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Pupil dilation responds to the intrinsic social characteristics of affective touch

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Affective Touch is characterized by both emotional and arousing dimensions that rely on specific features of a gentle human caress. In this study, we investigated whether and how both the nature of the touching effector (Human hand vs. Artificial hand) and touch type (Dynamic vs. Static) influenced the participants' pupil dilation and their subjective experience during tactile stimulation. We observed that when participants received a dynamic touch, their pupil dilation increased more when the touch was produced by a human compared to an artificial hand. This discrimination was not present for static touch. Also, dynamic touch given by a human hand invoked a supralinear enhancement of pupil dilation indicating that the combination of these two features induced a stronger autonomic activation than the summed effects of each separately. Moreover, this specific type of touch was perceived as the most pleasant compared to all other tactile stimulations. Overall, our results suggest that pupil dilation could reflect the pleasant experience of human-to-human tactile interactions, supporting the notion that the autonomic nervous system is responsive to the emotional and hedonic aspects associated with Affective Touch as a part of a complex and holistic social experience, rather than solely reacting to its low-level sensory properties.

Keywords Pupil dilation, Affective touch, Stroke velocity, Human hand, Artificial hand, Skin-to-skin touch

Social interaction is a fundamental aspect of human life, and interpersonal touch plays a crucial role in shaping relationships and encouraging social connections[1]. Notably, social touch refers to the physical contact or tactile exchanges occurring between individuals during social engagements. It serves as a means of conveying greetings, affection, support, and comfort across diverse social scenarios[2]. A specific kind of social touch is Affective Touch, characterized by a gentle and enjoyable tactile stimulation capable of triggering profound emotional reactions and positive emotional states[3,4]. This form of touch can foster sentiments of care, intimacy, closeness, and trust among individuals[5–7].

Recent studies have shed light on the distinctive attributes of Affective Touch, suggesting the existence of dedicated neural pathways and supporting its *sui generis* nature[8–10]. A specialized somatosensory system, referred to as the CT-afferent system, stands out as it is selectively activated by soft and gentle strokes. Specifically, CT-fibers are sensitive to slow-moving caresses (1–10 cm/s) and exhibit heightened activation in response to touch stimuli with a temperature that closely aligns to human skin (i.e., 32 °C)[11,12]. These two key characteristics lend support to the notion that CT-fibers could distinguish Affective Touch from other kinds of touch exchange. Also, gentle stimulation of CT-innervated skin triggers the activation of the posterior insula[13], coupling it with both somatosensory and reward processing regions[14]. The posterior insula plays a pivotal role in autonomic regulation and interoception by integrating sensory, affective, and rewarding aspects of tactile stimulation[4]. Its direct connection with CT-fibers stimulation[15] further suggests how CT-targeted touch might trigger psychophysiological responses characterizing Affective Touch as a fundamental mechanism for emotion regulation and social-affective processing[16], even though recent advances suggest the possible involvement of Aβ mechanoreceptors contributing to the affective aspects of touch as well[17].

The complex interplay between Affective Touch, emotions, and the autonomic nervous system has been extensively investigated through psychophysiological responses. Notably, Affective Touch has been shown to induce transient increases in skin conductance[10]: a response that can be influenced by salient contextual factors both in the person receiving the touch[18,19] and in the person promoting it[20]. However, in line with the notion that Affective Touch can serve as a potential buffer against stressful situations[3,21,22] it has also been linked to reductions in blood pressure[23,24], stress hormone levels[25,26] and heart rate[27,28] along with an increase in heart rate

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variability[28]. Although skin conductance and heart rate have been extensively explored as markers of physiological modulation induced by Affective Touch, pupil dilation, a well-established indicator of physiological activation, remains relatively unexplored in this context[29]. Emotional stimuli indeed trigger the release of norepinephrine, a neurotransmitter involved in the regulation of pupil dilation[30], and heightened pupil responses have been previously noted for both positive and negative arousing stimuli in both visual[31–33] and auditory[34,35] domains. Thus, understanding the relationship between Affective Touch and pupil dilation will provide important insights into the physiological responses evoked by this kind of tactile stimulation.

