The Importance of Contextual Grounding in Affective Mediated Touch

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***Abstract*— We explore the effect of contextual grounding in amplifying the conveyance of social information via mediated touch. We implemented two touch modalities for 6 emotion-based scenarios to capture a broader spectrum of haptic feedback: normal indentation and skin-slip. Participants were provided emotional touch cues with no context and were asked to report their perceived emotional state, and then repeated the same process while receiving prompts of the scenario alongside the touch cues. Our user study (N=20) reveals that contextual grounding significantly enhances ($p < 0.01$) the participants' ability to discern emotions.**

I. MOTIVATION

Human touch is saturated with purpose and intention. Touch serves as an intrinsic medium of expression stemming from the earliest stages of human development, communicating emotions and sentiments often beyond the scope of words. Infants as young as five months utilize touch as a means to convey their feelings [1]. As individuals mature, their responses to touch become intricately intertwined with evolving notions of sexuality and romantic attraction [2]. Understanding the profound power of touch — with its inherent ability to elicit positive responses and convey affective information [3] — has given rise to the research area of *affective haptics* [4]. Mediated touch, which uses technology to replicate touch in remote settings, has gained increasing attention, particularly during periods when social distancing was paramount due to the COVID-19 pandemic. However, persistent challenges lie in effectively transmitting genuine emotions and intentions through such mediated touch platforms [5]. The way people interpret touch varies widely based on cultural, personal, and situational factors. Further studies must be conducted to continue uncovering how to effectively portray human touch through technology.

A variety of psychosocial, situational factors, and toucher's characteristics are known to impact an individual's experience and responses to social touch. Research indicates that the toucher's status, whether as part of an in-group (individuals who share one's identity) or out-group (individuals who do not share one's identity), as well as biases towards different groups can influence the perception and experience of social touch [6]. For instance, handshakes or touch-based exercises by white British adults with an out-group member (in this case, a Muslim individual) have been demonstrated to boost positive sentiments towards the entire out-group [7]. The degree of familiarity between individuals is also considered to influence the perception of touch in interpersonal settings. Touch from someone familiar, such as a relative or close friend, is typically perceived as more pleasant compared to touch from a stranger [8]. It was also found that only 20% of body regions are acceptable for touch by strangers, compared to 70% by close relations [9]. Not only does familiarity of the toucher play a crucial role in the touch experience, but also the physical appearance (facial expressions, etc.) of the toucher. Smiling faces increase the perceived pleasantness of a gentle social touch on the forearm compared to frowning faces [10].

Given the multifaceted nature and profound impact of social touch, researchers have used a variety of methods to build haptic systems aimed at replicating human touch. Traditional haptic devices focused on providing tangible feedback through direct physical interactions [11]. Other haptic devices were designed to create touch illusions, which are mounted to the hands or the other parts of the body and display sensations directly to the skin [12]. Some modalities, or methods of physical stimulation, are better suited to distinct scenarios based on their ability to activate specific mechanoreceptors in the human skin. Vibration actuators, if properly spaced and timed, can create a sensation that travels across the skin in a continuous motion [13], [14], [15]. Rotating tactors can provide lateral skin-slip in a timed sequence [16]. Normal indentation, where actuators are controlled in a way that multiple indentations to the skin are activated with a certain delay [17] can also create a touch illusion. Using these modalities, researchers aim to diversify and enrich the palette of emotions and sensations conveyed through mediated touch [18].

Combining contextual factors with different modalities can enhance the clarity of information conveyed during mediated social touch. However, given the many factors at play [19], it is vital to prioritize and constrain certain elements for clarity. This paper investigates the impact of contextual grounding for mediated social touch. Our objective is to bridge the divide between affective perception and mediated touch. We first outline our touch modality configurations and renderings of the touch gestures (Section II), followed by the study we conducted to explore the effects of contextual grounding (Section III). Subsequent sections delve into our notable findings (Section IV) and their implications (Section V).

