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In touch with your emotions: Oxytocin and touch change social impressions while others' facial expressions can alter touch

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Summary Interpersonal touch is frequently used for communicating emotions, strengthen social bonds and to give others pleasure. The neuropeptide oxytocin increases social interest, improves recognition of others' emotions, and it is released during touch. Here, we investigated how oxytocin and gentle human touch affect social impressions of others, and vice versa, how others' facial expressions and oxytocin affect touch experience. In a placebo-controlled crossover study using intranasal oxytocin, 40 healthy volunteers viewed faces with different facial expressions along with concomitant gentle human touch or control machine touch, while pupil diameter was monitored. After each stimulus pair, participants rated the perceived friendliness and attractiveness of the faces, perceived facial expression, or pleasantness and intensity of the touch. After intranasal oxytocin treatment, gentle human touch had a sharpening effect on social evaluations of others relative to machine touch, such that frowning faces were rated as less friendly and attractive, whereas smiling faces were rated as more friendly and attractive. Conversely, smiling faces increased, whereas frowning faces reduced, pleasantness of concomitant touch — the latter effect being stronger for human touch. Oxytocin did not alter touch pleasantness. Pupillary responses, a measure of attentional allocation, were larger to human touch than to equally intense machine touch, especially when paired with a smiling face. Overall, our results point to mechanisms important for human affiliation and social bond formation.

1. Introduction

To navigate in the social world, humans rely on information not just from their eyes, ears and nose, but also from their skin. Being touched by another human being can evoke

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powerful emotions. Sensory factors such as softness (Rolls et al., 2003), temperature, force and velocity (Löken et al., 2009), as well as top-down factors such as expectations (McCabe et al., 2008), previous experiences, and perceived identity of the toucher (Gazzola et al., 2012; Ellingsen et al., 2013), contribute to the appraisal of touch. People are remarkably accurate in detecting a wide range of emotional messages, even when these are communicated exclusively through touch (Hertenstein et al., 2006). Moreover, interpersonal touch, ranging from a reassuring pat on the shoulder to a sensual caress, can be a source of pleasure, which may serve as a foundation for affiliative behavior and social bonding (Morrison et al., 2010).

Positive consequences of interpersonal touch on social behavior have been demonstrated by a range of naturalistic studies. For example, restaurant diners tipped more if the waitress had casually touched them when returning their change (Crusco and Wetzel, 1984). Similarly, people were more satisfied with a library visit if the librarian had casually touched their hand (Fisher et al., 1976). Note that in these studies, touch formed part of an affectively congruent situation. Less is known about the effects of, and appraisal of, touch in contexts where other available information is affectively incongruent, such as being casually touched by someone expressing anger. Appraisal of social situations relies on a combination of all available information from the senses, along with prior knowledge and expectations. According to the feelings-as-information view, affective information is also a powerful factor in appraisal of social and non-social situations, even when the affect is elicited by unrelated or incongruent events (Schwarz and Clore, 1983, 2007). For instance, Winkielman et al. (2005) showed that subliminally priming participants with smiling faces made them drink more fruit juice, compared to people primed with frowning faces.

The neuropeptide oxytocin plays an important role in a range of emotional and social behavior in humans and animals (Bartz et al., 2011). Intranasally administered oxytocin improves the ability to ''read'' others emotions (Domes et al., 2007; Bartz et al., 2010; Leknes et al., 2012; Van IJzendoorn and Bakermans-Kranenburg, 2012) and enhances social attention (Gamer et al., 2010; Ellenbogen et al., 2012). Oxytocin has been hypothesized to promote human affiliation through its calming and antinociceptive effects (Uvnäs-Moberg, 1997), and intranasal oxytocin increased perceived attractiveness and trustworthiness of faces with neutral emotional expressions (Theodoridou et al., 2009). Moreover, physical touch is associated with peripheral oxytocin release, for instance in response to stroking touch in dogs and rodents (Lund et al., 2002; Odendaal and Meintjes, 2003). Oxytocin has been proposed to play a key role in social grooming behavior in nonhuman primates (Pedersen et al., 1988; Francis et al., 2000). Human studies have reported that high frequency of physical contact with a partner predicts elevated oxytocin plasma levels (Light et al., 2005). People given a massage are more trusting in a subsequent social interaction (trust game), an effect that covaries with plasma oxytocin levels (Morhenn et al., 2008). Interestingly, the subjects' plasma oxytocin levels increased after receiving massage succeeded by participation in the trust game, but not after massage or trust game alone. Furthermore, peripheral levels of oxytocin are positively associated with parental touch of infants. Specifically, high plasma oxytocin predicts affectionate touch in mothers, and stimulatory touch in fathers (Feldman, 2012).

Here, we investigate the reciprocal influence of gentle human touch and happy/frowning faces on the evaluation of these stimuli, and we assess the role of oxytocin in these interactions. We address (1) how social impressions of others are affected by human touch and oxytocin; (2) how hedonic experience of touch is affected by congruent and incongruent visual information (facial expressions) and oxytocin; and (3) whether these changes are underpinned by pupillary responses. According to the feelings-as-information model, the impact of a given affective response should increase with its perceived informational value to the task at hand (Schwarz, 2012). We therefore predicted stronger reciprocal influences between face stimuli and human touch compared to machine touch, and that oxytocin would potentiate these effects. Separate data from this study showed that intranasal oxytocin increases sensitivity to positive and negative facial emotional expressions (Leknes et al., 2012), in line with recent findings that intranasal oxytocin increases empathic accuracy (Bartz et al., 2010) and social attention (Guastella et al., 2008; Ellenbogen et al., 2012).