Earlier research has indicated that pupil dilation is influenced by the speed of touch rather than its pleasantness[36], concluding that pupil responses primarily encode the sensory characteristics of tactile stimulation and do not distinctly respond to the emotional aspects of touch. However, the majority of the studies investigating Affective Touch employed brushes or mechanical tools to deliver tactile stimuli[27,28,36,37]. This might have restricted the possibility of targeting the hedonic effects associated with an actual human touch. Interestingly, Ellingsen and colleagues (2014)[38] have reported that pupil dilates more in response to human touch compared to a mechanical vibratory stimulus, particularly when Affective Touch was accompanied by the presentation of images displaying a positive facial expression. This observation implies that pupil response can discern between distinct types of tactile interactions and potentially even capture the emotional experience accompanying touch. Thus, a touch given by a human hand, as opposed to artificial means, appears to be a pivotal factor in evoking distinct pupillary responses that are aligned with the emotional aspect of touch. Nevertheless, this study employed a silk glove for both types of tactile stimuli, thus losing the low-level characteristics associated with direct skin-to-skin contact. Additionally, visual and tactile stimuli were presented simultaneously, and no control was applied to the velocity.

Although previous studies have made strides in understanding the significance of specific attributes of Affective Touch, such as the stroking velocity and the nature of the touching effector, they have largely focused on investigating these features individually, examining one characteristic at time. Thus, this approach has made it challenging to draw comprehensive conclusions on the intricate interplay between these distinct characteristics and how those contribute to eliciting a physiological response. Expanding on this literature, we investigated whether the interaction between the social aspect of the effector (i.e., being touched by a real human hand) and the bottom-up affective component of touch (CT-fibers) might play a significant role in determining the salience of Affective Touch at an autonomic level. Indeed, dynamic stimuli inherently convey more information than static ones, and when targeting CT-fibers they are known to evoke autonomic and affective responses[8]. In this scenario, the human hand also possesses specific sensory characteristics (e.g., softness, warmth, texture) that signal to the receiver's sensory system that they are being touched by another individual. Consequently, this type of sensory information, processed at a low level, becomes socially relevant[1]. Therefore, this study focuses on how these low-level sensory features, when coupled with the social relevance of being touched by a human hand, may modulate the neurophysiological responses, specifically pupil dilation, which serves as an indicator of the salience of Affective Touch. We hypothesized that the combination of these characteristics -a human hand and a dynamic stimulus- would be more salient than their counterparts taken alone (i.e., an artificial hand and a static stimulation, respectively), thereby eliciting a stronger pupil response. In the present study, we explored whether and how the nature of the stroking effector (Human vs. Artificial) modulates pupillary responses in individuals receiving caress-like touches at CT-optimal velocity (Dynamic condition, 3 cm/s[12]). Additionally, we collected explicit pleasantness ratings to examine the hedonic experience when a CT-optimal touch was produced by a real human hand compared to the other conditions. As a control, experimental subjects also received static touch (Static condition) from both hand types, as we aimed to ensure that any observed differences between human and artificial hands were specific for the dynamic touch.

Our hypotheses encompass several scenarios. If pupil size merely tracked stroking speed, as hinted by prior research[36], we anticipated finding greater pupil responses during a dynamic touch condition compared to the static touch condition, regardless of the nature of the hand promoting the touch (Human vs. Artificial). Conversely, if pupil size only reacted to the nature of the hand promoting the touch, we expected to observe greater pupil responses during human-initiated touch compared to artificial-initiated touch, irrespective of the type of touch (Dynamic vs. Static). Finally, if pupil size could jointly respond to distinct features characterizing Affective Touch, we hypothesized that pupil responses to dynamic touch would be specially influenced by the nature of the hand promoting the touch. This would be reflected in larger pupil dilation when touch is promoted by a human hand, but exclusively under dynamic conditions.

Materials and methods

Participants

Thirty right-handed Italian volunteers (16 females and 14 males, mean age 23.9 ± 2.3 and 24.6 ± 2.8 respectively) took part to this study. Most of the participants were undergraduate students at the Department of Psychology (University of Turin) and were recruited from a participants' database or through flyers posted on the University website. All experimental subjects gave written informed consent to participate, which was approved by the local ethics committee and performed in accordance with the Declaration of Helsinki. At the end of the experiment, all participants were informed about the aims and the scopes of the experiment and did not receive any compensation for participation in this research study.