II. EXPERIMENTAL SETUP

The primary objective of our work was to investigate the impact of contextual grounding in mediated social touch. We sought to discern how different touch modalities influenced

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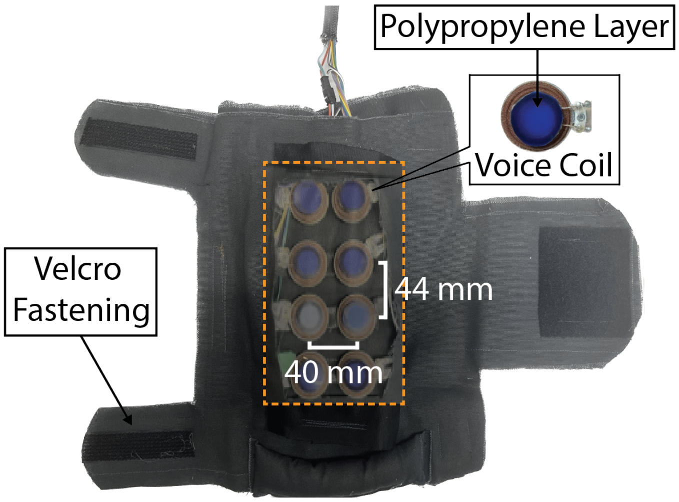

Fig. 1: Wearable device containing a 2×4 array of voice coils which provide stimuli using normal indentation.

perceived emotions, particularly when complemented with context in the form of audio descriptions. We evaluated two modalities for creating mediated social touch sensations: (1) normal indentation using voice coil actuators and (2) skin-slip using servo motor actuators. Our work focused on the same six emotions (attention, calming, gratitude, happiness, love, and sadness) from which data-driven touch cues were created in a previous study [20]. In this section, we describe the technical details of the design of the normal indentation and skin-slip haptic devices and their actuation signals.

A. Normal Indentation Device

To explore the impact of adding contextual grounding to touch cues provided by normal indentation, we used a 2×4 array of voice coils in a wearable sleeve [20] calibrated to distribute force across time and location (Fig. 1).

This modality has been previously validated for its ability to convey a comfortable and realistic touch illusion and its fidelity in transmitting the actuator's signal [17], [20]. To ensure force directionality and prevent the fabric's elasticity from diminishing the tactile feedback, we added an inelastic canvas patch along the sleeve's central region. The annular ring on the voice coil could cause discomfort, so we added a thin polypropylene layer to optimize force distribution, and included a fabric layer to thermally and electrically insulate the user from the actuators as done in [17], [20]. Each individual voice coil actuator (Tectonic Elements TEAX19C01-8) is able to achieve a 1.5 mm skin indentation as detailed. The sleeve was worn on the forearm of the non-dominant arm with the actuators lying on the dorsal side.

B. Skin-Slip Device

In order to similarly evaluate the effect of adding contextual grounding to skin-slip-based touch cues, we developed a device that built upon the skin-slip design presented in [16], [21]. Instead of a linear array of tactors as was done previously, for our skin-slip device (Fig. 2) we arranged 8 servo motors (DYNAMIXEL XC330-M181-T) in a 2×4 matrix, which were all securely mounted on a sturdy 3D-printed base. The tactor, affixed to the motor, was designed and 3D-printed to induce a skin-slip sensation upon motor rotation. A 3D-printed cover was designed to comfortably position the user's arm, and a white fabric cover was added to ensure the tactor makes smooth contact with the skin. A controller (OpenRB-150) was used to configure and control the motors directly from a PC. These motors, which can be commanded to rotate at varying speeds, apply shear force directly on the user's skin, eliciting a variety of tactile sensations.