Touch is thought to intensify emotional displays from other sensory modalities (Knapp and Hall, 1997). We therefore hypothesized that both oxytocin and human touch should ''sharpen'' judgments of friendliness and attractiveness of others. Specifically, that faces with positive or neutral expressions would appear more friendly and attractive with concomitant touch or enhanced central oxytocin, whereas faces with angry expressions would appear *less* friendly and attractive. Conversely, we expected the hedonic experience of touch to be modulated by concomitant viewing of smiling or frowning faces, such that touch pleasantness would be enhanced by happy expressions and reduced by angry expressions. In line with the view that oxytocin is involved in the reward aspects of social processing (Uvnäs-Moberg, 1998; Insel and Young, 2001; Dölen et al., 2013), we also hypothesized that human touch pleasantness would be increased by oxytocin treatment. We further expected these behavioral and hedonic effects to be mirrored by the pupillary response during the tasks. The pupil dilates in response to rewarding and salient events, and is considered an accurate physiological index of attentional allocation (Beatty, 1982; Laeng et al., 2012).

2. Methods

The procedure of this study is also described in Leknes et al. (2012), which reported data on the effects of oxytocin on pupil response to, and emotional evaluation (i.e. anger and happiness) of, the visual stimuli.

2.1. Participants

Forty self-described healthy right-handed volunteers were recruited for this study, through announcements at the University of Oslo. A majority of the participants were undergraduate or graduate students at the Department of Psychology, University of Oslo. One participant completed one session only and was excluded, yielding a final study group size of 39 (20 females, mean age 26, range 20—39). All participants gave written informed consent to participate in

the study, which was approved by the Local Ethics Committee. Exclusion criteria were pregnancy and breast-feeding. Fourteen of the female participants used oral contraceptives. Of the remaining females, we estimated four to be in the luteal phase and two in the follicular phase of the cycle, based on reported number of days since the last menses. These females were in the same phase during both sessions. Participants received 200 NOK (about 36 USD) per session.

2.2. Study design

Each individual participated in two sessions on separate days (on average 3.4 (SD = 3.3, range 1–15) days apart), in counterbalanced order: once with 40 IU oxytocin (Syntocinon, Novartis, Basel, Switzerland; ten puffs alternating between the left and the right nostril) and once with saline (0.9%, Miwana, Gällivare, Sweden; ten puffs alternating as above), in a double-blind manner. While intranasal oxytocin has been shown to affect human brain processing and behavior in numerous studies (Bartz et al., 2011), the exact route of central action has yet to be identified (Churchland and Winkielman, 2012). However, a recent study on rodents suggests a central route that is parallel to peripheral uptake (Neumann et al., 2013). In both sessions, participants viewed gray-scale images of faces displaying happy, neutral, or angry emotional expressions on a computer screen. While viewing the images, participants received concomitant tactile stimulation on the left forearm; either a gentle stroke administered by an experimenter wearing a silk glove (human touch) or a mechanical vibratory stimulus with the same silk fabric touching the skin (machine touch). After each stimulus pair, participants rated qualities of the visual and tactile stimuli. Each session lasted for about 2 h. The test phase commenced on average 40 min after administration of the nasal spray and lasted approximately 25 min. Before the test phase, participants were seated alone in a room and were asked to refrain from any type of social interaction. The experimental protocol consisted of 10 blocks: 5 human touch blocks and 5 machine touch blocks presented in alternating order. The starting block type (human or machine) was counterbalanced across participants and conditions. Each block consisted of 10 stimulus pairs (simultaneous visual and tactile stimulation) presented for 3 s each. Before each stimulus pair, participants viewed a fixation cross for 5 s. Each stimulus pair was followed by the presentation of two rating scales; each scale was presented until the participant made a response. Pupil diameter was recorded during stimulus presentation.

2.3. Stimulus presentation

2.3.1. Visual stimuli

One hundred and twenty images of faces (20 males, 20 females) displaying angry, neutral and happy facial expressions from the Karolinska Directed Emotional Faces (Lundqvist et al., 1998) were used for stimulus presentation. The order of presentation was pseudo-randomized. Images of all 40 individuals within the stimulus set were presented in each session, and no images were repeated across sessions. Eighty happy and angry ''hybrid'' images containing hidden facial expressions were also included in the visual stimulus set (these data are reported in Leknes et al. (2012)), resulting in a total of 200 images, whereby 100 were used in each session.

Because pupil size is affected by ambient luminance, the background section of each image was altered to obtain the same net average luminance for all images using Matlab (The Mathworks Inc., Natick, MA, USA). The section of the images containing face or hair was unaltered. Each image (11 cm × 11 cm) was presented on a computer monitor situated 104 cm in front of the participant, yielding a visual angle of 6°, as used by Laeng et al. (2010). Participants were tested in a windowless room with constant artificial lighting. All visual stimuli and rating scales were presented using e-Prime 2.0 (Psychology Software Tools Inc., Sharpsburg, PA, USA).

