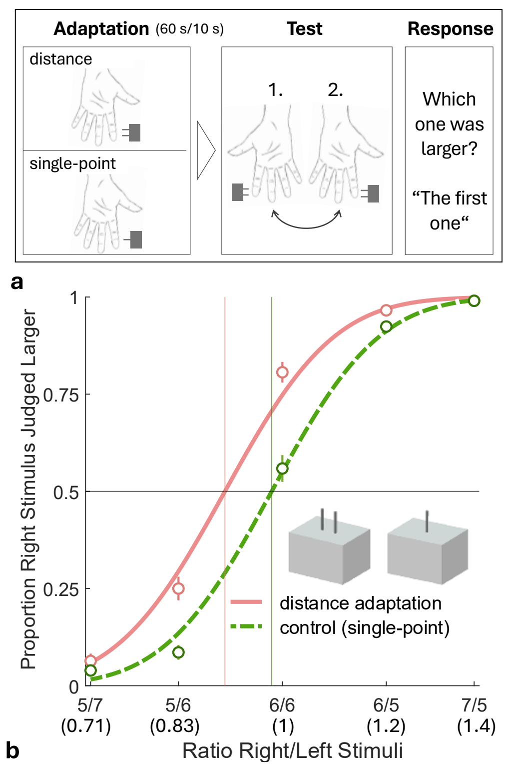

Fig. 1. a, Experimental procedure. b, Averaged psychometric functions for distance adaptation and control condition (N = 34). Every data point shows the fraction of times participants judged the stimulus presented to the right index finger as larger than the stimulus presented to the left index finger for each RF/LF stimulus ratio. Curves are cumulative Gaussian functions. Error bars represent SEM. Vertical lines represent mean PSEs.

Results showed that distance adaptation produced a substantial aftereffect in the expected direction, decreasing perceived size of the distance on the adapted finger when being adapted to the 7 mm distance, but not when receiving the single-point control. A one-way repeated measures ANOVA on log PSEs revealed a significant main effect of the within-participant factor "adaptation condition" (two levels: distance and control), $F_{1, 33} = 57.32, p = <.001, \eta^2 = 0.64$. One sample t-tests confirmed that the aftereffect appeared only in the distance adaptation condition (mean = 0.92, SD = 0.06, range: 0.78-1.04; t_{33} = -9.03, p = <.001, one-sided, d = −1.55), but did not occur in the control condition (mean = 0.98, SD = 0.06, range: 0.79-1.11; t_{33} = -1.63, p = .113, two-sided, d = −0.28).

Simple linear regressions were used to further assess the relationship between skin properties, tactile abilities, and aftereffect magnitude. Those showed strong relations between skin properties and tactile abilities, but no relationship of either with aftereffect magnitude. Linearity of the data as well as normality and homoscedasticity of residuals was visually inspected and approved (normality assessed with Q-Q plot and homoscedasticity by plotting actual residuals against predicted residuals) and residual independence was given (all p > .05 in Durbin-Watson test). Hydration and elasticity were highly correlated (r = 0.69, p > .001). Results of the first linear regression analysis indicated that hydration significantly explained 20.5% of the variance in tactile sensitivity, $F_{1,\,33}$ = 9.49, R^2 = 0.21, p = .004, with a standardized regression coefficient of -0.48, p = .004 (Fig. 2a), indicating lower sensitivity thresholds with higher levels of hydration.

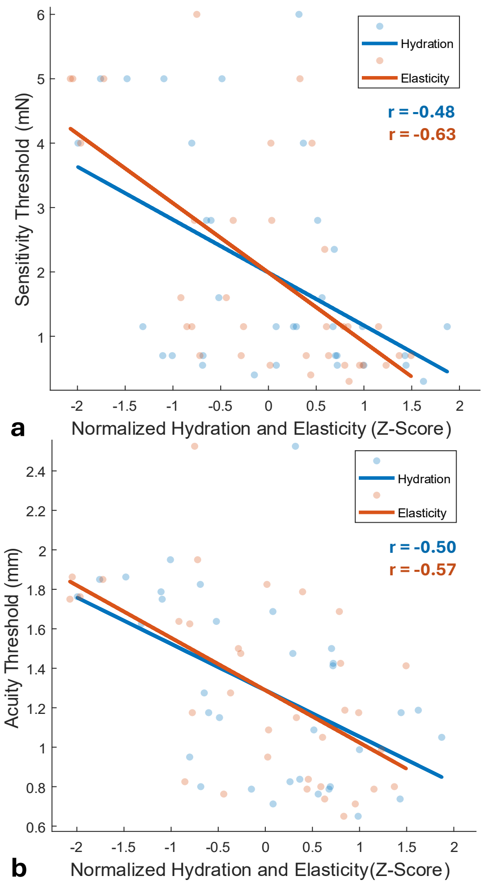

Fig. 2. a, Scatterplot including separate lines representing the linear regression of sensitivity (monofilament detection) on hydration and elasticity. For visualization reasons, hydration and elasticity are given as z-values. b, Scatterplot including separate lines representing the linear regression of acuity (ridge size in grating orientation discrimination) on hydration and elasticity.