C. Actuation Signals

The touch signals (Fig. 3(a)) were adopted from previous studies where researchers collected sets of sensor signal recordings through a pressure-sensing sleeve and mapped the sensor signals to normal indentation signals [20]. In this prior work, authors converted pressure data into sequences of floating-point numbers to indicate current levels from 0 to 1.0 A that would be used to command voicecoils to recreate the touch gesture (detailed in Section II-A). In our research, we must also convert the recorded pressure data and voice coil drive signals to signals that can equivalently drive the servo motors in our skin-slip device. To align the touch pattern generated by the skin-slip device to the one generated by the normal indentation device, we used the model presented in [16] to map the normal indentation signal to the depth of skin indentation caused by a servo motor (Fig. 3(b)).

To get a relationship between the current C and the depth of skin indentation from the servo motor D_{sm}, we first map current C to motor angle θ:

$$\theta = \arcsin\left(C + \frac{(C - C_{\min})(\sin\theta_h - \sin\theta_c)}{C_{\max} - C_{\min}}\right) \quad (1)$$

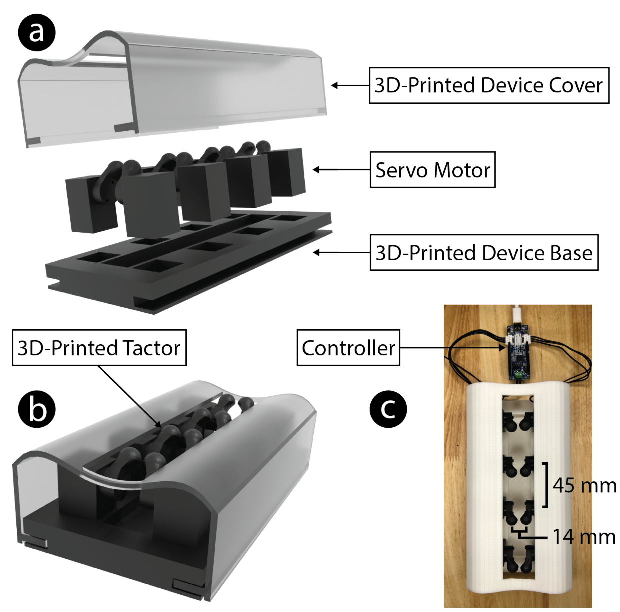

Fig. 2: Table mounted device which provides skin-slip stimuli using a 2×4 array of servo motor actuators.

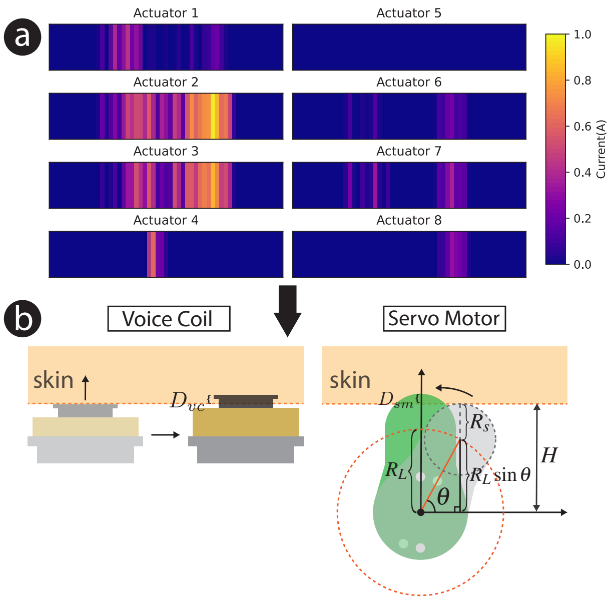

Fig. 3: Illustration of mapping from touch signal to actuation. a) Visualization of the time-series touch signal as a heatmap for each actuator. b) Illustration of a tactor's motion into the skin by normal indentation and skin-slip.

where $C_{min} = 0$, $C_{max} = 1$, $\theta_c = \theta$ when the tactor is just beginning to press into the skin, and $\theta_h = \theta$ when the tactor reaches its maximum indentation, which is 90°.

Given θ, D_{sm} was then calculated as:

$$D_{sm} = R_L \sin\theta + R_s - H \tag{2}$$

where R_L is the radius of the trajectory from the center point to the rounded top (14 mm), R_s is the radius of the rounded tactor tip that is in contact with the skin (6 mm), and H is the distance from the center of rotation to the skin.