2.3.2. Tactile stimuli

2.3.2.1. Human touch. Human touch stimulation consisted of 3 s duration soft strokes with a velocity of approximately 5 cm/s, a stimulus known to be optimal in activating CT-fibers (Löken et al., 2009). As C-fibers fatigue rapidly (Vallbo et al., 1999), the strokes were alternated between two parallel areas (each about 15 cm long) of the left forearm. The strokes were administered by a research assistant wearing a silk glove, which was used in order to reduce variability caused by changes in the temperature and moisture levels of the skin of the hand. The smooth glove also reduced friction, thus making the stroking as smooth as possible. These characteristics make it comparable to the paintbrush stimulation typically used in psychophysical studies addressing the functions of CT-fibers (Bjornsdotter et al., 2009; Löken et al., 2009), while using real human touch increases ecological validity. The experimenter was concealed from the participant's view behind a curtain, in order to avoid distraction due to visual contact/interaction between the experimenter and the participant. Each participant was touched by the same experimenter during both the oxytocin and the placebo sessions.

2.3.2.2. Machine touch. A 70 Hz vibration, for a duration of 3 s, was administered by a vibratory device on three successive areas of the dorsum of the left hand. The device was handheld by the experimenter, who was in the same proximity of the participant as during human touch. Vibratory stimuli of this frequency mainly activate myelinated Aβ fibers and not CT-fibers (Bessou et al., 1971). Therefore this stimulation was used as a control stimulus for the CT-activating touch, differing from the gentle stroking in social relevance and C-fiber activity. The part of the device that was in contact with the skin was covered with silk fabric.

2.4. Behavioral measures

Ratings of two aspects of the face stimuli and two aspects of the touch stimuli were recorded: (1) Perceived friendliness and attractiveness; (2) touch pleasantness and intensity. Each aspect was measured via two visual analog rating scales (VAS) that were displayed directly after each combined stimulus. The rating scales were 1A: How attractive was the person? (Anchors: Unattractive–Attractive); 1B: How friendly was the person? (Anchors: Not Friendly–Friendly); 2A: How pleasant was the touch? (Anchors: Unpleasant–Pleasant); and 2B: How intense was the touch? (Anchors:

Not noticeable—Intense). Perceived facial expression (3A: How angry was the person?; 3B: How happy was the person?) was also rated; these data are reported elsewhere (Leknes et al., 2012). The order of presentation of the rating scale pairs was pseudo-randomized within each session and within each rating scale pair. Since each face stimulus was only presented once to each participant, each unique stimulus was rated on one aspect only (friendliness/attractiveness, touch pleasantness/intensity, or anger/happiness). Thus the different rating scale pairs were associated with independent visual stimuli separated in time. Participants were instructed to pay attention to all aspects of the stimuli in every trial, since the subsequent rating scales could be related to touch experience, social characteristics, or facial expression.

Mood was measured at three time points during each session: (1) before the nasal spray administration; (2) immediately before the experimental protocol; and (3) immediately after the experimental protocol. Participants rated their current level of fear, sadness, irritability, happiness, calmness and anxiety using VAS with anchors Not at all-Very much so.

2.5. Pupillometry

The pupil diameter of the participant's left eye was measured by using a non-invasive infrared eye tracker (iView × Hi-Speed monocular system, SMI-SensoMotoric Instruments, Teltow, Germany) at a rate of 240 Hz for the duration of each stimulus pair (3000 ms).

2.6. Data analysis

2.6.1. Behavioral data

Repeated-measures ANOVAs were conducted using SPSS 12.0 (SPSS Inc., Chicago, IL, USA) for each of the rating scales (Friendliness, Attractiveness, Touch Pleasantness, and Touch Intensity) using the following within-subjects factors: treatment (oxytocin or saline); tactile stimulus (human touch or machine touch); explicit facial expression (angry, neutral, happy); and face gender (male or female). We also investigated the following between-subjects factors: participant gender (male or female) and session order (oxytocin or saline at session 1). The degrees of freedom for the within-subjects comparisons were corrected for deviance from sphericity using the Greenhouse—Geisser algorithm. For statistically significant effects, contrasts were performed to establish the exact nature of the differences. To correct for multiple comparisons, we used false discovery rate (FDR) correction for the performed contrasts (Benjamini and Hochberg, 1995; Storey, 2002), with a FDR threshold of 0.05. In the results, we report both p and FDR-corrected (q) statistics. A separate repeated-measures ANOVA was conducted on the mood ratings with treatment, session and mood scale as factors.

2.6.2. Pupillometry data

Pupil diameter data for each participant and each session were pre-processed in Matlab. Some data sets were lost due to technical constraints (malfunction of software or hardware). Good-quality recordings from both sessions were