Additional regressions indicated that hydration significantly explained 20.30% of the variance in spatial acuity, $F_{1,\,33}$ = 10.92, R^2 = 0.23, p = .002, with a standardized regression coefficient of -0.50 (Fig. 2b), indicating lower acuity thresholds with higher levels of hydration. Further, elasticity significantly explained 37.4% of the variance in tactile sensitivity, $F_{1,\,33}$ = 20.75, R^2 = 0.37, p = <.001, with a standardized regression coefficient of -0.63 (Fig. 2a), indicating lower sensitivity thresholds with higher levels of elasticity. Similarly, elasticity explained 30.4% of the variance in spatial acuity, $F_{1,\,33}$ = 15.39, R^2 = 0.34, p < .001, with a standardized regression coefficient of -0.57 (Fig. 2b), indicating lower acuity thresholds with higher levels of elasticity. In contrast, none of the regressions involving aftereffect magnitude as the dependent variable reached significance, i.e. hydration, elasticity, tactile sensitivity did not meaningfully explain variance in aftereffect magnitude (all p > .52) (Fig. 3).

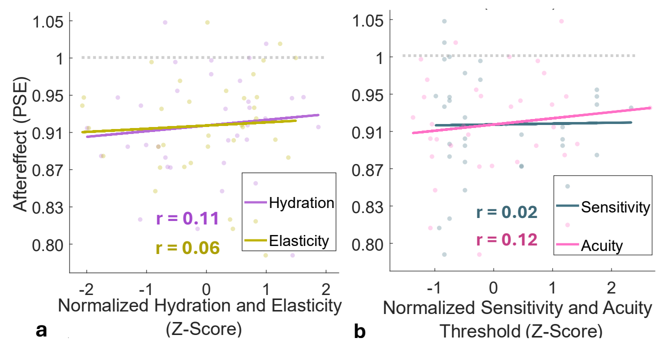

Fig. 3. a, Scatterplot including separate lines representing the linear regression of aftereffect magnitude (lower values indicate stronger magnitude) on hydration and elasticity. b, Scatterplot including separate lines representing the linear regression of aftereffect magnitude on sensitivity and acuity. Aftereffect values are computed as the difference value between distance adaptation and control condition. Calculations are done on the log-PSEs, those are transformed back to ratios and given here for intuitive reasons.

IV. Discussion

In this study we assessed inherent interindividual differences in skin properties and their relation to basic tactile abilities. Further, we assessed a potential relationship with tactile adaptation aftereffects, namely the tactile distance aftereffect. Specifically, we investigated whether interindividual differences in skin hydration and elasticity are associated with substantial differences in tactile sensitivity and spatial acuity and whether these in turn affect the individual susceptibility to tactile distance aftereffects. We found that indicators of skin health, i.e. higher hydration and elasticity, were related to improved tactile perception, i.e. higher tactile sensitivity and spatial acuity. These findings underline the importance of biophysical skin properties for tactile perception, particularly for detecting light pressure and discriminating spatial structures. The magnitude of the tactile distance aftereffect on the other hand seems to be mostly independent from both skin properties and the measures of tactile sensitivity and acuity. This suggests that certain perceptual processes such as adaptation might be rather independent from differences in sensory responses at the initial peripheral level, but interindividual differences in their expression might rather stem from cortical idiosyncrasies.