H and θ_h were adjusted to match the maximum indentation by a servo motor, $D_{sm_{max}}$, to the maximum indentation by a voice coil $D_{vc_{max}}$, which is 1.5 mm.

III. User Study

We conducted a human subject study to determine the effect that context plays in mediated social touch communication and to compare the two presented touch modalities (Fig. 4). Twenty individuals (aged 19-32; 9 females, 11 males) participated in the study. Three of the participants had prior experience with haptic devices and 17 did not. The study was approved by the University of Southern California Institutional Review Board under protocol UP-19-00712, and all subjects gave informed consent. All individuals participated in both phases of the study (haptics only, followed by context and haptics), which took approximately 30 minutes.

Using immersive storyboards originally conceived by behavioral scientists, we strove to replicate genuine touch experiences within identifiable scenarios. Each touch signal was paired with a corresponding audio (and text) prompt to anchor the touch within a particular emotional context. We also introduced touch signals without any accompanying context, culminating in a total of twelve differentiated touch signals: six with narrative grounding and six without. These emotion-embedded scenarios (attention, calming, gratitude, happiness, love, and sadness) were first developed in [20] and are provided in the Appendix. To bolster the immersive experience, participants were isolated using temporary walls, emphasizing their full engagement.

Our study was designed and conducted in an attempt to support or refute these hypotheses motivated by prior work:

H1: The perception and interpretation of touch sensations are significantly influenced by the surrounding context, such that the same touch modality can elicit different emotional responses depending on whether or not situational context has been provided.

H2: The specific modality employed by a touch-based device can evoke unique emotional responses, distinct from those elicited by other modalities.

A. Phase 1: Haptics Only

In all trials, participants were seated at a table and wore headphones playing white noise to block sounds from the actuators. Phase 1, the no-context trials, were always conducted before Phase 2, context-provided trials, in order to avoid biasing participants' perception of the haptic cues. The order of the device was pseudo-randomized for each participant with half of the participants receiving normal indentation first and the other half receiving skin-slip first. Participants completed all trials for a single device before moving to the next one. The normal indentation device was worn on the lower portion of their non-dominant arm with the actuators lying on the dorsal side, and the participant rested their arm on the table. The skin-slip device was placed on the table, and the participant rested the dorsal side of their non-dominant lower arm on the device.

During the study, participants were instructed to imagine that someone was communicating to them through the device while receiving a haptic signal that corresponded to one

Fig. 4: User study setup. Participants wore noise-canceling headphones that played either white noise (phase 1) or audio descriptions of the social scenario (phase 2) and looked forward at a computer screen that provided the same descriptions of the social scenario via text during phase 2. Participants completed the study with both the normal indentation device (right) and skin-slip device (left).

of the six emotional prompts described above (attention, calming, gratitude, happiness, love, and sadness). Using the Self-Assessment Manikin (SAM) [22], participants rated the valence and arousal of the emotion they felt was being conveyed during the interaction. Since dominance is an indication of one's internal emotions, not conveyed emotions, we did not measure this component of the SAM in the study. Participants then repeated this process for the second device.

B. Phase 2: Context and Haptics

Participants completed the same trials as above with additional context provided to the interaction. The order of the devices was randomized, and a participant completed all trials before moving to the second device. At the beginning of each trial, an audio recording describing the social scenario was played and corresponding text was shown on the computer screen to provide context for the interaction. After the audio recording finished playing, the participants received the corresponding haptic cue. Participants then rated the valence and arousal of each interaction using the SAM [22] (excluding dominance) similar to Phase 1.

IV. Results

Participants' ratings of valence and arousal for all trials are shown in Fig. 5. We also plot benchmark valence and arousal values for the six emotions, which were found in previous research [23]. Fig. 5(a-b) shows the comparison of valence and arousal ratings with and without context. Fig 5(c-d) shows the comparison of valence and arousal ratings across the two modalities.

