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Using facial electromyography to assess facial muscle reactions to experienced and observed affective touch in humans

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Corresponding Author:	Leah Mayo, PhD Linköping University Linköping, Non-US or Canadian Address SWEDEN
Corresponding Author's Institution:	Linköping University
Corresponding Author E-Mail:	leah.mayo@liu.se
Order of Authors:	Anbjørn Ree
	India Morrison
	Håkan Olausson
	Uta Sailer
	Markus Heilig
	Leah M. Mayo, PhD
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Dr. Leah M. Mayo
Center for Social and Affective Neuroscience
Linköping University
SE-58431 Linköping, Sweden

Dr. Aaron Berard
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Dr. Berard,

We are pleased to submit the revised version of our manuscript, "Using facial electromyography to assess facial muscle reactions to experienced and observed touch in humans" for publication in the *Journal of Visualized Experiments.*

We are grateful to the editor and reviewers for their thorough and constructive feedback. As requested, we have made extensive changes to the manuscript, including a more directed protocol, a more detailed results section, and a more thorough discussion. We have also included additional figures and a table including details of our tasks. Most importantly, we have included enough information to ensure that others can replicate our experimental setup in their own endeavors to explore affective touch using facial electromyography.

We hope that the editor and reviewers find our revisions to be satisfactory on all accounts, and will be happy to provide further clarifications if needed.

Sincerely,

Leah M. Mayo
(on behalf of all authors)

TITLE:

Using Facial Electromyography to Assess Facial Muscle Reactions to Experienced and Observed Affective Touch in Humans

AUTHORS & AFFILIATIONS:

Anbjørn Ree[1], India Morrison[2], Håkan Olausson[2], Uta Sailer[1], Markus Heilig[2], Leah M. Mayo[2]

[1]Department of Behavioral Sciences in Medicine, Institute of Basic Medical Sciences, Faculty of Medicine, University of Oslo, Norway

[2]Center for Social and Affective Neuroscience, Department of Clinical and Experimental Medicine, Linköping University, Sweden

Corresponding Author:

Dr. Leah M. Mayo (leah.mayo@liu.se)

Email Addresses of Co-Authors:

Anbjørn Ree (anbjorn.ree@medisin.uio.no)

India Morrison (india.morrison@liu.se)

Håkan Olausson (hakan.olausson@liu.se)

Uta Sailer (uta.sailer@medisin.uio.no)

Markus Heilig (markus.heilig@liu.se)

KEYWORDS:

facial electromyography, C-tactile afferents, affective touch, affect, emotion, corrugator

SUMMARY:

We describe a protocol to assess facial muscle activity in response to experienced and observed tactile stimulation using facial electromyography.

ABSTRACT:

“Affective” touch is believed to be processed in a manner distinct from discriminatory touch and to involve activation of C-tactile (CT) afferent fibers. Touch that optimally activates CT fibers is consistently rated as hedonically pleasant. Patient groups with impaired social-emotional functioning also show disordered affective touch ratings. However, relying on self-reported ratings of touch has many limitations, including recall bias and communication barriers. Here, we describe a methodological approach to study affective responses to touch via facial electromyography (EMG) that circumvents the reliance on self-report ratings. Facial EMG is an objective, quantitative, and non-invasive method to measure facial muscle activity indicative of affective responses. Responses can be assessed across healthy and patient populations without the need for verbal communication. Here, we provide two separate datasets demonstrating that CT-optimal and non-optimal touch elicit distinct facial muscle reactions. Moreover, facial EMG responses are consistent across stimulus modalities, e.g. tactile (experienced touch) and visual (observed touch). Finally, the temporal resolution of facial EMG can detect responses on timescales that supersede that of verbal reporting. Together, our data suggest that facial EMG is

a suitable methodology for use in affective tactile research that can be used to supplement, or in some cases, supplant, existing measures.

INTRODUCTION:

C-tactile (CT) afferents are proposed to convey the affective component of touch, which can be distinguished from the discriminative aspects of touch processed via Aβ fibers[1,2]. CT-mediated affective touch is believed to play an integral role in social affiliative behaviors[3], leading to the "skin as a social organ" hypothesis[4]. Physical[5,6], developmental[7], and psychiatric[8,9] factors can influence CT-mediated touch processing. Thus, establishing an objective measure to quantify affective reactions to CT-relevant touch is critical to allow for comparisons across populations.

In recent years, much insight has been gained regarding the characteristics of CT afferents. These unmyelinated afferents demonstrate an inverted U-shaped firing frequency, with velocities of 1-10 cm/s ("CT-optimal") eliciting the greatest frequency and both greater ("fast non-optimal") or lesser ("slow non-optimal") velocities eliciting reduced firing[10]. CT firing frequency correlates with self-reported ratings of touch "pleasantness", producing a similar inverted U-shaped curve in pleasantness ratings[10]. Moreover, CT-afferents also respond most robustly to stimuli close to skin temperature[11]. These fibers also show distinct conduction speeds. The unmyelinated CT afferents are slower[2] and thus the volley of afferent input to the cortex shows a temporal lag when compared to the speed of the faster, myelinated Aβ fibers[1,12]. Affective and discriminative touch can also be distinguished on a neural level. While both types of touch activate overlapping somatosensory areas, affective touch is more likely to activate the posterior insula, while discriminative touch activates sensorimotor areas[13-16]. This activation pattern is consistent whether the touch is directly experienced or merely observed[17], suggesting that affective touch is not just a "bottom-up" process driven by physical activation of CT afferents, but also involves "top-down" integration of multimodal sensory processing.

Situations in which CT processing is deficient or otherwise atypical has also provided insight into the functional significance of these afferents. In a unique patient group with a heritable mutation affecting the nerve growth factor β gene, there is a reduction in the density of thin and unmyelinated nerve fibers, including CT afferents. Compared to healthy controls, these patients report touch at CT-optimal velocities as less pleasant[5]. The converse scenario is also true; patients who lack myelinated Aβ fibers are able to retain a faint sensation of pleasant touch carried by the still intact CT afferents[6]. Abnormal affective touch processing is not just confined to instances of physical changes in CT-afferents. Across patient and healthy populations, those higher on the spectrum of autistic traits reported reduced pleasantness ratings of touch[8]. Psychiatric patients also demonstrate reduced hedonic ratings of affective touch, with a history of childhood maltreatment as one of the most consistent predictors of dysregulated affective touch awareness[8]. Dysregulation in the CT-based affective touch system in anorexia nervosa has also been reported[9]. Thus, both physical and psychological factors can influence affective touch processing, and as such, it is imperative to establish methodologies that can be applied to all individuals in an equitable and comparable manner.

Insights into normo-typical and dysregulated affective processing have the opportunity to

provide a more nuanced picture of many patient groups. However, one potential limitation of affective touch research is the necessity of self-reported ratings. At times, self-report can be unreliable[18] and subject to recall bias[19]. Inquiries of self-report can psychologically remove a participant from the current setting, limiting the ecological validity of the responses and removing them temporally from the experience[20]. Moreover, self-report relies on a firm understanding of language and semantics, making cross-cultural and developmentally diverse (e.g. infant and toddler-aged individuals) comparisons challenging. For instance, individuals with an autism spectrum diagnosis frequently show distinct behavioral responses to touch[21], but can also have difficulties in communicating verbally[22]. Thus, finding non-invasive methods to measure responses to touch that circumvent a reliance on self-report may translate, at least, to a better understanding of the mechanisms of affective touch, and at most, novel insights into dysregulation of social processing in patient populations.

Facial electromyography (EMG) is a suitable candidate to objectively assess affective responses to touch. It has been used to measure valence-specific reactions to visual[23], audio-visual[24], olfactory[25], and gustatory[26] stimuli. Facial EMG is a safe and non-invasive method consisting of surface electrodes that adhere to the face[27]. These surface electrodes record facial muscle activity continuously in real-time with time scale sensitivity in the tens of milliseconds. Of particular interest is the corrugator supercilii ("corrugator"), which is activated when furrowing the brow and relaxes during a smile. As a result, corrugator activity has a linear relationship with affective valence, with increased response to negative stimuli and decreased activity in response to positive stimuli[28]. In addition, the zygomaticus major ("zygomatic") is the muscle activated as the corners of the mouth pull up into a smile. The zygomatic displays a "J-shaped" activation pattern with positive stimuli eliciting the greatest response, and the most negative stimuli eliciting a greater response than neutral stimuli[28]. Facial EMG recordings of these muscles can even be observed when stimuli are presented outside conscious awareness or when individuals are explicitly trying to suppress their reactions[29,30]. Importantly, facial EMG can be used alone or in combination with self-report ratings or other physiological recordings. Thus, it is an ideal methodology to assess affective reactions to tactile stimulation[31,32].