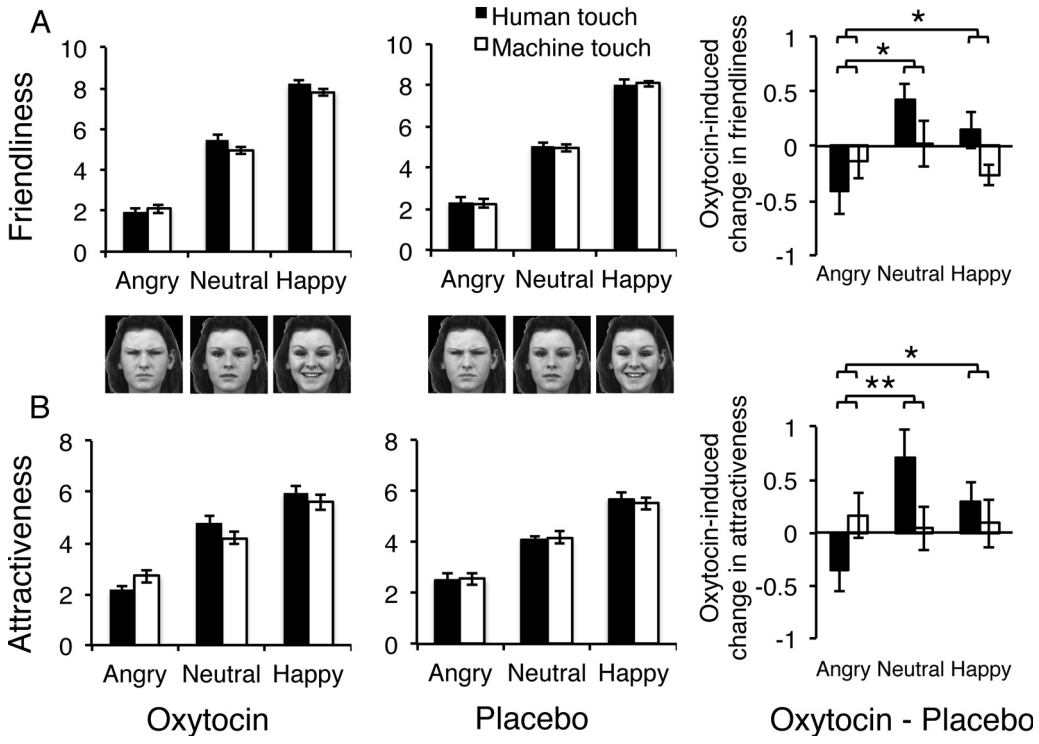

Figure 1 After oxytocin treatment, human touch sharpened social evaluation of others. After intranasal oxytocin, participants rated angry faces as less friendly (A) and attractive (B), but neutral and happy faces as more friendly and attractive, when accompanied by human touch relative to machine touch. Difference-scores (oxytocin − placebo) are displayed in the panels to the right, to illustrate the interaction. Error bars represent standard error of the mean. *$p < 0.05$, **$p < 0.01$.

obtained for 25 participants; only these data were analyzed (50 sessions). Eye blinks and artifacts were excluded, leaving physiologically plausible pupil sizes of 1—9 mm (Encyclopædia Britannica Online, s. v. "pupil"). Average time series were created for each stimulus type; these time series were smoothed using a 10 Hz cut-off low-pass filter (a 5-pole Chebyshev Type II filter). The time series were normalized to reflect the total dilation of the pupil for each stimulus type by subtracting the average pupil size during the first 200 ms from all points in the time series. For statistical analysis, the trimmed mean pupil dilation at 1000—3000 ms for each stimulus type, session and participant was entered into a linear multilevel (mixed models) analysis, based on a maximum likelihood approach (Baayen et al., 2008), using SPSS with the following variables: drug treatment (oxytocin or placebo); tactile stimulation type (human touch or machine touch); and visual facial expression (angry, neutral, happy).

3. Results

3.1. After oxytocin treatment, human touch sharpened ratings of friendliness and attractiveness

A repeated measures ANOVA revealed that relative to machine touch, concomitant human touch increased perceived friendliness ($F(1, 35) = 7.42$, $p = 0.01$, human touch: 5.14 ± 0.73 (mean $\pm$ SD), machine touch: 4.95 ± 0.79), but not attractiveness of the faces ($F(1, 35) = 0.38$, $p = 0.54$). Further, there was no significant main effect of oxytocin on ratings of friendliness ($F(1, 35) = 0.26$, $p = 0.61$) or attractiveness ($F(1, 35) = 2.2$, $p = 0.15$). However, there was a significant three-way interaction between treatment, tactile stimulus, and expression on ratings of both friendliness ($F(2, 69.5) = 3.9$, $p = 0.025$) and attractiveness ($F(1.9,66.8) = 6.26$, $p = 0.004$). Planned contrasts (treatment * tactile stimulus * expression) revealed that after oxytocin treatment relative to placebo, social evaluations of faces were "sharpened" when paired with human touch compared to machine touch. Specifically, angry faces were rated as less friendly and attractive while neutral and happy faces were rated as more friendly (neutral > angry: $p = 0.016$, FDR-corrected $q = 0.025$; happy > angry: $p = 0.026$, $q = 0.031$, Fig. 1A) and attractive (neutral > angry: $p = 0.003$, $q = 0.02$; happy > angry: $p = 0.04$, $q = 0.038$, Fig. 1B).

3.2. Facial expression of others shaped pleasantness of human touch more strongly than machine touch

As expected, human touch was significantly more pleasant than machine touch ($F(1, 35) = 53.7$, $p < 0.001$) (Fig. 2A). Further, the ANOVA revealed a main effect of facial expression, where tactile stimuli were least pleasant when presented together with an angry face, and most pleasant when presented together with a happy face ($F(1.5, 52.5) = 22.2$, $p < 0.001$) (Fig. 2B). Facial expression also interacted with tactile stimulus ($F(2, 68.2) = 7.9$, $p = 0.001$). Specifically, planned contrasts revealed that the pleasantness of human