To determine the effect of context and actuation type on participants' ratings of valence and arousal, we conducted a two-way ANOVA for each distinct touch signal with context and actuator type as factors and either valence or arousal as the dependent variable (Table I). In our analysis, we first concentrated on the interaction effects between the two factors. If no significant interaction effect emerged, the main effects were highlighted; if there was a significant interaction, we further examined the individual effects of each factor. Given that our independent variables were binary (context or no context and voice coil or servo motor), post-hoc tests were omitted. Additionally, we conducted a Bland-Altman analysis to assess the agreement between observed data and established benchmarks regarding the context and type of actuation to further investigate which contextual settings and actuation modes align observed emotional responses more closely with the established emotional connotations of the touch signal (Table II). These established benchmarks are taken from prior work which collected the associated emotional ratings, in terms of valence, arousal, and dominance, of the English words themselves [23].

A. Valence

The two-way ANOVA shows that there was a main effect of the existence of context on associated valence ratings for sadness, happiness, calming, gratitude, and love. However, the presence of context did not significantly influence the valence ratings associated with attention. The type of actuation did not have a significant effect on any of the emotion-based touch signals. Furthermore, no interaction effect was observed between the existence of context and type of actuation for all six touch signals with emotion. The Bland-Altman analysis reveals a reduced absolute mean difference in valence relative to established benchmarks when context is enabled. This observation holds true across all five emotions which shows a significant main effect of context on associated valence in the previous two-way ANOVA.

B. Arousal

The two-way ANOVA shows that there was a main effect of the existence of context on associated arousal for sadness, attention, happiness, gratitude, and love. No significant effect of the existence of context on arousal was observed for calming. Regarding the type of actuation, a main effect was observed on the associated arousal for sadness, calming, and gratitude. However, for the other three touch signals (attention, happiness, and love), no significant difference in arousal was identified. Additionally, there was no interaction effect between the presence of context and the type of actuation across all six touch signals. The Bland-Altman analysis reveals a decrease in the absolute mean difference in arousal compared to established benchmarks when context is enabled for the emotions of attention, love, and sadness. However, the same result does not hold for gratitude and happiness. For the type of actuation, our observations indicated a lower absolute mean difference in arousal relative to established benchmarks in the case of calming and gratitude when using voice coil actuators. However, a lower absolute mean difference was noted for sadness when employing servo motor actuators.

V. Discussion

The present study provides insights into the nuanced relationship between context, touch modalities, and the emotional perception of the interaction. Our study revealed that the emotional resonance of mediated touch is significantly enhanced by its contextual grounding, underscoring the need to consider the environment and circumstances in which it is experienced for a fuller understanding of its impact. From Fig. 5(a) and Table II, it is evident that when context is enabled, it effectively guides participants' perceptions of valence to align with the inherent valence of the interaction, as defined by the established benchmarks. This finding emphasizes the profound influence that context can have in interpreting and understanding conveying emotions with touch signals. In Fig. 5(b), the presence of context significantly elevates participants' perceived arousal levels in general, highlighting the potential of context in modulating and amplifying the perceived intensity of emotional stimuli. It is crucial to note, however, that a heightened arousal level does not inherently signify a more accurate emotional connection since our findings suggest that while there is a significant increase in rated arousal levels for gratitude and happiness when context is enabled, they do not necessarily converge toward the established benchmarks. In conclusion, our results