In sum, facial EMG can be combined with self-report ratings to determine how CT-optimal tactile stimulation influences facial muscle activity as a potential indicator of affective response. One can take advantage of the velocity-dependent firing frequency of CTs to apply touch at CT-optimal and non-optimal velocities, and touch can be applied both to the CT-rich arm and the putatively CT-lacking palm. Comparisons can be made across modalities to determine whether affective responses to touch require direct stimulation or can be elicited via mere observation, suggestive of shared processing across sensory modalities. Finally, upon establishing facial EMG as a suitable methodology to study affective reactions to affective touch, researchers can then explore how affective touch processing may be influenced by various interventions (e.g., drug administration; stress exposure), how it changes throughout development[7], how it is influenced by the relationship of the interactants[33], and whether it is dysregulated in clinical populations[8].

PROTOCOL:

This protocol is based on Mayo et al.[31] (Experiment 1) and Ree et al.[32] (Experiment 2). Ethical approval was granted by the Regional Ethical Review Board, Linköping, Sweden (Experiment 1) and the local ethical committee at the Department of Psychology, University of Oslo, Norway (Experiment 2).

1. Participant screening and preparation

1.1. Recruit participants who lack tactile or uncorrected visual disturbances and are free of any neurological or psychiatric disorder, unless a specific patient population is being recruited.

1.2. Ensure that participants are fully able to understand task instructions (e.g., fluent in the language that tasks are administered).

1.3. If including more than one task (e.g. Experienced, Observed), ensure that task order is counterbalanced across participants, stratifying for gender, age, or other distinguishing factors.

2. Stimuli and task construction

NOTE: See **Table 1** for experimental design.

2.1. Experienced touch task (Experiments 1 and 2)

2.1.1. Create trials such that they consist of a baseline period, touch administration, and self-report ratings, all separated by jittered ITIs.

2.1.1.1. Baseline periods consist of a blank screen, fixation cross, or other neutral scene prior to tactile stimulation.

2.1.1.2. Tactile stimulation is followed by a short (e.g. 1-2 s) ITI, then self-report ratings are obtained.

2.1.1.3. A jittered inter-trial interval (ITI; e.g. 6-7 s) follows self-report ratings to allow muscle activity to return to baseline levels before the next trial begins.

2.1.2. Use either audio (Experiment 1[31]) or visual (Experiment 2[32]) cues to ensure that touch is delivered at the appropriate velocity.

2.1.2.1. To use audio cues, have cues delivered to headphones worn by the experimenter to track the pace of the stimulation using a metronome. Distinguish velocities using tones of differing pitches (or other distinguishing audio cue, e.g., a cue saying “10 cm/s”) that precede the stimulation cues.

2.1.2.2. To use visual cues, display cues on a tablet only in view of the experimenter. Use a moving bar to track velocity of touch administration.

2.1.3. Prior to the start of the study, practice to ensure that touch is delivered at the appropriate velocity and a consistent pressure. To do so, apply brushstrokes to the scale in a similar manner as to the participant. The scale readout is used to determine if the pressure changes throughout touch administration. For instance, a pressure of 0.4 N would read as 40 g on the scale.

2.2. Observed touch task (Experiment 1)

2.2.1. Ensure that videos of touch administration are of similar length, regardless of velocity.

2.2.1.1. Include both CT-optimal (1-10 cm/s) and non-optimal (less than 1 cm/s or more than 10 cm/s) velocities.

2.2.2. Start trials with a fixation cross or other neutral condition followed by video.

NOTE: Videos contain touch delivered to CT-rich hairy skin (arm), CT-lacking glabrous skin (palm), and a non-social condition in which touch is delivered to a fake wooden arm (Fig. 2; see supplemental videos).

2.2.2.1. After a 1-2 s ITI, obtain self-report ratings.

2.2.2.2. Allow another 6-7 ITI following ratings to precede the next trial to allow EMG activity to return to baseline.

3. Facial electromyography

3.1. Data acquisition and filtering guidelines (based on previous protocols[27,34])

3.1.1. Use software to apply filtering steps either in real-time or offline. Typical filtering steps include a comb band stop filter to filter out potential noise from AC power (50/60 Hz), followed by smoothing and rectification.

NOTE: Initial basic filtering steps may be set on EMG amplifiers (e.g., a high pass filter of 10 Hz and a low pass filter of 500 Hz or 1000 Hz).

3.2. Electrode application (based on previous protocols[27,34])

3.2.1. Briefly describe the application process to the participant. Use neutral words (“sensor”) instead of potentially anxiety-evoking words (“electrode”)[34].

3.2.1.1. Decide what information to tell the participants regarding the purpose of the sensors.

NOTE: In the current studies, participants were told sensors would measure muscle and sweat activity during the session.

3.2.2. Clean the participants' skin prior to electrode application.

3.2.2.1. Use water to wipe clean the areas in which sensors will be applied.

3.2.2.2. Use an exfoliant scrub to lightly abrade the same areas. Use caution to prevent major skin irritation, though minor irritation is likely to occur.

3.2.3. Use electrode pairs consisting of two 4 mm shielded bipolar recording electrodes plus one monopolar reference electrode.

3.2.3.1. Apply adhesive collars to the electrodes such that they adhere to the skin.

3.2.3.2. Once collars adhere to the outer rim of the electrodes, fill sensors with a conductive electrode gel, taking care to prevent the formation of air bubbles.

3.2.4. Place electrode pairs parallel to the muscle(s) of interest and perpendicular to potential sources of noise, such as other muscles[34].

3.2.4.1. Corrugator: Affix one electrode directly above the eyebrow along an imaginary vertical line that traverses the inner corner of the eye. Place the second electrode 1 cm lateral and slightly superior to the first, along the border of the eyebrow.

3.2.4.2. Zygomatic: Place the first sensor midway along an imaginary line that connects the upper ear (where the ear meets the skull) and the corner of the mouth. Place the second electrode 1 cm medial (towards the mouth). Take care to avoid the masseter muscle.

3.2.4.3. Use an 8 mm unshielded, monopolar recording electrode as a reference electrode. Place the electrode in the middle of the forehead, equidistant (above) the inner brows and (below) the hairline.

3.2.4.4. Ensure that electrode wires are placed such that they do not impede vision. Use medical tape to ensure long-term adherence of the electrodes to skin and reduce noise/artifacts due to cord movement.

3.2.5. Determine the quality of electrode application with an impedance monitor. Acceptable impedance levels are below 20 kΩ. If electrodes need to be reapplied to reach appropriate impedance levels, use a clean pair of electrodes.

4. Task procedure

4.1. General order

4.1.1. Following sensor application, complete task(s). If using more than one task,

counterbalance order across participants.

4.1.2. Ensure that participants are seated comfortably to minimize extraneous movement that may introduce movement artifacts[34].

4.2. Experienced touch task

4.2.1. Seat participants in front of computer with the to-be-touched arm extended laterally, resting comfortably (e.g., on a cushion).

NOTE: It is recommended to apply touch to the arm that is not being used for self-reported ratings in order to minimize potential movement artifacts in the EMG signal.

4.2.2. Occlude view of the arm from the participant either using a curtain separator[31] or goggles that occlude lateral vision (**Figure 1**[32]) [35].

4.2.3. Instruct the participant to focus on how the touch makes them feel.

4.2.4. Vary touch location to avoid CT fatigue[36].

4.2.5. Administer touch using a 75 mm goat hair brush applied to designated section(s) marked on the arm (and palm). Alternatively, apply touch using a force-controlled robot[37].

4.2.6. Use consistent touch administration direction, e.g., back-and-forth (distal-to-proximal, then proximal to distal) or single direction (proximal-to-distal only)

4.3. Observed touch task

4.3.1. Seat participant in front of the computer that will display the videos.

4.3.2. Instruct the participant that they will have to rate how the video made them feel.

4.3.3. Ensure that the participant is out of view of the experimenter[34].

5. Data cleaning and analysis

5.1. To assess the mean EMG activation to a specific touch stimulus type, compare the response to the touch stimulus to the preceding baseline, i.e. [mean activation during 6 s touch stimulation] – [mean activation during 1 s prestimulus "baseline"], as suggested by Fridlund and Cacioppo[34].

5.1.1. Average responses for each touch stimulus type (CT-optimal, non-optimal and, if appropriate, each location (arm/palm).

5.1.2. Do this for each muscle (corrugator, zygomatic) and self-report rating (pleasantness, intensity) individually.

5.2. To obtain a more sensitive time course, compute mean EMG activation during smaller time intervals (e.g., 700 ms; see **Figure 5**[32]). Subtract the same 1 s baseline from all intervals to remove baseline EMG activity.

NOTE: Prior to analysis, it is recommended to have data manually checked by raters blinded to touch conditions to eliminate trials with artifactual activations[34].

REPRESENTATIVE RESULTS:

CT-optimal touch elicits distinct EMG responses compared to fast non-optimal touch across modalities

The first experiment addressed whether differential EMG reactivity could be detected in response to CT-optimal (3 cm/s) and fast non-optimal (30 cm/s) tactile stimulation that was directly experienced (**Figure 3**) or merely observed (**Figure 2** and **Figure 3**)[31].