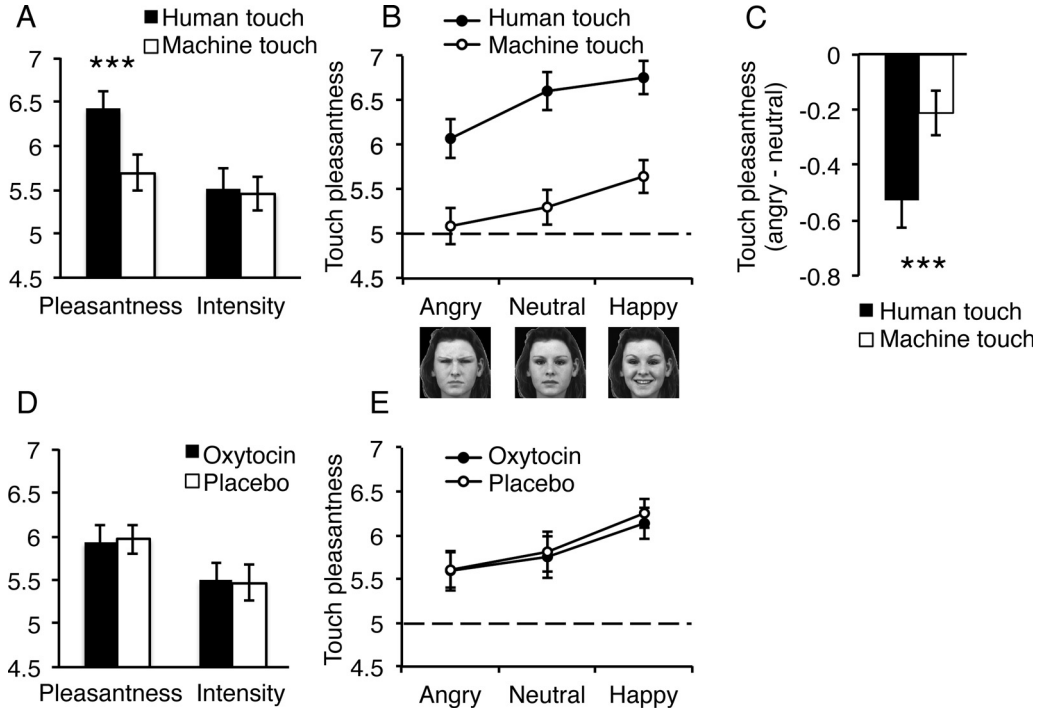

Figure 2 Modulation of the touch experience. (A) Human touch was more pleasant than machine touch, but of equal intensity. (B) Touch pleasantness was altered by the facial expression of concomitantly viewed faces. Specifically, tactile stimuli were most pleasant when accompanied by a happy face and least pleasant when accompanied by an angry face. (C) Moreover, pleasantness of human touch was more negatively affected by viewing an angry face than machine touch was. (D) Oxytocin did not alter touch pleasantness or intensity. (E) Oxytocin did not significantly interact with emotional expression to alter touch pleasantness. Dashed lines refer to the midpoint (neutral) of the pleasantness scale. Error bars represent standard error of the mean. ***$p < 0.001$.

touch was significantly more affected by concomitant viewing of angry faces, compared to machine touch ($p = 0.001$, $q = 0.006$) (Fig. 2B and C). Human and machine touch did not significantly differ in perceived intensity ($F(1, 35) = 1.6$, $p = 0.21$).

3.3. Oxytocin did not alter touch experience

Contrary to the hypothesis, we did not find evidence that intranasal administration of oxytocin affected touch experience. There was no significant main effect of treatment on touch pleasantness ($F(1, 35) = 0.92$, $p = 0.34$) (Fig. 2D), nor were there any significant interactions with facial expression ($F(2, 67.5) = 1.7$, $p = 0.19$) (Fig. 2E) or tactile stimulus ($F(1, 35) = 0.24$, $p = 0.63$). Similarly, there was no significant main effect of treatment on touch intensity ratings ($F(1, 35) = 0.06$, $p = 0.8$), and no significant interactions with facial expression ($F(2, 67.5) = 0.76$, $p = 0.45$) or tactile stimulus ($F(1, 35) = 0.23$, $p = 0.63$).

3.4. Exploratory analysis addressing emotional sensitivity

As previously reported (Leknes et al., 2012), the ability to differentiate faces implicitly expressing anger from faces implicitly expressing happiness (emotional sensitivity) was a significant moderator of the effects of oxytocin on emotion judgments. We therefore performed exploratory ANOVAs (with factors treatment, touch stimulus, and expression, like above), adding emotional sensitivity score as a covariate, to investigate whether this index also affected social impressions and/or touch perception.

There was an interaction between expression and emotional sensitivity on touch pleasantness ($F(1.5, 52.4) = 7.9$, $p = 0.002$). Specifically, exploratory contrasts using the interaction term [expression * emotional sensitivity] showed that people with the highest emotional sensitivity were most negatively affected by looking at an angry face compared to a neutral ($p = 0.003$, uncorrected) or happy face ($p = 0.003$, uncorrected). Further, there was an interaction between touch stimulus and emotional sensitivity on touch pleasantness ($F(1, 35) = 5.8$, $p = 0.02$). Specifically, those with higher emotional sensitivity reported a smaller pleasantness difference between human and machine touch ($p = 0.02$, uncorrected). There were no further effects of emotional sensitivity on touch pleasantness (p's > 0.16), and no significant effects on attractiveness ratings (p's > 0.6). As previously reported, those with high emotional sensitivity also reported the greatest differences in rated friendliness between implicit angry and implicit happy faces at baseline (Leknes et al., 2012). Emotional sensitivity did not affect the influences of treatment, tactile stimulus, and explicit expression on friendliness (p's > 0.1).