Experimental setting and design

Participants were invited to sit in a comfortable position, place their left arm on a table with their palm facing down, and lean their chin and forehead on a headrest to ensure stability and reduce any unintentional movement (Fig. 1a). Given that in this study we were interested in investigating how pupillary dilation vary as a function of different tactile stimulations, the experimental session started with a 9-point grid system calibration. Each touch

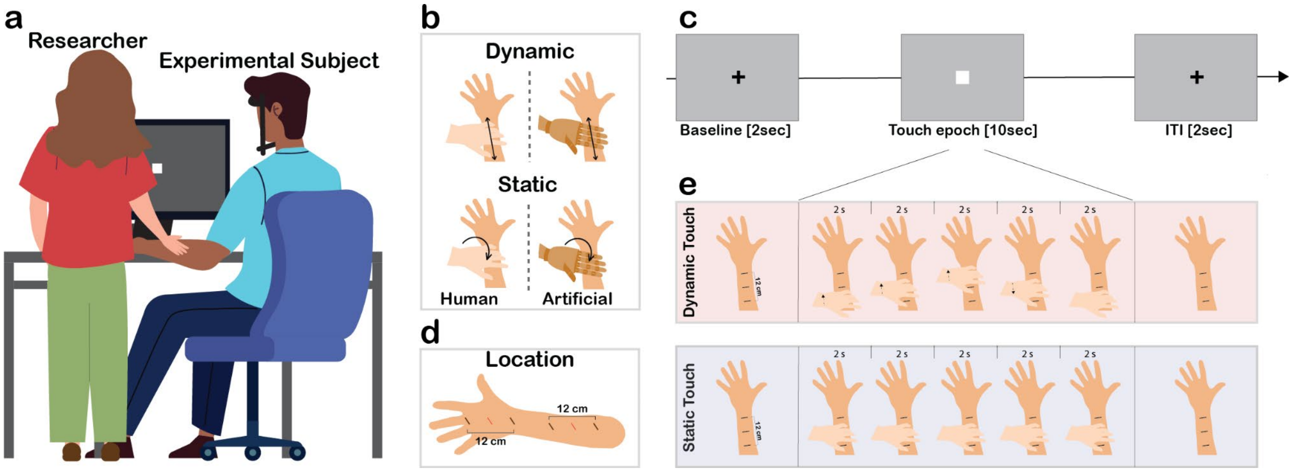

Fig. 1. Experimental setting and variables.

was delivered by either a Human hand (i.e., the experimenter's hand; Human condition) or an Artificial hand (i.e., a wooden hand; Artificial condition) (Fig. 1b). The wooden hand aesthetically resembled a real human hand . This enabled us to manipulate tactile low-level sensory aspects that characterize a real human hand while simultaneously controlling for visual similarities. The wooden hand was operated by the same experimenter who conducted the session.

Additionally, participants received two types of touch: a dynamic [i.e., a dynamic stroking at 3 cm/s[12]; Dynamic condition] and a static touch (Static condition) (Fig. 1b). Each trial started with a 2 second fixation cross (baseline) followed by a 10 second grey square (stimulus) presented in the center of the screen, during which the participant received a tactile stimulation (Fig. 1c). In each experimental session, one of two experimenters delivered the tactile stimulation. The female experimenter delivered touch only to male participants, while the male experimenter delivered touch only to female participants. Across all experimental sessions, the two experimenters were always the same. Before the beginning of the experiment, participants' left dorsal hand and forearm were marked with two 12 cm distant signs in order to guide the experimenter in the action of promoting the touch for the Dynamic Touch conditions. Moreover, a point in the middle of the subjects' hand and forearm was measured to indicate the area for the Static Touch (Fig. 1d). Both experimenters were extensively trained to deliver touch at constant pressure and velocity maintaining a constant stroking speed of 3 cm/s over the 12 cm distance between two marks during the entire 10 second period (Fig. 1e).

Given that pupil dilation recording is sensitive to eye movements and blinks, participants were instructed to keep their gaze fixed on the target stimulus and blink as little as possible. A 10 second period of tactile stimulation was followed by a 2 second ITI where subjects were allowed to rest. Before the beginning of the next trial participants were asked to rate the pleasantness of the touch received, on a scale from 0 to 10. Participants' subjective ratings were recorded by the experimenter as an indicator of the pleasantness associated with each touch. Each participant received 4 tactile stimuli per condition (i.e., Dynamic_Human, Dynamic_Artificial, Static_Human, and Static_Artificial) for a total of 16 tactile stimulations presented in a random order. For each condition, the touch was delivered twice on the dorsal side of the hand and twice on the dorsal side of the forearm, two hairy CT-rich sites mostly involved in interpersonal touch[39,40] (Fig. 1b). We delivered tactile stimulation in two different locations to avoid habituation effects.