Experienced CT-optimal touch was rated as more pleasant than non-optimal touch ($F(1,28) = 32.2$; $p < 0.001$; **Figure 3A**) regardless of touch location ($p = 0.063$; velocity x location: $p = 0.32$). Similarly, observed CT-optimal touch was rated as more pleasant that non-optimal touch (touch velocity: $F(1,28) = 47.5$; $p < 0.001$; touch type: $F(2,56) = 6.09$, $p = 0.004$; type x velocity interaction $F(2,56) = 5.87$, $p = 0.005$). CT-optimal touch to the arm was rated as more pleasant than touch to the palm ($p = 0.024$) and non-social touch (e.g., touch to the wooden arm; $p = 0.001$). Fast non-optimal touch was always rated as more intense (**Figure 3B**), regardless of whether the touch was experienced (touch velocity: $F(1,28) = 34.3$, $p < 0.001$; touch location: $p = 0.28$; velocity x location interaction: $p = 0.64$) or observed (touch velocity: $F(1,28) = 35.1$, $p < 0.001$; touch type: $p = 0.40$; velocity x type interaction: $p = 0.39$).

Experienced fast, non-optimal touch elicited robust corrugator reactivity that was mitigated by recruitment of CT-afferents during CT-optimal touch (effect of touch velocity: $F(1,28) = 4.84$, $p = 0.036$; effect of touch location: $p = 0.93$; touch velocity x location interaction: $p = 0.42$; **Figure 3C**). Corrugator response significantly differed between CT-optimal and non-optimal touch for touch to the arm ($p = 0.050$) but only trend level effects were seen for touch to the palm ($p = 0.092$). There was no main effect of touch velocity ($p = 0.11$) or type ($p = 0.79$) on corrugator reactivity to observed touch, but there was a touch velocity x type interaction ($F(2,56) = 3.80$, $p = 0.028$). Post hoc tests revealed that fast non-optimal touch elicited greater corrugator reactivity than CT-optimal touch particularly for videos of touch to the arm ($p = 0.007$), but not touch to the palm ($p = 0.13$) or non-social touch ($p = 0.25$). Zygomatic activity was not significantly affected by experienced touch (effect of touch velocity: $p = 0.15$; effect of touch type: $p = 0.73$; touch velocity x type interaction: $p = 0.63$; **Figure 3D**), nor observed touch (main effect of touch velocity: $p = 0.37$; main effect of touch type: $p = 0.84$; touch velocity x type interaction: $p = 0.23$).

CT-optimal touch elicits EMG responses distinct from slow non-optimal touch

Experiment 2 assessed whether slow non-optimal (0.3 cm/s) would elicit similar responses as fast

non-optimal (30 cm/s)[32]. We found that slow non-optimal touch was rated as less pleasant (**Figure 4A**) and less intense (**Figure 4B**) than CT-optimal touch. Similar to fast non-optimal touch, slow non-optimal touch elicited robust corrugator activity that was attenuated by CT-optimal touch (effect of touch velocity: $F(1,83) = 9.723$, $p = 0.002$; **Figure 4C**). There was no effect of touch on zygomatic activity ($p = 0.35$; **Figure 4D**).

We next assessed the time course of EMG responses. During the first 700 ms, a window putatively free of CT input, there was no difference in corrugator reactivity (-0.031 ± 0.06 μV and -0.017 ± 0.49 μV, $p_{Bon} = 0.98$; **Figure 5A**). However, over the next 5.6 s, corrugator reactivity in response to CT optimal touch decreased gradually, whereas it gradually increased in response to slow non-optimal touch: during interval 2, the corrugator reactivity was marginally lower for CT optimal touch than non-optimal touch ($p_{Bon} = 0.071$). During intervals 3, 5, 6, 7 and 8, the corrugator reactivity was significantly lower during CT optimal touch than during non-optimal touch ($p_{Bon} < 0.034$; **Figure 5A**). This pattern was absent in analysis of zygomatic reactivity ($p = 0.83$; **Figure 5B**).

FIGURE AND TABLE LEGENDS:

Figure 1: Example of experimental setup for the Experienced Touch task. Seat the participant in front of the computer with their arm extended laterally, comfortably resting on a cushion. If obtaining self-report ratings, it is recommended to apply touch to the arm that is not used to provide ratings to avoid potential movement artifacts from contaminating the EMG signal. The arm should be occluded from view of the participant[35,39], either with customized glasses, as above, or using a curtain separator. This figure is adapted from Ree et al.[32]

Figure 2: Example of touch stimuli used in the Observed Touch task. The observed touch task included 6 s videos of touch to the (**A**) CT-rich arm, (**B**) CT-lacking palm, and (**C**) non-social touch to a wooden arm.

Figure 3: CT-optimal touch elicits distinct responses compared to fast non-optimal touch across modalities. (**A**) CT-optimal touch (3 cm/s) is consistently rated as more pleasant than fast non-optimal touch (30 cm/s) across both tasks. Experienced touch is rated as most pleasant, followed by social (arm, palm) observed touch, then non-social touch (e.g. touch to a wooden arm). (**B**) CT-optimal touch is (3 cm/s) rated as less intense across modalities, regardless of modality or social content. (**C**) Fast non-optimal touch (30 cm/s) elicits more corrugator reactivity than CT-optimal touch (3 cm/s). This difference is most robust for touch to the CT-rich arm. (**D**) CT-optimal touch (3 cm/s) marginally increases zygomatic reactivity, though this does not reach significance for any modality or location. Bars and errors bars represent mean and standard error of the mean; *$p < 0.05$ effect of velocity. This figure is adapted from Mayo et al.[31]

Figure 4: CT-optimal touch (3 cm/s) elicits distinct responses as compared to slow non-optimal touch (0.3 cm/s). (**A**) CT-optimal touch (3 cm/s) is rated as more pleasant than slow non-optimal touch (0.3 cm/s). (**B**) CT-optimal touch (3 cm/s) is rated as more intense than slow non-optimal touch (0.3 cm/s). (**C**) Mean corrugator reactivity in response to CT-optimal (3 cm/s) is reduced compared to slow non-optimal (0.3 cm/s). (**D**) Touch does not significantly influence zygomatic

reactivity. Bars and error bars represent means and standard error of the mean; *$p < 0.05$. This figure is adapted from Ree et al.[32]

Figure 5: Corrugator responses to CT-optimal touch are temporally specific. (**A**) When binned in intervals of 700 ms, CT-optimal touch elicits significantly less corrugator reactivity. The exception is in the first 700 ms, which is putatively free of CT input due to the slower conduction velocity of these unmyelinated afferents. (**B**) Zygomatic reactivity is not significantly different in response to optimal or slow non-optimal touch at any of the time points. Dots represent means and bars represent standard errors of the mean. This figure is adapted from Ree et al.[32]

Table 1: Summary of Experimental Designs. In the Experienced Touch task of Experiment 1, touch was delivered at CT-optimal (3 cm/s) or fast non-optimal (30 cm/s) velocities to hairy (arm) and glabrous (palm) skin. The Observed Touch instead included videos of touch delivered to the arm, palm, or to a wooden arm (e.g., non-social) at the same touch velocities. The "non-social" condition was included to control for potential responses elicited by low-level periodicity information encoded in the movement[17], and determine the relevance of social content[38] on ratings and EMG responses. Results were analyzed using repeated measures analysis of variance (ANOVA) with touch velocity and touch type as within-subjects factors. A post-hoc power analysis based on Experiment 1 suggests at least 22 individuals should be included to achieve similar effects. In Experiment 2, touch was delivered to the arm at CT-optimal (3 cm/s) or slow non-optimal (0.3 cm/s) velocities. Touch was delivered for a total of 2min, but here we only report on the first 6.3 s in order to compare results to Experiment 1. Each velocity was repeated twice. In all experiments, self-reported ratings of the affective quality (e.g., pleasantness) and discriminative aspects (e.g., intensity) were assessed[10].

DISCUSSION:

Here, we report on the use of facial electromyography (EMG) as a method to study affective responses to observed and experienced touch. Previously, many studies have focused on the use of self-report ratings to characterize the affective quality of touch. Touch that optimally activates CT afferents (e.g., 1-10 cm/s) is consistently rated as more pleasant than either faster or slower touch velocities[10]. In contrast, ratings of intensity seem to track with velocity, with faster touch velocities rated as more intense, likely mediated via Aβ fibers[37]. Using two separate datasets, we show that both fast and slow non-optimal touch elicit robust corrugator reactivity that is attenuated during CT-optimal touch. Thus, we find that touch that is rated as less pleasant (e.g., non-optimal touch) also increases corrugator activity, suggestive of enhanced negative affect. In addition, we find that responses are similar across modalities. That is, both observed and experienced touch elicit similar facial muscle activity. In both modalities, these effects were only significant for touch to the arm, and not the palm or a wooden arm. Thus, while self-reported ratings of experienced and observed affective touch are similar regardless of location (arm, palm), facial EMG only significantly differentiates between touch velocities applied to the CT-rich arm, and not the CT-fiber-lacking palm.