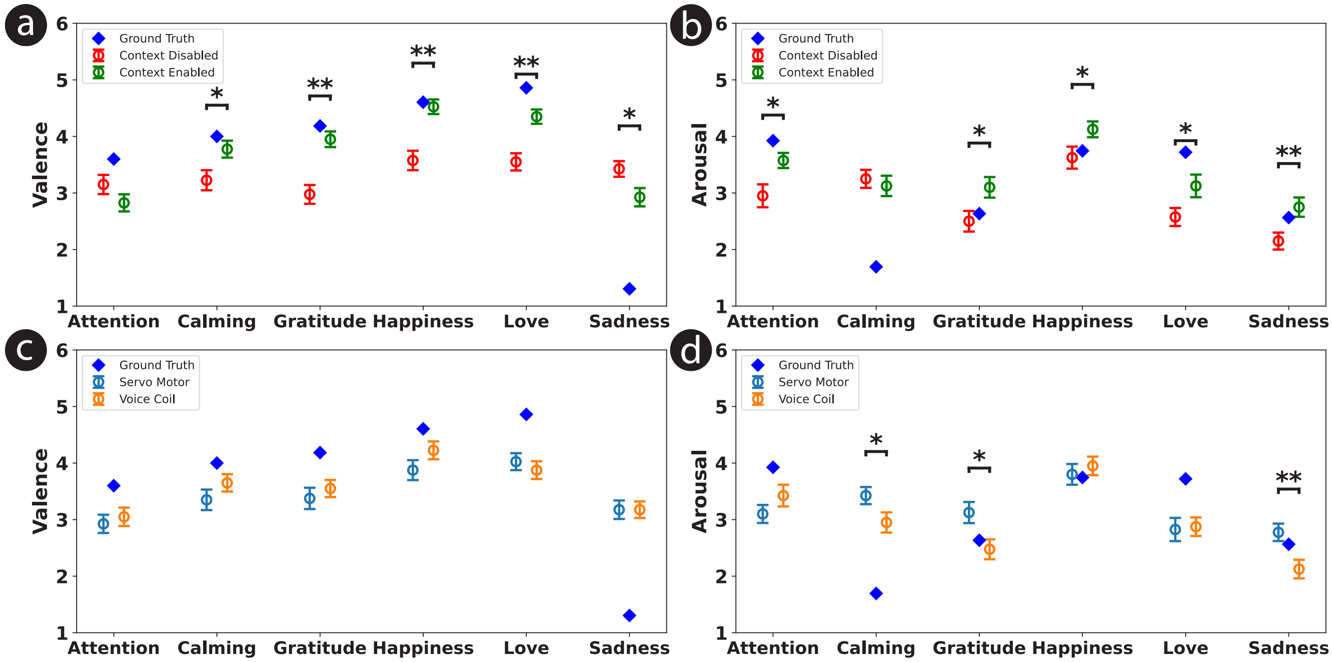

Fig. 5: Ratings of valence (a and c) and arousal (b and d) in relation to main effects: the existence of context (a and b) and the type of actuation with context and without context (c and d) across various emotion touch signals. Data is presented as mean ± standard error, where *: $p < 0.05$ and **: $p < 0.01$. The established benchmarks of valence and arousal for each context are presented as a blue diamond. The original benchmark value has been linearly adjusted to fit within our specified range.

Signal Emotion	Source	Valence				Arousal			
		df	*F*	*p*	η^2	*df*	*F*	*p*	η^2
Attention	Context	1	1.996	.161	.025	1	6.653	**.012***	.079
	Actuation	1	.295	.588	.004	1	1.799	.184	.021
	Context:Actuation	1	.106	.745	.001	1	.266	.607	.003
Calming	Context	1	5.600	**.021***	.067	1	.280	.598	.003
	Actuation	1	1.666	.201	.020	1	4.047	**.048***	.050
	Context:Actuation	1	.046	.830	.001	1	.549	.461	.007
Gratitude	Context	1	20.027	**<.001****	.207	1	5.754	**.019***	.065
	Actuation	1	.645	.424	.007	1	6.753	**.011***	.076
	Context:Actuation	1	.119	.732	.001	1	.040	.842	.001
Happiness	Context	1	20.323	**<.001****	.201	1	4.343	**.041***	.053
	Actuation	1	2.759	.101	.027	1	.391	.534	.005
	Context:Actuation	1	2.027	.159	.020	1	1.563	.215	.019
Love	Context	1	16.079	**<.001****	.173	1	4.649	**.034***	.056
	Actuation	1	.565	.454	.006	1	.038	.845	.001
	Context:Actuation	1	.063	.803	.001	1	2.459	.121	.030
Sadness	Context	1	5.421	**.023***	.066	1	7.632	**.007****	.082
	Actuation	1	.001	.999	.001	1	8.957	**.004****	.096
	Context:Actuation	1	.488	.487	.001	1	.477	.492	.030