3.5. Human touch produced larger pupil responses to happy expressions, but smaller pupil responses to angry expressions, compared to machine touch

Average pupil size was 3.7 mm, and the mean stimulus-induced pupil dilation during the 3 s stimulus presentation period was 0.3 mm (8%). The effects of drug administration, tactile stimulus, facial expression and other factors on pupil dilation at 1000–3000 ms were assessed using a linear mixed models approach. p values from type III F-test for fixed effects are reported. For non-significant effects, example p values are reported from 1700 ms after stimulus onset. As previously reported, oxytocin significantly increased pupil dilation responses to visuotactile stimuli (Leknes et al., 2012), but there was no significant interaction between oxytocin treatment and tactile stimulus or facial expression (e.g. treatment-by-expression interaction, $p = 0.50$ at 1700 ms). Human touch also significantly increased pupil dilation compared to machine touch ($F(1, 456) = 9.01$, $p = 0.003$, Cohen's $d = 0.19$, human touch: 0.26 ± 0.19, machine touch: 0.22 ± 0.16, in the interval 1000–3000 ms). Furthermore, there was a significant interaction between tactile stimulus and facial expression ($F(1, 456) = 2.548$, $p = 0.039$). A planned contrast revealed that human touch (relative to machine touch) produced larger increases in pupil dilation when paired with a happy face than when paired with an angry face (happy [human > machine] > angry [human > machine]: $p < 0.001$, $q = 0.013$, $d = 0.60$, Fig. 3). There was no main effect of facial expression on pupil dilation at any time during the stimulus period (for example, $p = 0.45$ at 1700 ms). There were also no effects of the gender of the participant ($p = 0.46$ at 1700 ms), or the order of treatment presentation (oxytocin or saline first, $p = 0.58$ at 1700 ms).

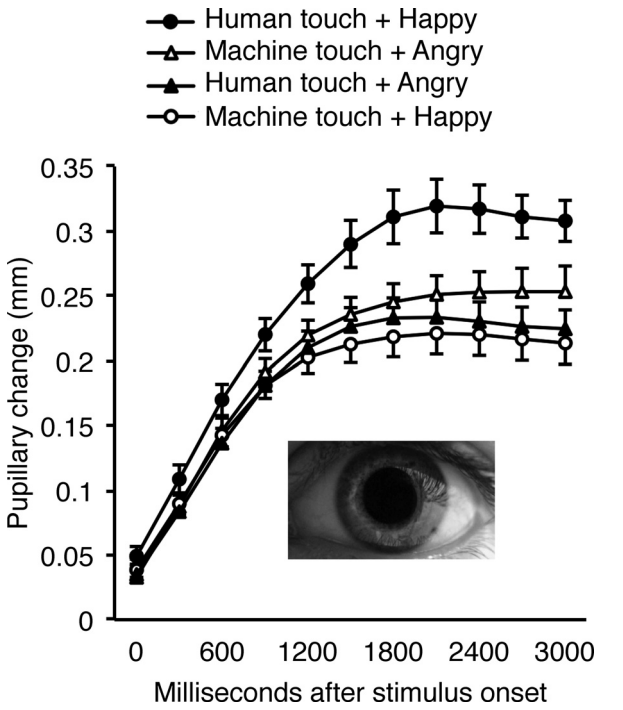

Figure 3 Pupil responses to visuotactile stimulation. Pupil responses were larger to human touch than machine touch. Furthermore, there was an interaction between touch stimulus type and emotional expression, in which human touch produced larger pupil dilation than machine touch when accompanied by a happy face, but smaller than machine touch when accompanied by angry faces.

3.6. No effect of oxytocin on mood

As previously reported (Leknes et al., 2012), we found no significant main effect of oxytocin treatment on self ratings of fear, sadness, irritability, happiness, calmness, or anxiety ($F(1, 26) = 1.4$, $p = 0.246$). There were also no significant interactions between oxytocin treatment and session number (first or second) or time of rating (pre-treatment, pre-testing, post-testing) on mood scores (all p's > 0.39).

3.7. No effect of female oral contraceptive use

Oxytocin interacts with estrogen and other female sex hormones. Since 14 of the female participants used oral contraceptives, and the remaining 6 had normal hormonal cycles, we explored whether this affected the outcomes. We performed a separate ANOVA including females only, with the same factors as above (treatment, touch stimulus, and expression), and with oral contraceptive use as a covariate. There were no significant interactions between oxytocin and oral contraceptive use on ratings of attractiveness ($p = 0.13$), friendliness ($p = 0.60$), intensity ($p = 0.64$), or pleasantness ($p = 0.83$).

4. Discussion

In order to decide if someone is a friend or a foe, people typically integrate multisensory information with knowledge, affect and expectations. In this study, we found that human touch and oxytocin treatment altered impressions of others. Conversely, seeing other people smiling or frowning affected the pleasantness of concomitant touch. After oxytocin treatment, being touched by another human sharpened participants' social evaluation of others, such that faces with angry expressions were rated as *less* friendly and attractive, while faces with neutral or happy expressions were rated as *more* friendly and attractive. The touch experience itself was rated as most pleasant when presented along with a happy face and least pleasant when presented with an angry face, an effect that was stronger for human touch than machine touch. We did not, however, find evidence that oxytocin affected the touch experience. Pupillary responses were larger to human touch than to equally intense machine touch, indicating that more attention was allocated to human touch. This effect was strongest when paired with a happy face. The present findings may elucidate mechanisms of social bonding and affiliation.