The results further show that the temporal sensitivity of facial EMG yields insight into emotional processing that cannot be obtained solely by self-report. Namely, we found that corrugator

reactivity to CT-optimal touch becomes evident at a timescale that coincides with known conduction velocities of CT afferents[1,12]. Thus, in the initial 700 ms of touch, which are believed to be dominated by Aβ activation, there is no difference in EMG activation between the two touch velocities. However, the distinction between CT-optimal and non-optimal touch becomes evident following the first 700 ms, consistent with the previously reported temporal time lag of CT-afferents[2,12]. Hence, facial EMG is able to detect changes in affective responses to touch that occur with a temporal specificity that is likely inaccessible via verbal reporting.

Across both studies, we find that CT-optimal and non-optimal touch can be distinguished via corrugator activity. However, we did not find an effect of touch on zygomatic reactivity, which is in contrast to previous reports[40]. One potential reason for the discrepancies between the current data and previous findings include methodological differences such as inclusion of a post-touch period in the analysis. Thus, we stress the importance of methodological considerations such as the length of the touch stimulation and inter-trial intervals when designing these experiments.

There are several factors that should be considered when assessing affective reactions to touch. One potential area of concern is the gender of the experimenter (and thus, toucher) to that of the participant, as well as the relationship, if any, between the two[41]. Moreover, one should ensure that participants are precluded from viewing the experimenter and touch application, as visual processing of touch can influence the perception of touch[35,39]. There are also concerns to weigh during task design. For instance, it is important to consider the potential for order effects, both in regards to touch stimuli presentation (e.g. discussed in[42]) or touch location[43]. If several touch repetitions are used, one may want to vary touch location to avoid CT fatigue[36]. Here, we used a brush to apply touch to compare to previous studies[17], though it is possible that EMG responses may be different using more ecologically valid methods (e.g., touch by hand).

While we believe the use of facial EMG will be of a great benefit to the field of affective touch, there are limitations to this methodology that warrant consideration. Training is required to learn how to apply the electrodes correctly, producing an increased burden on the experimenter on the outset of experimental planning. Excessive movement, talking, or other environmental factors present during the experiment may cause artifacts in the EMG signal, thus constraining some experimental design features. Moreover, the application of electrodes to the face may elicit an attempt to discern the purpose of the study. As such, one must consider what information to tell the participant regarding not only the purpose of the experiment, but also the use of the electrodes during the experiment. In the current experiments, the participants were told that the purpose of the study was the investigate decision-making and perceptions of various sensations[32] or reactions to social interactions[31]. In both cases, participants were told that the electrodes would measure sweat and muscle activity and were fully debriefed following the conclusion of the experiment. These concerns and others are addressed thoroughly in Fridlund and Cacioppo 1986[34].

In sum, we demonstrate that facial EMG is a reliable, robust, and informative method to assess the affective valence of tactile stimulation. This method provides a means to implicitly assess responses to tactile stimulation independent of verbal reports, paving the way for studies in

infants and young children, cross-cultural comparisons, investigations of clinical conditions, and other situations in which semantics and language may otherwise preclude scientific exploration.

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The authors have nothing to disclose

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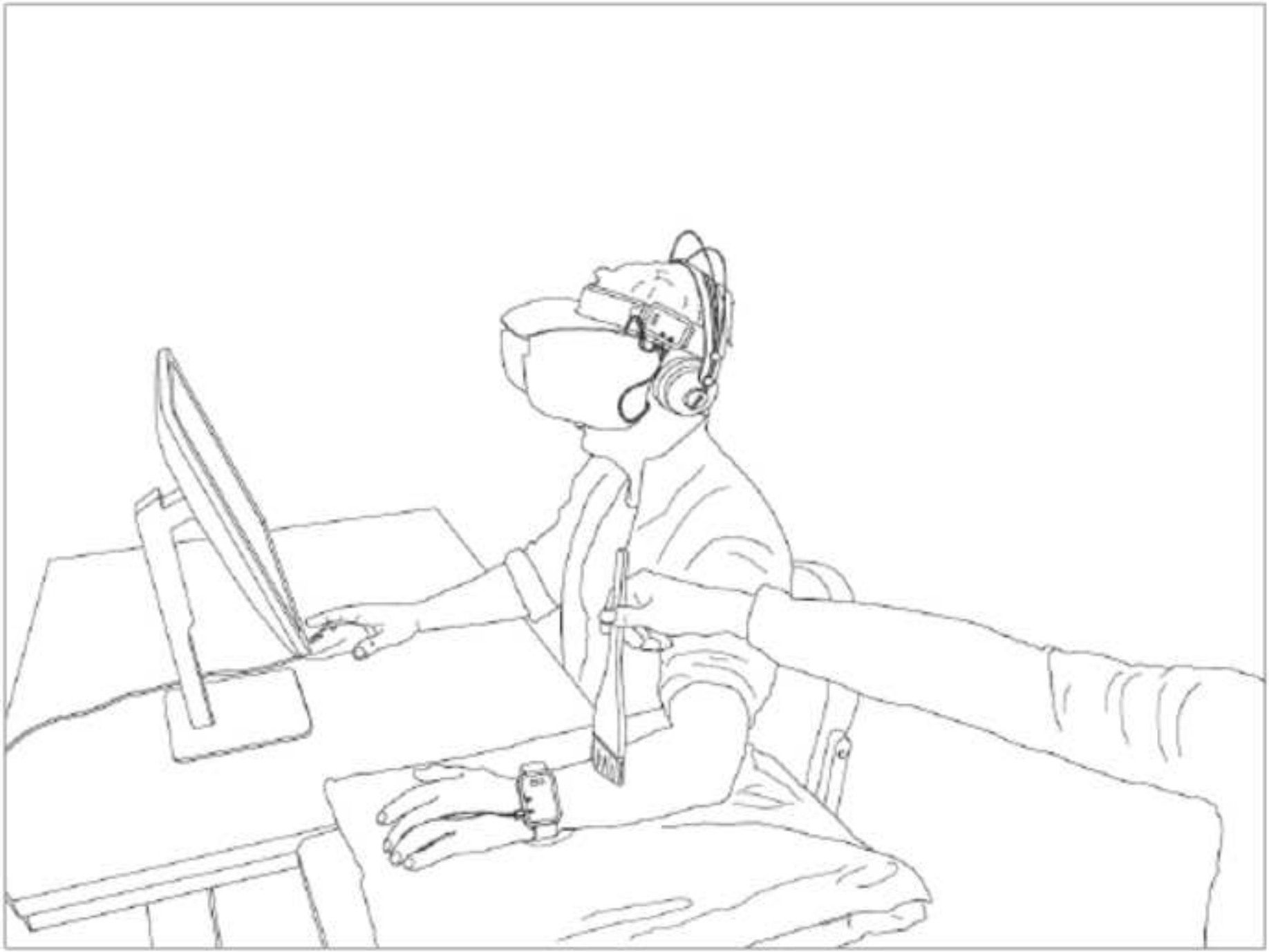