Given that pupil dilation is sensitive to light we conducted the whole experimental session in a dark experimental room where the only source of illumination was the computer monitor. Specifically, stimuli were presented on a 17-inch LCD monitor at a screen resolution of 1280 × 1024 pixels (60-Hz refresh rate), and the distance from the eyes to the monitor was set at 58 cm. The task was implemented on Psychtoolbox (MATLAB©, The Mathworks Inc.), and pupil size was recorded at a 1000 Hz sampling rate using an Eyelink®-1000 monocular-arm (SR Research, Osgoode, ON, Canada).

(a) Experimental setting: the participants sat facing a computer monitor with their chin and forehead on a headrest to ensure stability and reduce any unintentional movement during pupil recording. They were invited to place their left arm on the table with their palm facing down. The researcher standing behind on the left side of the experimental subject promoted different types of tactile stimulations on either the dorsal side of the hand or the dorsal side of the forearm of the participant. (b) Touch Location: dorsal side of the hand and forearm. (c) Experimental variables: participants received either a Dynamic touch (a dynamic stroking with a speed of 3 cm/s) or Static touch, both delivered for the full 10 second. The nature of the stroking effector promoting the touch was either a Human hand or an Artificial hand. (d) Task progression: Each trial started with a 2 second fixation cross (baseline) followed by a 10 second grey square (stimulus) presented in the center of the screen, during which the participant received a tactile stimulation. The tactile stimulation ended with the beginning of a 2 second ITI. (e) Tactile stimulation progression: during Dynamic touch condition participants received a dynamic stroking at 3 cm/s[12] for the whole 10 second touch epoch whereas during Static touch condition participants received a static touch lasting 10 second as well.

Data analysis

Control analysis

The spatial location control analysis allowed us to ensure that participants kept their gaze on the center of the screen while receiving tactile stimulations, and that pupillary measures were not biased by eye movements. Heatmaps in Fig. 2a represent the spatial distribution of fixations during tactile stimulations. Axes represent pixels coordinates calculated according to standard Eyelink® 1000 1024 × 768 screen resolution. Additionally, we ran sensitivity analyses to ensure that our N allowed to achieve good statistical power (Supplementary Information and Figure S1).

Pupillometry analysis

Pupillary changes were first baseline corrected on a trial-by-trial basis by subtracting the mean change in pupil diameter 1000ms before the beginning of tactile stimulations. Next, to control for inter-individual variability, pupil data were z-scored for each subject across all conditions[31,41]. In each trial, missing samples due to blinks or loss of the eye-tracking signal during the tactile stimulation period were interpolated via spline interpolation using the nearest valid adjacent samples. Pupil responses were then averaged across trials for each condition. Based on visual inspection of the average response profile, the mean change in pupil diameter was extracted for the time window ranging from 0 to 4 s after stimulus onset (Fig. 2b). Data were analyzed via a 2-way repeated-measures ANOVA with Hand type (Human vs. Artificial) and Touch type (Dynamic vs. Static) as within subject factors. Post-hoc analyses following significant main effects and interactions were performed by running two-tailed pairwise t-tests, and multiple comparisons were corrected using False Discovery Rate (FDR[42]). All p values < 0.05 were considered significant. Crucially, to investigate any possible effect of gender and age on pupil responses we first ran a 2 × 2 × 2 repeated measures ANOVA with Gender, Hand type and Touch Type as factors.

To test the hypothesis that Dynamic_Human touch alone induced a larger pupil size than Dynamic_Artificial plus Static_Human touch, supralinearity was quantified by contrasting, for each participant, the average pupil size in the Dynamic_Human condition against the sum of the average pupil size in the Dynamic_Artificial plus Static_Human conditions. The effect of Dynamic_Human condition was then compared with the summed Dynamic_Artificial and Static_Human condition with a paired-sample t-test to determine significance.