TABLE I: Two-way ANOVA assessing associated effect of the existence of context and type of actuation on emotion scales across different touch signals with emotion. *: $p < 0.05$ and **: $p < 0.01$.

show that the presence or absence of an emotional framework (context) significantly influences an individual's perception of affective mediated touch. In instances where the context was provided, participants' understanding of the emotions being transmitted was significantly altered. This observation lends credence to our first hypothesis (**H1**), reinforcing the notion that context is not merely an ancillary element but a fundamental aspect of mediated touch communication.

Our exploration into perceived emotions across different touch modalities yielded intriguing results. As shown in Fig. 5(c), the distinctions in perceived valence across modalities were not as pronounced as one might anticipate. In essence, irrespective of the tactile modality employed, associated valence remained largely consistent, indicating that both modalities are able to equivalently transfer the information regarding the embedded valence of the touch signal. Fig. 5(d) suggests a significant increase in perceived arousal when using skin-slip as the actuation type for calming, gratitude, and sadness. The increased arousal observed in gratitude and sadness may be attributed to the skin-

Signal Emotion	Emotional Scale	Source	μ	σ	Upper LoA	Lower LoA
Calming	Valence	**With Context**	-0.225	0.947	1.631	-2.081
		Without Context	-0.775	1.121	1.421	-2.971
Gratitude	Valence	**With Context**	-0.240	0.876	1.476	-1.956
		Without Context	-1.215	1.049	0.842	-3.272
Happiness	Valence	**With Context**	-0.085	0.816	1.515	-1.684
		Without Context	-1.035	1.083	1.088	-3.158
Love	Valence	**With Context**	-0.510	0.802	1.062	-2.082
		Without Context	-1.310	0.959	0.570	-3.190
Sadness	Valence	**With Context**	1.615	1.023	3.619	-0.389
		Without Context	2.115	0.874	3.828	0.402
Attention	Arousal	**With Context**	-0.345	0.844	1.309	-1.999
		Without Context	-0.970	1.280	1.539	-3.479
Gratitude	Arousal	With Context	0.470	1.150	2.724	-1.784
		Without Context	-0.129	1.154	2.133	-2.393
Happiness	Arousal	With Context	0.375	0.883	2.105	-1.355
		Without Context	-0.125	1.233	2.293	-2.543
Love	Arousal	**With Context**	-0.595	1.264	1.883	-3.073
		Without Context	-1.145	1.009	0.834	-3.124
Sadness	Arousal	**With Context**	0.189	1.080	2.307	-1.927
		Without Context	-0.410	0.948	1.449	-2.269
Calming	Arousal	Servo Motor	1.725	0.958	3.602	-0.152
		Voice Coil	1.250	1.131	3.467	-0.967
Gratitude	Arousal	Servo Motor	0.495	1.180	2.809	-1.819
		Voice Coil	-0.154	1.109	2.018	-2.328
Sadness	Arousal	**Servo Motor**	0.214	0.973	2.123	-1.693
		Voice Coil	-0.435	1.042	1.608	-2.478

TABLE II: Bland-Altman analysis to evaluate the agreement of the existence of context and type of actuation with established benchmarks on emotion scales across different touch signals with emotion. The table selectively presents paired comparisons that exhibited a significant main effect in the preceding Two-way ANOVA analysis. Within this table, settings that show a higher degree of agreement with the established benchmarks are highlighted in bold for emphasis. μ: mean difference from established benchmarks, σ: standard deviation of differences from established benchmarks, Upper LoA: upper limit of agreement, Lower LoA: lower limit of agreement.