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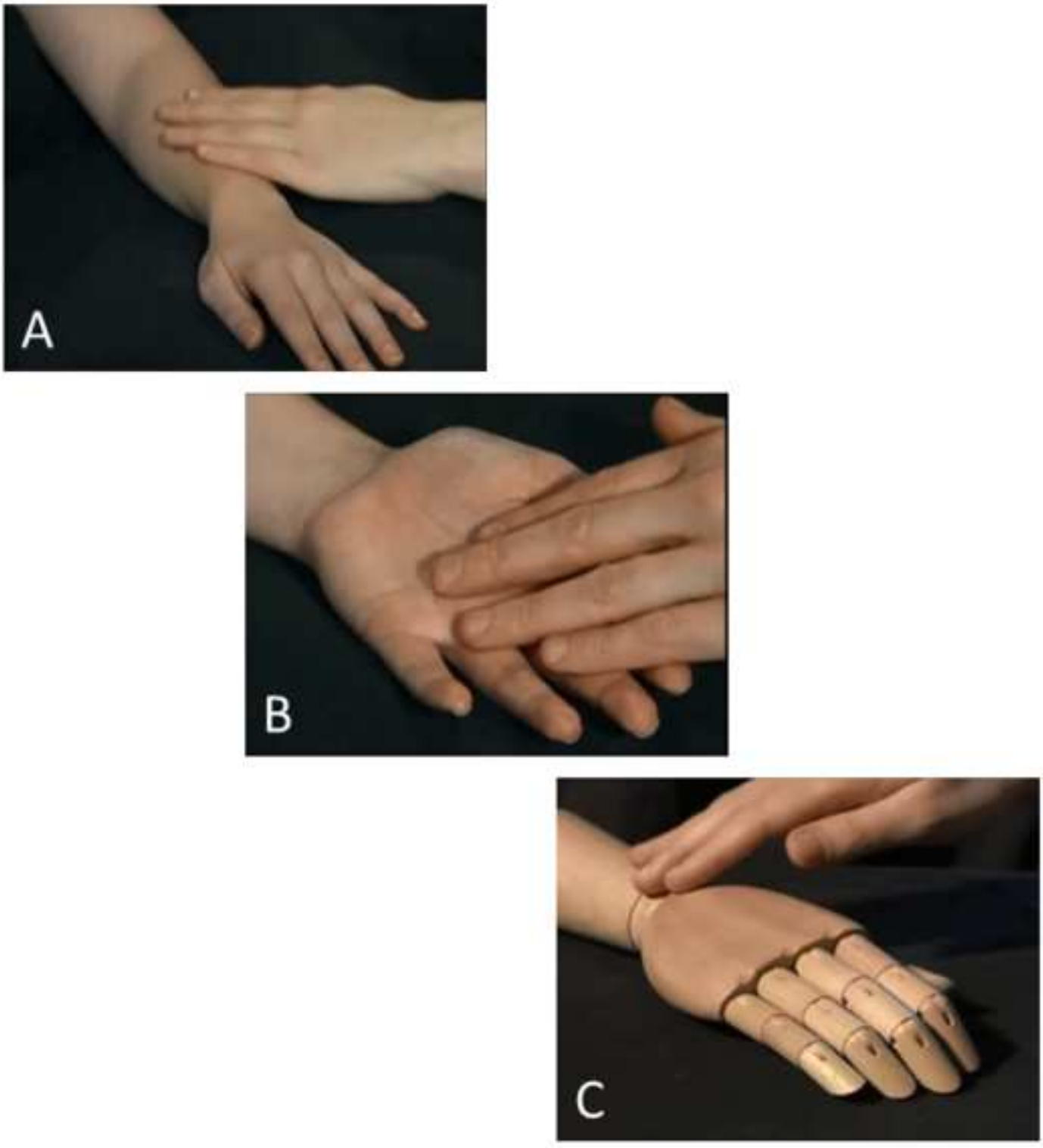

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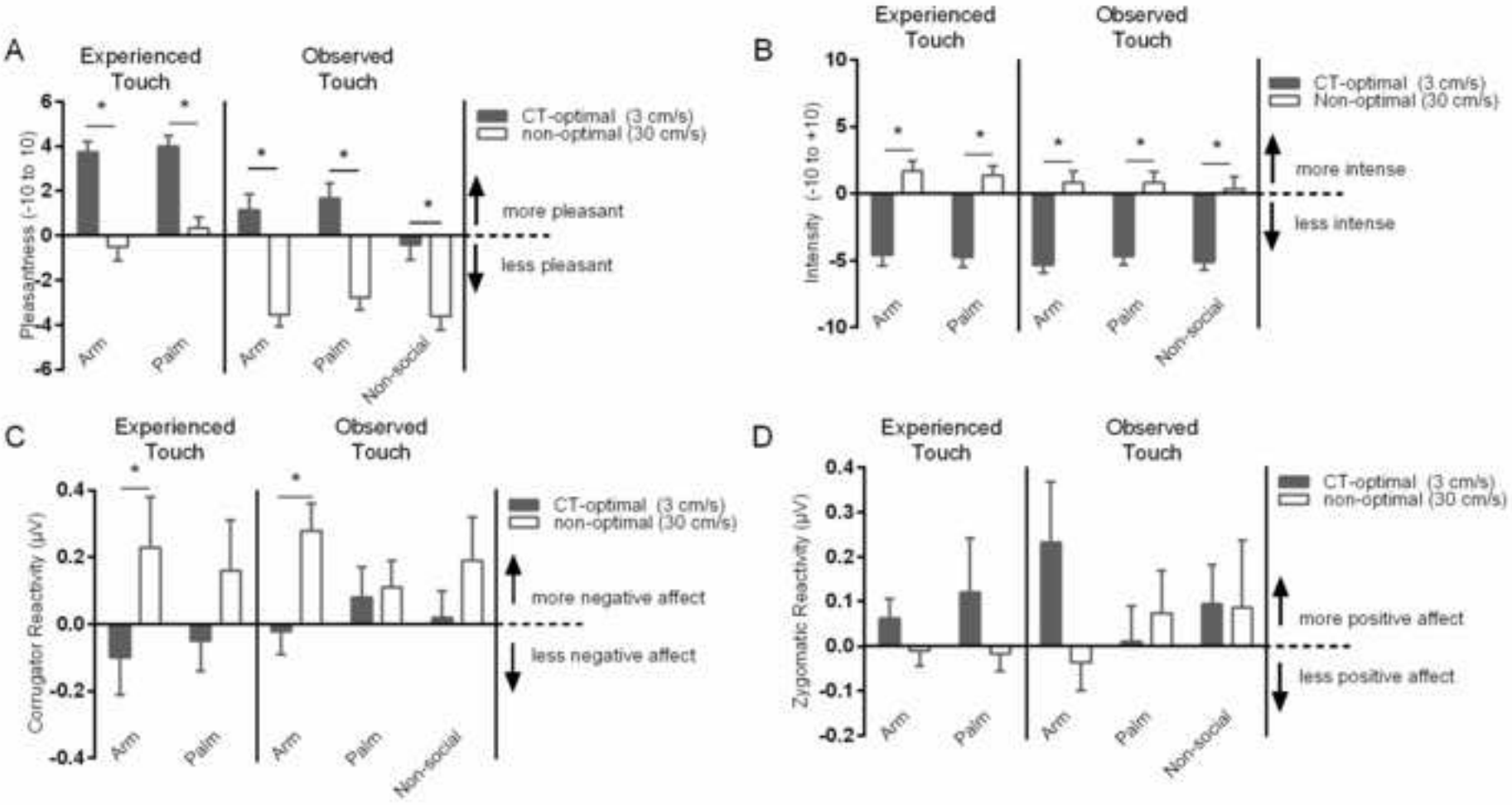

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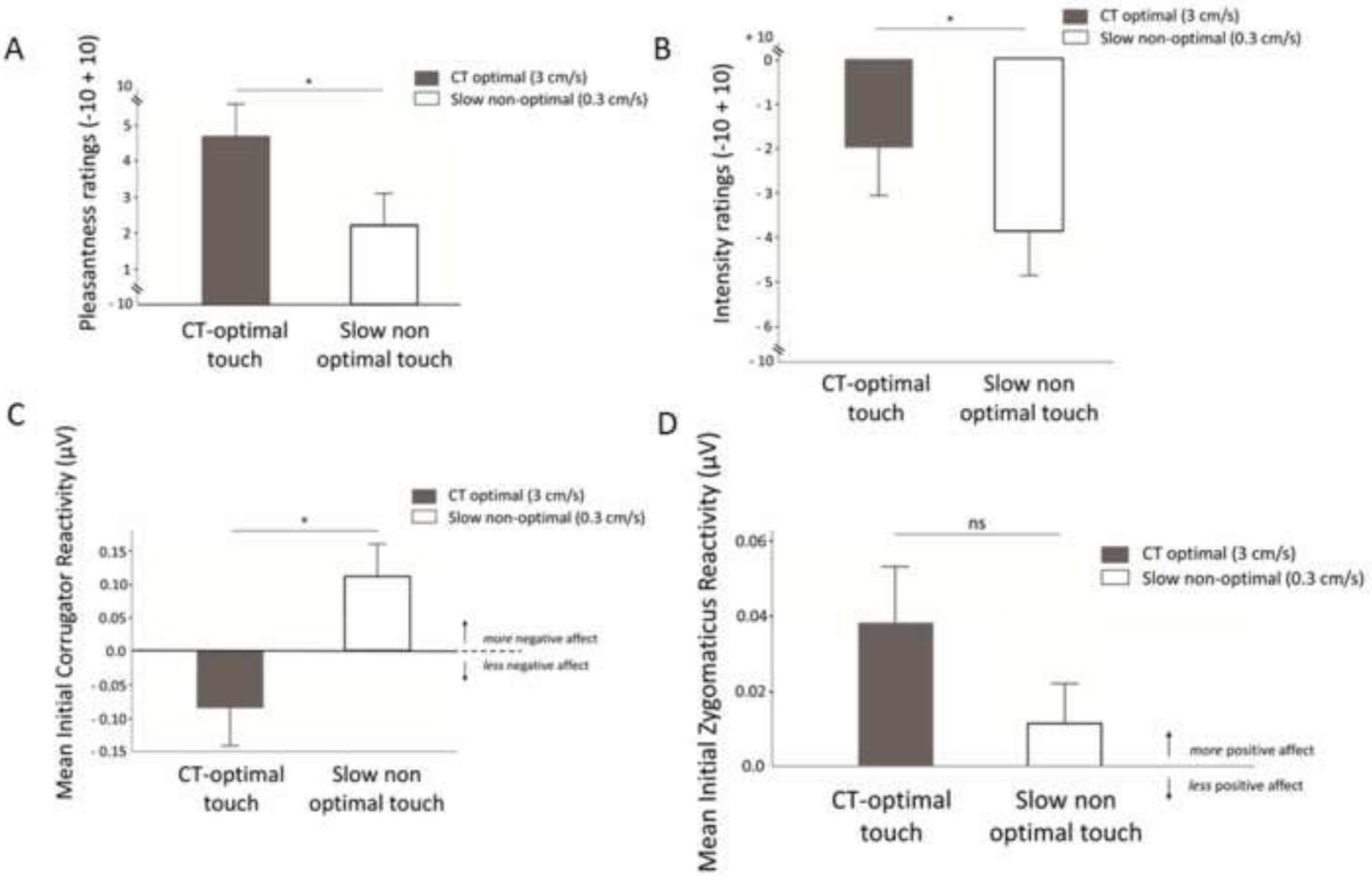