Also, we investigated whether the blink rate changed across the four conditions by using nonparametric Wilcoxon Signed-Rank tests, as Kolmogrov-Smirnov tests showed that blink rate distributions were highly skewed in all conditions (all ps < 0.001). Finally, given that physiological responses could vary as a function of

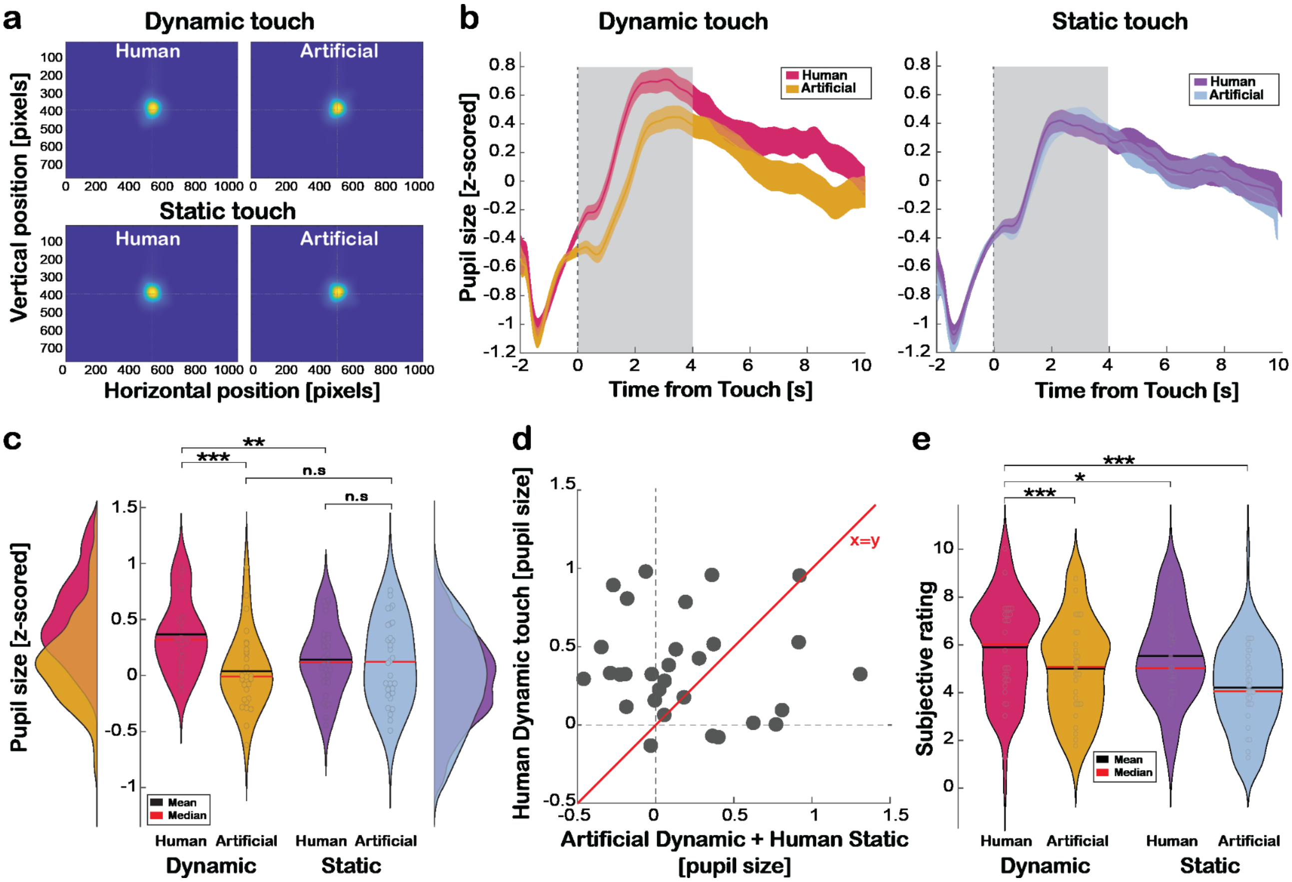

Fig. 2. Pupil Dilation responses and subjective rating.

an individual's age, we conducted four Pearson's correlations (one for each experimental condition) to examine if pupil size varied with age.

Subjective rating

To test whether different kinds of tactile stimulations impacted the perceived pleasantness, subjective ratings were analyzed by running a 2-way repeated-measures ANOVA with Hand type (Human vs. Artificial) and Touch type (Dynamic vs. Static) as within subject factors. Post-hoc analyses following significant main effects and interactions were performed by running two-tailed pairwise t-tests, and multiple comparisons were corrected using FDR. All p values < 0.05 were considered significant.