slip motion generated by the servo motors, which seems to produce a more solid and intense sensation compared to the linear motion generated by normal indentations regarding gestures resembling a grab or squeeze, indicating the need for further investigation on how different actuation types and their physical properties impact the conveyance of emotions for various social touch gestures. This outcome has led us to reevaluate our hypothesis 2 (**H2**), which did not find empirical support in our current experiment. The explanation for this phenomenon may be rooted in the inherent nature of skin deformation. Both normal indentation and skin-slip, while distinct in their tactile presentation, deform the skin. This commonality could potentially be the linchpin in ensuring consistent emotional interpretations. It underscores the notion that, at a fundamental level, certain touch modalities might share overlapping emotional footprints, due to their shared end-effect on the skin.

This discovery also emphasizes the necessity of simultaneously investing in the development and optimization of emotionally rich contextual scenarios when designing mediated touch experiences. By doing so, it is possible to bridge the gap between pure tactile sensations and the genuine emotional messages they aim to convey, ensuring a more holistic and impactful user experience. In a prior investigation, Askari et al. [19] demonstrated that the textual tone markedly influences the perception of comfort and dominance in mediated social touch. Our findings further suggest a profound effect on emotional responses. Future investigations might delve deeper into the granularity of context (e.g. in VR), examining which elements or narratives more effectively enhance the impact. Additionally, contextual factors can be employed as statistical priors for quantitatively evaluating affective mediated touch, integrating the essence of touch with machine learning-derived metrics.

VI. Conclusion and Future Work

In this work, we explored the significance of contextual grounding in conveying information through mediated touch. We crafted two distinct touch modalities and integrated a suite of six emotive prompts to establish affective context. Results from our 20-participant study underscored that context-enhanced mediated touch substantially amplifies the valence and arousal of the provided sensation. Interestingly, minimal differences were observed between the touch modalities. Future efforts will focus on exploring a broader range of modalities and integrating more comprehensive contextual grounding techniques, with the aim of establishing a robust and affectively resonant mediated touch environment.

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APPENDIX

Social Scenarios

- Attention: "You're at a crowded party with the person sitting next to you, but you've drifted off into a side conversation with other people. The person you're talking to is telling you a fascinating story, and you're completely rapt. It's like no one else is in the room. You're not purposefully ignoring the person you came to the party with, but you're really focused on hearing all the details. Then, the person you came to the party with touches you in a way that signals they need your attention."
- Calming: "What a crappy week. You're stressed out, and things just keep piling on. You really aren't in the mood to meet the person sitting next to you for dinner, but you can't back out now. You walk through the door in a state, and that must show because they reach out and touch you in the most compassionate and tender way. You feel instantly understood, and it brings a wave of calm. Your blood pressure feels like it just dropped 20 points, in a good way."
- Gratitude: "You and the person sitting next to you are at a dinner party with a group of friends you've known for a long time. You have a knack for being able to spot a train wreck before it happens, so when you sense the conversation is getting dangerously close to a topic that could damage the reputation of the person sitting next to you, you steer it back on track. You don't expect any credit for such agile social maneuvers, but when they reach out and telegraph "thank you" with their touch, you instantly know you've done good."
- Happiness: "When the person walking toward you just can't stop smiling, you know something is going really right. They're beaming, and you can just tell they're having the best day ever, almost walking on clouds. They bound over to you and reach out to touch you, and it's like an electric bolt of pure joy flows through you."
- Love: "You and the person sitting next to you are spending the afternoon together. You're walking to get a bite, the weather is amazing, and you're catching up on everything in the way that friends do. You look at them, and it suddenly strikes you how much this friendship means to you, that life is so much easier and better with them around. They reach out to express their love for you."
- Sadness: "Even if it doesn't say anything out loud, a heavy heart is a loud presence. It's almost like another person in the room. Or maybe instead of a presence what you are feeling is an absence. The absence of joy. It seems like the person next to you is in mourning, like they've lost something that was important to them. That makes you instantly want to fill up the space with something like compassion or help or just being there."