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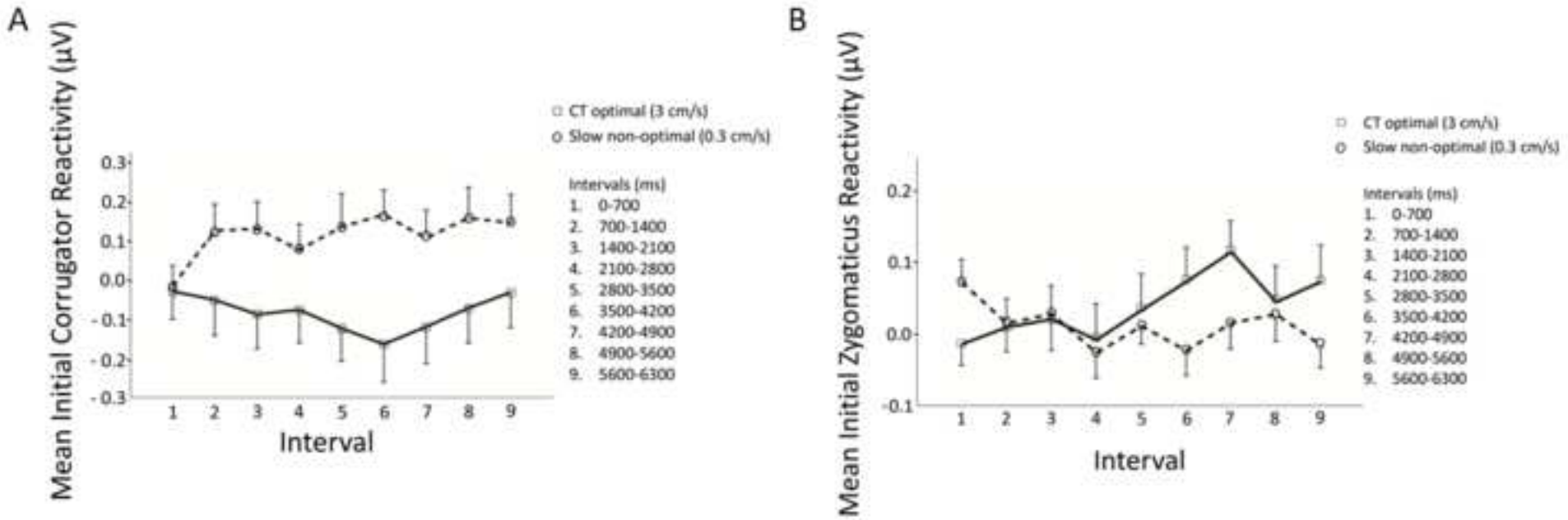

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Table

	Study N *(M/F)*	**Velocity** *CT-optimal*	*Non-optimal*	**Touch Location/Type**	**Touch Duration**	**Number of repetitions**
Experiment 1						
Experienced Touch	30 (17/13)	3 cm/s	30 cm/s	Arm, palm	6 sec	8 x velocity, location (32 total)
Observed Touch	30 (17/13)	3 cm/s	30 cm/s	Arm, palm, non-social	6 sec	4 x location, type (24 total)
Experiment 2						
Experienced Touch	44 (17/27)	3 cm/s	0.3 cm/s	Arm	6.3 sec (of 2min)	2 x velocity (4 total)

Table of Materials

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Name of Material/ Equipment	Company	Catalog Number
4mm Ag-AgCl sheilded reusable electrodes	Biopac	EL654
75mm goat hair brush	IN-EX Color AB	77062
8mm Ag-AgCl unsheilded reusable electrode	Biopac	
Acqknowledge software	Biopac	ACK100W
Adhesive collars	Biopac	ADD204
Cables	Biopac	BN-EL30-LEAD3; LEAD2
Electro-gel	Biopac	GEL100
EMG aplifier x 2	Biopac	BN-EMG2
El-Prep	Biopac	ELPREP
MP160 data acqusition system	Biopac	MP160WSW
Presentation software	Neurobehavioral systems	

Comments/Description

Touch application; https://www.in-exfarg.se

Used for application of filtering steps, analysis

LEAD3 includes ground, LEAD2 is only bipolar recording electrodes

Facial exfoliant

Task presentation software

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14. JoVE articles are focused on the methods and the protocol, thus the discussion should be similarly focused. Please revise the Discussion to explicitly cover the following in detail in 3-6 paragraphs with citations:
a) Critical steps within the protocol
b) Any modifications and troubleshooting of the technique
c) Any limitations of the technique
d) The significance with respect to existing methods
e) Any future applications of the technique
We have modified our Discussion as requested.

15. References: Please do not abbreviate journal titles. If there are six or more authors, list the first author and then “et al.”.
We have updated our references accordingly.

16. Please ensure that the references appear as the following: [Lastname, F.I., LastName, F.I., LastName, F.I. Article Title. Source. Volume (Issue), FirstPage – LastPage (YEAR).] For more than 6 authors, list only the first author then et al. See the example below:

Bedford, C.D., Harris, R.N., Howd, R.A., Goff, D.A., Koolpe, G.A. Quaternary salts of 2-[(hydroxyimino)methyl]imidazole. Journal of Medicinal Chemistry. 32 (2), 493-503 (1998).
We have updated our references according to the provided format.

17. Table of Materials: Please sort the items in alphabetical order according to the Name of Material/Equipment.
We have sorted the table as requested

Reviewers' comments:

Reviewer #1:
Manuscript Summary:
This manuscript presents a new method for assessing emotional responses to affective touch using facial electromyography (EMG). The authors present two studies that both show that facial EMG of the corrugator supercilii muscle is sensitive to touch at CT-optimal and non-optimal frequencies, and that touch at the CT-optimal frequency suppresses corrugator activity. The authors suggest this method may be more effective at measuring affective responses to touch than self-report measures in some populations. The manuscript is very well written, clear, and thorough, and describes a method that will be useful to researchers studying affective responses to touch. Suggestions for improvement of the manuscript are below; these are mostly minor points for clarity.

Major Concerns:
One important aspect of this manuscript is the relationship between self-report and electromyographic measures, as the authors suggest EMG may be a more usable measure of emotional reactivity in certain populations. It would strengthen the manuscript to spend more time describing the relationship between self-report and EMG measures in the results (from both study 1 and study 2), rather than just mentioning them in the legend for figure 3D.
We have expanded our discussion of the relationship between self-report and EMG in the discussion, as suggested by the reviewer.

Further, it's clear EMG may be useful for populations with difficulty verbalizing self-report measures, but are the authors suggesting it is a more sensitive measure of emotional reactivity? Or does it merely have broader potential applications than self report? What about it's translational potential; has it been used to assess affect in animal models?
We appreciate these important points brought forth by the reviewer. At this stage, we cannot say for certain that this measure is more sensitive or if it is assessing a distinct dimension of affective processing. However, we know from other studies that interventions such as drug administration [1] or stress exposure [2] can influence EMG responses independent of changes in self-report ratings. Thus, as a method, EMG may be useful in tapping into certain facets of affective processing that may not be accessible via self-report. The role of facial expressions in human (and animal) behavior has recently gained much interest (e.g. [3]) and we are interested in the potential translational opportunities it puts forth.

Minor Concerns:
Abstract
Excellent, concise abstract.

Introduction
Good description of the CT-afferent literature that is appropriately detailed. The background information on populations with dysregulated CT-afferent signaling could be moved to the discussion, as this method is being presented in healthy populations and that would be a future application of the protocol.
We appreciate the reviewer's suggestion. Unfortunately, we have been asked to limit our discussion and are thus unable to move the section as requested.

A couple of sentences introducing the two experiments that validated the methods could be added here to improve the flow of the manuscript.
We have added this to the manuscript prior to the results section.