Results

Pupil size

We found a main effect of Hand type [$F_{(1,119)} = 10.196$, $p = 0.002$, $\eta^2 = 0.079$], indicating a stronger pupil dilation when participants received a touch from a Human hand compared to an Artificial hand [$t_{(119)} = 3.193$, $p = 0.002$, $d = 0.292$]. Crucially, we also found a significant Hand type by Touch type interaction [$F_{(1,119)} = 7.402$, $p = 0.007$, $\eta^2 = 0.059$], indicating that the magnitude of increase in pupil dilation during the touch produced by a Human hand differed depending on the type of touch (Supplementary Table 1). Specifically, post-hoc t-tests showed that only during Dynamic touch participants exhibited a stronger pupil dilation when receiving a touch from a Human hand compared to an Artificial hand [$t_{(119)} = 4.023$; $p < 0.001$, $d = 0.367$], indicating that pupil dilation specifically encodes skin-stroking caress only when given by a Human hand. Furthermore, we observed that a touch produced by a Human hand elicited a significant increase in pupil dilation for Dynamic compared to Static touch [$t_{(119)} = 2.966$; $p = 0.007$, $d = 0.271$]. During Static touch participants did not show any difference between a Human and Artificial hand [$t_{(119)} = 0.213$; $p = 0.832$, $d = 0.019$]. More importantly, we did not observe any difference in pupil dilation between Dynamic and Static conditions when the touch was initiated by an Artificial hand [$t_{(119)} = 1.079$; $p = 0.379$, $d = 0.099$] (Fig. 2b and c).

Since previous studies have shown that CT input employs between 700 and 1200 ms to reach the cortex[43,44], we also replicated the same analysis on a later window (i.e., from 2 to 4 seconds) and we found consistent results (see Supplementary Information and Figure S2). Also, these effects were not influenced by participant's gender (all ps > 0.05; Supplementary Table 2) nor by the age (all correlations across all conditions showed a $p > 0.05$ between age and pupil size). Finally, these findings were not affected by Touch Location (i.e., dorsal side of the hand and forearm; see Supplementary Information).

For supralinearity analyses, we summed, for each participant, the pupil size of "Human Static" and "Artificial Dynamic" conditions and scattered this sum against the participant's pupil size in the only "Human Dynamic" condition. As such, a participant whose pupil size is larger in the "Human Dynamic" than in the sum of "Human Static" and "Artificial Dynamic" conditions, would fall above the unity line indicating equality between the two measures plotted on the X and Y axes. These analyses showed that 70% ($n = 21$) of participants fell above the unity line, thus displaying a supralinear effect revealing a larger pupil size in the Dynamic_Human condition alone than in the Dynamic_Artificial plus Static_Human conditions summed together [$t_{(29)} = 1.781$, $p = 0.043$, $d = 0.325$] (Fig. 2d). Our results show a stronger pupil dilation when touch was delivered simultaneously at CT-optimal speed and by a human hand. This kind of touch invoked a supralinear enhancement of pupil dilation indicating that the combination of these two features induced a significantly stronger physiological activation than the summed effects of each delivered separately.

Moreover, we did not find any differences in blink rates across conditions (all ps > 0.160), suggesting that participants did not show differences in blinking activity depending on the Hand type nor on Touch type.

Subjective ratings

In line with pupil dilation findings, we observed a main effect of Hand type [$F_{(1,119)} = 32.062$, $p < 0.001$, $\eta^2 = 0.212$], indicating that participants preferred to receive a touch from a Human hand than from an Artificial hand [$t_{(119)} = 5.662$, $p < 0.001$, $d = 0.517$]. Also, we found a main effect of Touch type [$F_{(1,119)} = 15.087$, $p < 0.001$, $\eta^2 = 0.113$], indicating that participants preferred to receive a Dynamic than a Static touch [$t_{(119)} = 3.884$, $p < 0.001$, $d = 0.355$]. Finally, we also found a significant Hand type by Touch type interaction [$F_{(1,119)} = 4.125$, $p = 0.045$, $\eta^2 = 0.034$], which showed that participants preferred to receive a Dynamic touch from a Human hand (Supplementary Table 3). Indeed, post-hoc pairwise comparisons showed that Dynamic touch from a Human hand condition received the highest ratings compared to all other conditions [Dynamic_Human vs. Dynamic_Artificial: $t_{(119)} = 3.657$, $p < 0.001$, $d = 0.334$; Dynamic_Human vs. Static_Human: $t_{(119)} = 2.343$, $p = 0.021$, $d = 0.214$; Dynamic_Human vs. Static_Artificial: $t_{(119)} = 7.070$, $p < 0.001$, $d = 0.645$] (Fig. 2e). These results, in line with physiological findings, indicate that participants rated as the most pleasant a dynamic touch delivered by a human hand. Crucially, these findings were not affected by Touch Location (i.e., dorsal side of the hand and forearm; see Supplementary Information and Figure S3 and S4).