4.1. After oxytocin treatment, human touch sharpened social evaluations of others

Being actively touched by another person signals that this person is in close proximity and is likely making an approach. The ability to efficiently decide whether a person is a friend or a foe may therefore be more important if this person touches you. Hence, socially relevant touch can be a powerful modulator of behavior in a range of social settings (Gallace and Spence, 2010). Naturalistic studies have demonstrated that interpersonal touch can positively modulate attitudes and behavior (Crusco and Wetzel, 1984), even when the touch is not explicitly remembered (Fisher et al., 1976). Much of the literature reporting positive effects of interpersonal touch has focused on touch in positive social situations where the touch is likely to be congruent with the visual or auditory components of the social interaction (Gallace and Spence, 2010). Our results demonstrate that the effect of human touch on social behavior is dependent on the emotional valence of the context. Rather than causing a general positive shift, human touch, relative to machine touch, intensified the evaluations of social characteristics in others, making faces expressing anger look less friendly and less attractive, while making faces expressing neutral or happy emotions look more friendly and attractive. This is in line with the view that touch increases the salience of emotional information from other modalities (Knapp and Hall, 1997; Hertenstein et al., 2006), which may underlie the observed consequences of touch in social behavior (Gallace and Spence, 2010). Coherent with the feelings-as-information view, human touch may have conveyed information that was more relevant than machine touch to the interpretation of the faces, and thus had a larger impact on these evaluations (Schwarz and Clore, 1983), even though the visual and tactile stimuli originated from separate sources. This finding was mirrored by increased pupillary responses to human touch compared to machine touch, indicating that more attention was allocated to the visuotactile stimuli during the presence of human touch.

Interestingly, the sharpening effect of human touch on social evaluations was observed only when oxytocin levels were elevated after intranasal treatment. This is consistent with evidence showing that oxytocin increases interest toward social stimuli (Domes et al., 2007; Bartz et al., 2010; Leknes et al., 2012). Moreover, recent studies indicate that oxytocin increases trust toward within-group members (Declerck et al., 2010; Van IJzendoorn and Bakermans-Kranenburg, 2012), but may be non-effective (Van IJzendoorn and Bakermans-Kranenburg, 2012), or even reduce trust toward out-group members (De Dreu et al., 2011), especially when these are perceived as threatening (De Dreu et al., 2010). As we previously reported (Leknes et al., 2012), oxytocin enhanced perceived happiness and anger of faces with explicit and implicit (''hidden'') emotional expressions. This effect was moderated by baseline ''emotional sensitivity'' (i.e. how well people are at differentiating between implicit expressions of anger and happiness at baseline), such that those who had poorer baseline emotional sensitivity gained the greatest improvement from oxytocin.

Some studies suggest that touch in social contexts elicits oxytocin release in humans (Light et al., 2005; Holt-Lunstad et al., 2008; Morhenn et al., 2008) and animals (Uvnäs-Moberg, 1998; Lund et al., 2002; Odendaal and Meintjes, 2003). Thus, it is possible that human touch induced endogenous oxytocin release, which in combination with the exogenously elevated oxytocin levels produced the observed sharpening effects. Alternatively, human touch may have sharpened impressions through a non-oxytocinergic mechanism, which was modulated by the elevated oxytocin levels. For instance, the endogenous opioid system is thought to interact with oxytocin to mediate grooming-like social touch (Dunbar, 2010). The dopamine system is also known to interact with oxytocin (Rosenfeld et al., 2011).

The sharpening effect of human touch and oxytocin may reflect mechanisms important for human affiliation, by which

social or emotional information obtained when being actively touched by another person may be biased (sharpened) in order to promote a ''quick-and-dirty'' judgment of them (Tversky and Kahneman, 1974). This is similar to biases in other senses. For example, people overestimate change in auditory pitch for rising tones, which likely signals an approaching object, compared to falling tones (Neuhoff, 1998).

Although human touch differed from machine touch in its interaction with oxytocin, it is not known whether human touch differs from no touch. Thus, an alternative interpretation could be that machine touch attenuates a sharpening effect of oxytocin, perhaps because of distraction. However, the two touch stimuli were matched on sensory intensity, stimulus duration, proximity between the toucher and the participant, and the type of surface (silk fabric) touching the skin. This, together with the notion that the two stimuli did not affect friendliness or attractiveness differently in the placebo condition, minimizes the likelihood that human touch and machine touch differed in terms of distraction. Thus, the interpretation that human touch and oxytocin interactively sharpens social impressions of others, in line with the vast literature showing the potency of these in shaping social processing and behavior, may provide a more prudent interpretation.