Protocol:
A little more clarity on the control conditions would be helpful. What is the wooden hand controlling for? The authors note it is to "control for responses simply elicited by motion," but it seems as though responses to videos of the wooden hand and palm are similar. What are we to make of that? Does that mean the wooden hand condition is unnecessary?
This is an interesting point raised by the reviewer. The inclusion of the non-social condition (e.g. wooden arm) was to control for the possibility that velocity-sensitive responses may simply reflect the low-level frequency or periodicity information encoded within the videos [4]. The palm trials were included because the palm putatively lacks CT afferents, but is often engaged in social interactions (e.g. shaking of hands). Thus, we included this condition to determine whether generally social stimuli (e.g. stimuli containing two or more people) could elicit responses similar to stimuli that specifically depicted touch to an area rich in CT afferents.
We find that only the videos of touch to the CT-rich forearm at CT-optimal and non-optimal velocities can elicit differential corrugator activation. In the palm and non-social conditions, there was no significant difference between CT-optimal and non-optimal touch velocities. However, all CT-optimal videos were rated as more pleasant than non-optimal. As such, EMG of the corrugator muscle appears to be specifically activated in response to the observation of touch that potentially activates CT afferents, even if other stimuli (e.g. touch to the palm) are rated as pleasant. Thus, we do believe that inclusion of all three types of touch stimuli are informative.

The authors note the experimenters might want to occlude the participant's arm from view; it should be explained why this might be done.
We have included the following statement: "Occlude view of the arm from the participant either using a curtain separator or goggles that occlude lateral vision to avoid influence of vision on tactile perception(e.g. [6])"

Results
The sample sizes for each study should be reported in the results.
We apologize for this oversight; we have included a table that denotes task information and sample sizes. Specifically, 30 individuals were in Experiment 1 and 44 individuals in Experiment 2.

Discussion
It should be added to the discussion that the identity of the person doing the touch (romantic partner, friend, stranger) may influence affective responses.
This is an important point raised by the reviewer which we have now included in the discussion.

Reviewer #2:
Minor change
- Please go through the text: Some of the sentences seem incomplete because (1) the words are in the wrong order and/or repeated or (2) the reference style.
We have now thoroughly proofread the manuscript to correct these errors.

Major changes
As this is an invited manuscript, because of its novel methodology:
- Please do not refer to Experiment 1 and 2 from the "original paper(s)". This JoVE manuscript is original in itself (so it shouldn't matter that one experiment is still under review).
We have removed this wording from the manuscript

- Please reduce the Result section to only describing the methodology.
We have attempted to reduce the result section to include only the relevant information.

- Please reduce the Discussion of the results (findings), and increase the discussion of the methodology used (e.g. in relation to data validity and reliability, as data were collected in two ways - EMB and self-report).
We have made an effort to modify the discussion as requested.

Reviewer #3:
The manuscript describes a novel method to measure the affective component of CT-fiber activating touch, which the researchers replicated in two independent studies. The method described is of high scientific standard and quality, and I have no doubt that the protocol will be used a lot in the affective touch field. The protocol will help with the standardization of the affective touch application across studies and therefore it will increase comparability of studies. However, as of now, the manuscript lacks details in the method and results, which are necessary for a proper replication and understanding of the methods. I address these points in detail below.

Some general questions and remarks:

*Is it correct that you find similar effects in corrugator reactivity for the experienced and observed touch condition? If so, what is the purpose of the observed touch condition? Is it a control condition?
Yes, we do find similar findings across modalities. Previous studies [4] have reported that affective touch can elicit similar brain activation patterns, regardless of whether it is directly experienced or merely observed. Thus, we wanted to determine if similar consistencies across modalities existed in EMG responses. Accordingly, we found consistent differentiation between CT-optimal and non-optimal touch in both experienced and observed conditions. However, this only applied to the trials that were directed to hairy (arm) skin and not to the glabrous (palm) skin

Can you give an explanation why you find similarities between the 2 modalities? Does this imply that the corrugator (de)activation in the CT-optimal touch is not due to CT-fiber activation?
We hypothesize that affective touch is not only driven by bottom-up activation of CT-afferents, but also involves top-down integration of information from multiple sensory modalities. This is described at length in our previous paper [7]. Unfortunately, since this paper is focused on methodology, we are precluded from discussing this interpretation within the manuscript itself, but we agree that it is an intriguing finding.

*You describe the temporal specificity of the corrugator response and list this as an advantage compared to the self-reports. Can you provide an example/ application where this temporal specificity would be useful/ helpful?
Specifically within the context of the current manuscript, we see a lack of corrugator activity early on (e.g. initial 700 ms) but then a distinct difference between CT-optimal and non-optimal touch velocities. This alone suggests that EMG can detect changes on timescales that may not be readily available via self-report. Similarly, this specificity may be useful in response to dynamic stimuli that change (e.g. randomly or contingent on response) or to stimuli that are presented briefly.

*You are comparing EMG activation between a CT-optimal and a CT-non optimal touch condition and find currogator activation during the CT-non optimal touch. The question for me is whether the CT-optimal "deactivation" of the currogator reflects a change in EMG signal or is similar to a non-activated currogator. I think this can be addressed either with additional analyses or a different control condition. My concern is that the effects are driven by the CT non-optimal touch, which would diminish the value of your method for research in clinical populations. Imagine that a clinical population is impaired in affective touch (= CT-optimal touch) processing and you want to measure corrugator activation to tap into this impairment. You probably will not see a difference in currogator activation, because the clinical population will not be impaired in the non-affective (CT non-optimal) touch processing.
This is a nice point made by the reviewer. Our response is two-fold. First, across all of our studies, we measure the mean EMG response during the stimulus (e.g. touch) compared to the immediately preceding 1sec baseline. This is due to the fact that, regardless of how well the sensors are applied/acquire data, there will always be background noise, as described in [8]. For instance, people rarely show totally zero activity in a given EMG site, as physiological

arousal/tension, movement, and activation in nearby muscles can all influence the baseline level of EMG. Thus, the realistic goal is not zero baseline EMG, but instead is to achieve a representative physiological baseline for the task at hand. As such, we find that non-optimal touch *increases* corrugator activity above this baseline. However, CT-optimal touch *reduces* corrugator activity as compared to this background EMG level.
In addition, we have proposed previously [7] that non-optimal touch may elicit a negative response as indexed by an increase in corrugator activity. However, recruitment of CT-afferents attenuates this otherwise negative response. Thus, if an individual lacked CT-afferents, we would expect to see increased corrugator reactivity to all touch, regardless of velocity. In doing so, we could conclude that the ability of CT-afferents to mitigate the negative response elicited by touch is absent. This is supported by the finding that our fast non-optimal (30 cm/s) and slow non-optimal (0.3 cm/s) elicit similar increases in corrugator reactivity, but in both experiments, this is mitigated by recruitment of CT-afferents.
We have begun to use this methodology to address these issues in clinical adolescent populations. We do find marked differences between patients and controls in regards to EMG responses to touch (but no differences in self-report ratings); however this data is not ready for publication quite yet.

*It would be helpful for the understanding of the protocol and the analyses if you would include a short paragraph at the end of your introduction with a brief summary of your study design (thus the different conditions, within- and between subject factors, dependent variables, …) and the purpose of the different aspects of your study design.
We have included a table that addresses this concern.

Please also clarify what the purpose of the intensity rating is.
The intensity rating is included to assess more discriminative features of touch. In general, increasing velocities are rated as more intense, while the affective quality (e.g. Pleasantness) shows a U-shaped curve (e.g.[9]).

*I am missing details/ advice on participant instructions. Especially to what extend participants should know of the purpose of the study.
The participants were informed that the main purpose of the study was to investigate how sensory input could influence decision making and perceptions of various sensations. They were further told that the facial EMG electrodes would measure muscle and sweat activity throughout the study. At the start of each task, participants were instructed to think of how the touch makes them feel. We then provide more detailed information in a short "debriefing" held after the session ended. These issues are discussed in length in [8], which is also now mentioned in the discussion.

There are some cases where your writing is a bit sloppy:

*In multiple instances words are missing:
o 2nd paragraph introduction, line 55: "with TOUCH velocities"
o In 2.1.2 of the protocol (line 150): "such AS A visual analog scale"
o In 2.2.1, line 169: "and non-optimal (….) TOUCH"
o In the results section, 2nd paragraph (line 284): "slow non-optimal TOUCH …. fast non-optimal TOUCH"

o In the discussion section, line 362: "between CT-optimal and non-optimal TOUCH becomes…"
*In 2.2.2 (line 178) the parenthesis should be deleted.
*Please refer to the correct Figures in section 5.2, line 249.
*In 3.2.2 (line 206) "to" should be deleted in "the electrodes to in order"
*Please be consistent in how you call your tasks. Sometimes you call the experienced touch task a condition, and sometimes a task.
*Ethics statement is missing
We have corrected or removed these inconsistencies from the manuscript.

Feedback on details from the manuscript, which will improve the ease of replicability of your method:
*Section 1.1: can you advice on the minimum number of participants with a short explanation why?
We have included the following in the manuscript: “A post-hoc power analysis based on Experiment 1 suggests at least 22 individuals should be included to reach a similar effect size.”