(a) Spatial location control: heatmaps show the gaze position during a 10 second grey square (stimulus) in which the participant received a tactile stimulation. None of the four heat maps (depicting the 4 experimental conditions) showed any meaningful eye movements deviation from the stimulus presented on the center of the screen. (b) On the left, pupil dilation traces aligned to the time of CT-optimal touch promoted by a Human hand (pink) and Artificial hand (yellow). The shaded traces represent ± s.e.m. centered around the mean. Vertical dotted grey line indicates the beginning CT-optimal touch (10 second duration). The grey-shaded area represents the analyzed epoch. On the right, pupil dilation traces aligned to the time of Static touch promoted by a Human hand (purple) and Artificial hand (light blue). (c) Violin plots show the z-scored mean pupil size values normalized to baseline during Dynamic touch given by a Human hand (pink), Dynamic touch produced by an Artificial hand (yellow), Static touch given by a Human hand (purple), and Static touch produced by an

Artificial hand (light blue). Data points overlaid on top show each subject. In black it is depicted the mean and in red the median. Distribution for Dynamic touch condition (pink for Human hand and yellow for Artificial hand) is shown on the left and distribution for Static touch conditions (Purple for Human hand and light blue for Artificial hand) is shown on the right. (d) Scatter plot shows the supralinearity effect by contrasting participants' pupil size in Dynamic_Human condition alone (y-axis) against Dynamic_Artificial plus Staticl_Human conditions summed together (x-axis). (e) Violin plots show the mean subjective ratings reported by participants in the four conditions: Dynamic touch promoted by a Human hand (pink), Dynamic touch promoted by an Artificial hand (yellow), Static touch promoted by a Human hand (purple), and Static touch promoted by an Artificial hand (light blue). Data points overlaid on top show each subject. In black it is depicted the mean and in red the median. ***, $p < 0.001$; **, $p < 0.01$; *, $p < 0.05$; n.s., not significant.

Discussion

In the present study, we investigated whether and how the social features of the stroking effector modulate pupillary responses in individuals receiving caress-like touches at CT-optimal velocity. We manipulated the nature of the stroking effector (Human vs. Artificial) and measured pupillary responses and subjective experiences in individuals receiving a caress-like touch. We employed a static touch as a control to ensure that any observed differences were specific only for touch delivered at CT-optimal speed (3 cm/s[12]), and not for other types of touch. Overall, we observed that when participants received a dynamic touch, they displayed an increase in pupil dilation for touch administered by a human compared to an artificial hand. Interestingly, such a difference did not emerge for the control static touch condition. Additionally, participants' self-reports consistently indicated that dynamic touch delivered by a human hand was perceived as the most pleasant in comparison to all other touch conditions.

Previous studies[36] investigated and compared the impact of different stroking velocities on autonomic parameters, including pupil dilation, and reported that pupil dilation increases as a function of stimulation velocity. However, it is noteworthy that most studies employed artificial tools to reproduce Affective Touch at a CT-optimal speed[28,36,37]. While this approach is valuable for precisely controlling stroking velocity and isolating activation related to Affective Touch from all top-down social components, it may lack ecological validity as it does not account for the nuances of human-to-human tactile interactions. Our results add knowledge to this body of work as we found that a dynamic touch elicits higher pupil dilation responses but only when touch is characterized by skin-to-skin contact. Thus, pupil dilation appears to reflect the high-level characteristics of the stroking effector. Indeed, as haptic features convey information about the nature of an external object[45], both the temperature and the softness of the touching hand likely inform the nervous system that the dynamic touch is coming from another individual. As such, this information becomes socially relevant[1], yielding autonomic reactions such as the strong modulation we observed in pupil dilation. Taken together, these results consistently support the idea that Affective Touch is linked to autonomic regulation, with pupil size reflecting not just the speed or effector features, but the experience as a whole. Indeed, we observed a higher pupil dilation when touch was delivered simultaneously at CT-optimal speed and by a human hand. Also, the observation of supralinear enhancement of pupil dilation in this kind of touch further supports the idea that the combination of these two features (velocity and stroking effector) can induce a significantly stronger autonomic activation than the summed effects of each delivered separately.