Our findings on the positive relationship between hydration and elasticity with tactile ability align with existing literature while also extending it, as previous research mostly either involved artificially altered skin properties via moisturizing agents [1–4] or venous occlusion [33], incorporated other perceptual objectives such as discrimination of compliance [6], focused on changes in the context of aging [8, 20, 34, 35], or investigated the consequences of skin mechanics for friction and vibro-temporal interactions without including psychophysical measurements [36–38]. We here demonstrate that a priori interindividual differences in skin disposition of young adults correlate with their ability to detect light pressure and recognize the orientation of fine structures. Notably, given that skin properties like hydration and elasticity decline with age due to reduced collagen and elastin [39], and tactile precision declines with age mostly due to a decrease in afferent density [7], this afferent density might be suspected as a confounding variable driving the effect, with skin properties merely representing covariates. However, as our sample is confined to a single age cohort (age range: 12 years), differences in afferent density due to aging would be marginal and the distinct contributions of skin properties to differences in tactile abilities are reemphasized. Regarding afferent density, one other covariate exists though which we did not explicitly measure: Finger pad area has been suggested to correlate negatively with afferent density (e.g., [40]), explaining for example gender differences for tactile sensitivity [41]. Notably, one study suggests hydration (but not elasticity) to correlate negatively with finger pad area [8]. Based on that, one could argue that the afferent density linked to finger pad area might be a confounder, which we cannot partial out. This seems negligible however, as elasticity is strongly related to tactile ability in the data of our study. Further, when including gender as a factor in the linear regressions, which is the main reason for differences on finger pad area differences in young adults [41], results do not substantially change (*r*s = -0.62 to -0.46). Taken together, potential confounders related to afferent density seem to be negligible, i.e. differences in tactile abilities observed in the current study are likely to be rooted in individual skin disposition. Notably, despite the narrow age range of our sample, we observed large interindividual variance in tactile abilities. While skin hydration and elasticity accounted for a significant portion of it (~20%), this suggests that additional, yet unidentified factors might be at play.

Further, we initially hypothesized that skin properties might influence aftereffect magnitude in a way that higher sensitivity and acuity, resulting from increased levels of skin hydration and elasticity, would increase the adaptation intensity and thus the subsequent aftereffect. Although this was not the case, one might argue that, alternatively, there is indeed an involvement of skin properties and basic tactile ability in aftereffect expression, but existing effects might simply cancel each other out: i.e., adaptation might be stronger when hydration, elasticity, and resulting tactile abilities are improved; but at the same time test stimuli might be perceived better, hence possibly reducing the aftereffect. The conclusion however that differences in skin properties do not systematically explain interindividual differences in the magnitude of this tactile aftereffect would still be valid. Note that we also checked mediation models to test whether tactile ability mediates a relationship between skin properties and aftereffect magnitude, potentially revealing any suppressed effects. We did not report these for the sake of brevity. As tactile ability neither had a mediating effect nor did it yield a separate prediction value for aftereffect magnitude, we further conclude that it would not mediate a relationship between e.g. afferent density and aftereffect magnitude. Overall, differences in intensity of sensory responses due to individual levels of tactile ability at the initial peripheral level do not seem to substantially contribute to the magnitude of subsequent adaptation aftereffects. If anything, then stronger and external manipulations might be needed to produce such effects [42], e.g. by manipulating application pressure (as an analog to e.g. visual contrast enhancement [17]), modulating attentional mechanisms [18], or varying the dissimilarity between adaptor and test stimuli. Intrinsic differences in the susceptibility to adaptation-aftereffects might instead be better explained by cortical differences in how sensitive the sensory system is to adaptation, modulating neural responses after prolonged exposure to an adapting stimulus. It is generally agreed that aftereffects, or the adaptation that is causing them, can be advantageous to the sensory system, rather than simply representing a failure of the system to accurately depict the world or being mere by-products of 'fatiguing neurons': Aftereffects can reflect neural strategies for optimizing perception, including calibration and gain control – which enables maximum use of the limited working range of neurons (see [43, 44]). For this reason, understanding why individuals vary in their inherent susceptibility to aftereffects seems particularly interesting, and future studies could tackle that by employing e.g. neuroimaging studies. Neuron tuning or receptive field size modulation have been previously proposed to be potential mechanisms responsible for tactile distance aftereffects; humans possibly differ in their tendency for these mechanisms.

Our findings reemphasize the importance of an individual's skin health for the functioning of tactile perception. Results further suggest that interindividual differences in the magnitude of tactile distance aftereffects are not substantially and systematically related to individual skin properties and associated differences in sensory responses. Skin properties hence show differential effects on different levels of tactile perceptual processes. Importantly, we do not exclude the possibility that tactile aftereffect magnitude can be modulated by input intensity, which could be tested in future works via experimental interventions. Interindividual variance in aftereffect magnitude though might rather be caused by inherent differences in the susceptibility to adaptation processes rather than peripherally caused input variations. One could speculate that these inherent tendencies might apply more generally to other aftereffects as well, which could be tested by comparing the magnitudes of different aftereffects on individual level. This would underline the stability of such cortically evolving processes.

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