*Section 2. Stimuli and task construction: for researchers who want to use your touch method, I feel like this section would be easier to read if you´d structure this part differently. I suggest you make a paragraph where you describe the touch application and a different paragraph where you describe the task design in detail
We have made efforts to clarify these sections within the constraints of the protocol requirements (e.g. we were instructed by the editor not to discuss the task details within the protocol).

*Section 2.1.1:

o Regarding "Velocities can be distinguished using tones of differing pitches that precede the stimulation cues": it sounds very hard to remember which tone corresponds to which velocity (I can imagine an alternative, where you could also use an audio recording saying "10 cm/s" before the stimulation cues). Could you make a more general statement out of this?
We appreciate the author’s comment. Since we only use two velocities, it was straightforward enough to distinguish between the anticipatory tones denoting the touch type. However, we have noted that readers are free to construct their own audio cues to their liking.

o Regarding "on an iPad or other device only in view of the experimenter": Great point! Could you add why this is important?
We have included the following statement: “Occlude view of the arm from the participant either using a curtain separator or goggles that occlude lateral vision to avoid influence of vision on tactile perception(e.g. [6])”

o Regarding "Stimuli should be of a consistent length": I find the use of the word "stimuli" confusing. A stimulus could also refer to the audio/ visual cues. I suggest you change the

wording to "stimulation" or "touch duration" (or something more appropriate). Same for section 4.3.
We have clarified this throughout.

o Regarding "the experimenter should train prior to the session": do you mean prior to every session? Or prior to data collection in general?
We only foresee training to be required prior to the first session, though this is based on the judgement of the experimenter. We have stated this more clearly within the manuscript.

o Regarding "i.e. by brushing on a scale": great point, but it is unclear how you would exactly do that. Do you mean doing the movements on the scale, or just a single push? Could you elaborate a little more on this?
We have updated the manuscript to read: “During training, use a scale to ensure that touch is delivered at a consistent pressure. To do so, apply brush strokes to the scale in a similar manner as they would to the participant. The scale readout is then used to determine if the pressure changes throughout touch administration. For instance, a pressure of 0.4N would register as 40gram on the scale.”

*Section 2.1.2: you write "participants should focus on a fixation cross or blank screen on the computer screen": can you please explain why this is important?
We have modified this section, but this statement refers to the need to achieve a task-relevant physiological baseline, as described above. Since we always compare the EMG response to the immediately preceding baseline, it is imperative that the baseline be free of potential contamination by responses elicited from other sensory stimuli.

*Section 2.1.3:

o General remark: this part is confusing because it does not read as a protocol but rather like a method section. I am also missing information on total number of trials, number of trials per block, duration of trial, and number of velocity types. Because of this I am confused about the following statement "In Experiment 2, the participants were exposed to repeated tactile stimulation": in experiment 1 you didn´t do that?
We have clarified this section and removed the reference portion.

o Regarding "Stimuli presentation should be (pseudo)randomized to avoid order effects": can you add a reference where they find order effects? Or alternatively can you describe how order affects your dependent variables?
We have added a section to the discussion section that highlight the potential influence of order effects.

*Section 2.2.1: You describe the delivery of touch to a wooden arm. Would you recommend this also for future studies? Please explain. I have the same question for the whole observed touch task. Do you recommend its use in future studies? Why (I think the purpose of the observed touch experiment is not completely clear)?
We appreciate the reviewer’s concern and have attempted to clarify within the text. Specifically, we used the observed touch task to determine whether affective touch requires

only “bottom up” activation of CT-afferents (e.g. the experienced condition) or if “top-down” contributions can also influence facial muscle activity in a similar manner. Based on [4], we know that information from these two modalities is indeed processed by shared neural resources. Moreover, [10] showed that people use different velocities when asked to stroke an artificial arm as compared to a human arm. Thus, we included this condition to determine if affective responses were shared across modalities and specific to social stimuli.

*Section 3.1: Regarding "It is recommended to use EMG amplifiers": this is a weird formulation. Is it possible to record EMG without an amplifier?!
We apologize for the wording. We simply meant to imply that the hardware could be used to apply basic filtering steps, while software could be used to apply additional filtering and processing. We have rewritten this accordingly.

*Section 3.2: a schematic overview of the exact placement of the electrodes would be helpful for other researchers to replicate the method.
We have included more thorough descriptions of electrode placement, as well as references that depict such placements. If the manuscript is accepted, it will be accompanied by a video that will include detailed information regarding sensor placement.

*Section 4.1:

o Does it matter which arm is used for the touch? Please explain.
In the classical microneurography studies exploring CT afferents, most recordings were obtained from the left arm [11]. However, when using facial EMG, we would recommend touch be applied to the arm that is *not* being used to provide self-report ratings. Moving the arm back and forth (between the location for touch administration and to grab the mouse) could induce movement artifacts into the EMG recordings. We have included this suggestion in the protocol.

o A picture of the set-up might be helpful for the reproduction of the methods.
We have included a picture, as requested.

*Section 4.3.:

o Does it matter what kind of brush is used? Please explain! Also explain why you use a brush instead of a hand, because in the introduction you write that CT-fibers are optimally activated with touch at skin temperature.
We used a 75mm goat hair painter’s brush, as listed in the materials list. Previous studies [4] have shown that a stiff brush (e.g. horse hair) is overall rated as less pleasant (compared to goat hair), but the pleasantness ratings for CT-optimal and non-optimal touch do not differ across brush types.
We used a brush instead of hand in an attempt to standardize the touch application, e.g. reduce variability due to skin temperature, moisture, etc. While we agree that hand touch would be more ecologically valid, we wanted the ability to standardize the touch application as much as possible, as well as be able to compare to previous studies that have used a brush to administer touch (e.g. [9, 11]). Moreover, recent evidence suggests that participants do not differ in pleasantness ratings of touch by skin or satin [12], perhaps

suggesting that we would perhaps find similar effects between touch via brush and hand. However, we agree that this is an important point and thus included it in the discussion.

o Who is applying the touch? Does it matter whether gender with participant is matched? Is the participant instructed on who is touching her?
This is an important point raised by the reviewers. The same experimenter applied the touch to all participants in a given study, thus we cannot say from our data alone whether this influences the outcome. However, other studies have found an effect of toucher gender [13], so we have included this potential issue within the discussion.

o Regarding "touch was applied to a 9cm section": is the size of the section important? Please explain
We have modified this section to remove this wording.

*Section 5: Could you please include a section with basic, general analysis steps regarding which conditions you compare and for what purpose? This helps with getting a general idea of what you can do with the tasks.
We have included basic analysis steps in the description of the tasks (Table 1), as well as reported the main effects and interactions more clearly in the results section.

o Please add dependent variable. It is unclear what "mean activation" you are referring to.
We have clarified this to state that the mean activation refers to the mean amplitude during each touch stimulus as compared to the mean amplitude during the immediately preceding 1sec baseline for the given muscle.

o Please be more specific regarding stimulus types, i.e. name them here.
We have clarified this wording throughout.

o It is unclear what the baseline in your task is, or when it is measured. Please clarify in the section where you explain your tasks.
The baseline is the background EMG signal, e.g. in the absence of any stimulus. Regardless of the quality of the sensor application/recording, there will always be a baseline EMG level that may fluctuate over time. To account for this, a “response” is quantified as the mean EMG activity during the stimulus (e.g. 6 sec) compared to the immediately preceding 1 sec baseline. Thus, the values reported are always a change from the baseline/background.

*Representative results section:

o General: If researchers want to use your method, I feel like it would be helpful for them to be able to compare their results with your results. Therefore could you please be more specific in your results section whether you report main effects, interactions, what kind of analysis you did (f.e. repeated measures Anova with which independent variables and which dependent variable). For this purpose, could you please also report the results of all the independent variables (if you haven´t already done this)? And could you also add somewhere how many participants you tested for the two experiments?
This information has been added to the manuscript in the appropriate locations.

o Paragraph 1: please clarify what "socially relevant trials" are
This wording has been removed from the manuscript.

o Paragraph 2: you describe that pleasantness ratings are related to corrugator reactivity. Could you add a correlation here?
Is a p-value missing on line 293 when describing the corrugator reactivity?
We appreciate the reviewer for point this out and have included this missing value.

*Figures: please add a description of the error-bars
We have updated the figure description to state that error bars represent the standard error of the mean.

o 3b: the size of the error bar is unclear in the CT non-optimal touch, because the y-axis only goes till -4. Please change so that other researchers who use your method can compare their results with yours.
We have corrected this as requested.

o 3c and d: please also add a similar graph for the zygomatic activation, so that other researchers can compare their results with yours.
We have added this as requested.

o 4a and b: very difficult to distinguish lines. Figure 4a and 4c show the same things, right? If yes, could you make a similar graph as in 4c for the zygomatic activation over time? And if 4a and 4c show the same results, I think 4a (and b if changed) are obsolete. The results are easier to understand from 4c.
We have modified our figures based on these requests.

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