4.2. Touch experience was altered by viewed facial expression, but not by oxytocin

While oxytocin interacted with human touch to alter social impressions of others, the touch experience itself was not significantly affected by oxytocin. Oxytocin is thought to be involved in reward aspects of social processing (Uvnäs-Moberg, 1998; Insel and Young, 2001). However, although intranasal administration of oxytocin in humans is often reported to influence social behavior like trust, social memory, empathic accuracy and social cognition (Bartz et al., 2011), oxytocin is rarely reported to affect hedonic feelings or mood (but see Shamay-Tsoory et al., 2009). Thus, other neurotransmitter systems (e.g. opioids) may be responsible for the hedonic aspects of touch and other social rewards. Given our sample size ($n = 40$, within-subjects design) and the relatively high dosage of intranasal oxytocin (40 IU), we consider a false negative unlikely. However, as the central effects of oxytocin are often reported to be specific to the social domain, oxytocin may play a role in hedonic touch experience in more naturalistic social settings, such as touch in close interpersonal relations. Similarly, since little is known about how the central enhancement of oxytocin following intranasal administration compares with endogenous oxytocin enhancement e.g. during pregnancy or breast-feeding, the present null finding must be interpreted with caution.

In contrast to oxytocin treatment, the emotional expressions of concomitantly viewed faces altered the pleasantness of touch. Touch was least pleasant when presented together with an angry face, and most pleasant with a happy face, and human touch was more strongly affected by the concomitant facial expression. This demonstrates the influence of top-down and cross-modal factors on the touch experience, in line with previous reports showing that the believed identity of the toucher (Gazzola et al., 2012) or the richness of applied skin cream (McCabe et al., 2008) alters perceived touch pleasantness. Interestingly, our results show that visually perceived facial expression impacted on touch pleasantness even though participants were fully aware that the person touching them was not the same person they were viewing. Moreover, the effect was also present, although weaker, for machine touch, indicating that the effect was not specific to the social touch domain. This finding mirrors previous reports showing that emotional stimuli can modulate behavior that generalizes beyond emotional or social aspects (Winkielman et al., 2005; Schwarz, 2012).

4.3. Human touch and a happy face evoked the largest pupillary responses

Pupil dilation responses to human touch were larger than responses to machine touch, supporting the notion that human touch increased the salience of the emotional context. Pupillary changes closely correlate with tonic norepinephrine release in the locus coeruleus, which plays a role in how attention is strategically allocated to stimuli of varying reward value (Aston-Jones and Cohen, 2005). The human and machine touch stimuli were rated as equally intense, suggesting it is the hedonic value or social meaning that is reflected by the pupil increase. The human touch stimuli used in this study were characterized by slow (around 5 cm/s) gentle strokes that are optimal for activating C-tactile (CT) afferents (Löken et al., 2009). CT afferents are likely to convey affective or social information of touch (Löken et al., 2009; Vrontou et al., 2013). In contrast, vibration (the machine control touch) mainly activates A-beta fibers (Bessou et al., 1971), which transmit more discriminatory qualities of touch (McGlone et al., 2012). Functional neuroimaging studies have found that CT-optimal touch activates the insular, anterior cingulate (ACC), and orbitofrontal cortices (OFC) relative to CT-suboptimal touch (McCabe et al., 2008; Bjornsdotter et al., 2009; Morrison et al., 2011; McGlone et al., 2012; Gordon et al., 2013). As retrograde tracing studies in primates have shown that the locus coeruleus receives its major input from ACC and OFC (Aston-Jones and Cohen, 2005), it is interesting to note that this type of touch produced larger pupillary dilations.

Increased pupil dilation has been observed in response to sexual stimuli (Hess and Polt, 1960), subliminal reward cues (Bijleveld et al., 2009), emotionally salient stimuli (Granholm and Steinhauer, 2004), and to intranasal administration of oxytocin (Leknes et al., 2012). Furthermore, women's pupillary responses to viewing pictures of their boyfriends were largest when they were in the ovulatory (fertile) stage of their menstrual cycle (Laeng and Falkenberg, 2007). Thus, pupil dilation responses to CT-targeted human touch may reflect a mechanism of social bonding and affiliation in humans. Human touch paired with a smiling face elicited the largest pupillary responses. This stimulus combination received the highest scores on all measures (pleasantness, attractiveness, friendliness), and is arguably the most emotionally congruent event, likely making it more socially meaningful and cognitively interesting than the other stimuli. Since large pupil sizes are associated with increased attractiveness (Wiseman and Watt, 2010), and signal

increased social interest in others (Laeng and Falkenberg, 2007), it is interesting to note that both gentle human touch and elevated oxytocin levels (Leknes et al., 2012) increased pupillary responses in this investigation. Consistent with the ideas that oxytocin (Bartz et al., 2010) and interpersonal touch (Knapp and Hall, 1997; Hertenstein et al., 2006) increases interest toward social stimuli, increased pupil dilation responses in these conditions may reflect a mechanism of social bonding and affiliative behavior.

In conclusion, we found that social information from visual and tactile sources had reciprocal effects on the appraisal of these stimuli. Human touch had a sharpening effect on social evaluation of others, making angry faces *less friendly and attractive*, while making neutral and happy faces *more friendly and attractive*. This effect was only present after oxytocin treatment, supporting the view that interpersonal touch modifies social behavior through oxytocinergic mechanisms. The hedonic experience of touch was in turn influenced by the emotional expression of concomitantly viewed faces, but not by oxytocin treatment. Touch was most pleasant when paired with a happy face, but least pleasant when paired with an angry face, an effect that was stronger for human touch than machine touch. The significance of human touch in these interactions was mirrored in increased pupil dilation responses to human touch compared to machine touch, especially when paired with a happy face. Together, these findings may reflect mechanisms of human affiliation, whereby social interactions involving touch from another person are given more salience, as they are likely to involve a direct approach from another person, which calls for immediate judgment of their intentions.

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Conflict of interest statement

The authors report no conflicts of interest.

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