In our study, we also invited participants to rate the pleasantness of the touch they received. Consistently with prior research[36,46–49], our participants reported higher levels of pleasantness when received a gentle stroking produced by a human rather than an artificial hand. This suggests that C-tactile afferents, the neural pathways responsible for the emotional and rewarding aspects of touch[50], may have a preference for slow, caress-like touch[12] and are finely tuned to touch that mimics human skin temperature[51]. However, recent evidence has begun to challenge the complex but apparently not direct relationship between Affective Touch and CT-system, given that numerous unresolved questions have emerged about the mechanisms of CT-fibers and their role in affect and emotion[17]. Nonetheless, our findings emphasize the pivotal role of human contact in evoking positive emotional responses, as our participants reported the highest levels of pleasantness when tactile stimulation was delivered by a human hand at a speed resembling that of a caress. It's worth noting that these findings exhibited a similar pattern to those observed for pupil dilation. As pupil dilation has been associated with salient and rewarding stimuli[52,53] and to social interest in others[54], a stronger pupil responses may reflect the reward-related processing of a socially relevant interaction occurring. However, we did not observe any significant correlation between autonomic and hedonic responses. Nonetheless, it has been reported that CT-optimal speed tactile stimulation carries a positive affective valence[27], pupillary responses mostly track salience (not valence) of a stimulus and several top-down contextual factors might come at play in driving the association between pleasantness and autonomic activation[55]. Indeed, the way individuals experience social touch in general[56] and Affective Touch specifically[57] can be influenced by several contextual and top-down factors beyond the physical sensation of the touch itself. Hence, future studies might build upon the present results and explicitly address such an intriguing question.

It is important to acknowledge some limitations in our study and consider potential avenues for future research. First, despite the researchers' extensive training, touch velocity, pressure and differences in friction remain prone to variability. Thus, future studies should investigate these features in a more controlled manner as essential aspects of Affective Touch. For instance, supports such as a metronome could be introduced to better control the velocity of the touch, while the use of silk gloves[58] or volar forearm[27] might control variability in friction. Next, to avoid effects of habituation and tiredness on pupillary responses[59], in our study we only exposed participants to four trials per condition. However, even though most studies adopted less than 10 trials, recent research showed that this might not be an adequate number of repetitions[60]. Therefore, future research should consider adopting a larger number of repetitions when investigating the hedonic aspects of Affective Touch. In this study, we always employed an opposite-gender experimenter and neglected possible differences related to human sexuality and biases related to having social interaction with different genders. It would be valuable for future studies to collect subjective experiences related to these aspects, as well as to task-related comfort and perception about the confederate's identity. Moreover, it could be interesting to consider participants' cultural differences to mitigate potential interference effects and shed light on differences in affective touch perception across cultures. Considering all these top-down factors related to the touch giver[61] and acknowledging that in our study the identity of the experimenter was explicit, future research should consider manipulating experimenters' identities and to include conditions where the visual access to the experimenter is occluded from the participant's view.

Summarizing, the present study investigated how two key features characterizing Affective Touch, such as touch velocity and the nature of the hand promoting the touch, influence both pupil dilation and subjective experience in the person receiving a tactile stimulation. We not only replicated previous observations regarding each feature alone, but also reported, for the first time, that their combination triggers a stronger physiological reaction than their isolated components along with a positive hedonic experience. These results shed light on the uniqueness of real human-to-human contact in shaping Affective Touch as a means of support and affection[62–64] having a strong adaptive and evolutionary value central to our relational and social development.

Data availability

Data and code used for this paper's analyses are made publicly available at https://github.com/SocialInteraction-LabUnito/Pupil_AffectiveTouch.

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Author contributions

G.B. and O.D.M. designed the study, G.B. performed the experiment, G.B. and A.M. analyzed the data, and G.B., A.M., F.C., and O.D.M. wrote the paper. A.B. and L.P. reviewed the manuscript.

Declarations

Competing interests

The authors declare no competing interests.

Ethical statement

The experimental procedure was approved by the Bioethical Committee of the University of Turin and conducted in accordance with the Declaration of Helsinki (World Medical Association, 2013).

Impact statement

Our research shows that slow, caress-like touch provokes heightened pupillary responses only when administered by a human hand, and that this response is accompanied by the highest subjective pleasantness ratings. The combination of sensory elements characterizing human-to human affective contact (stroke velocity and human hand features) emerge as a pivotal factor for experiencing Affective Touch as a comprehensive and rewarding phenomenon, one that holds central importance in promoting social bonding and individual wellbeing.

Additional information

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