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ORIGINAL INVESTIGATION

Oxytocin improves specific recognition of positive facial expressions

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Abstract
Background Oxytocin is a neuropeptide that is associated with increased trust. Perceptions of trustworthiness are associated with detection of positive facial affect, which suggests that oxytocin may enhance the recognition of positive facial affect. The present study tests this hypothesis.
Methods A double-blind, between-groups design was used, with 50 volunteers randomly assigned to receive intranasally administered oxytocin or placebo. Thirty-five minutes following the administration of oxytocin or placebo, participants identified anger, disgust, fear, happiness, sadness, and surprise expressions that were morphed with neutral faces such that they varied from 10% to 100% intensity.
Results Oxytocin significantly and specifically improved the recognition of happy facial expressions; no significant differences in recognition of other expression were found. The improvement was not associated with gender, response biases, or changes in mood, and it was most pronounced for subtle expressions.
Conclusions Acute oxytocin administration enhances healthy adults' ability to accurately identify positive emotional facial expressions. These findings reinforce oxytocin's role in facilitating affiliative interactions and have implications for the treatment of conditions that are marked by social affiliation deficits.

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Introduction

Oxytocin is a neuropeptide that plays a pivotal role in promoting affiliative behaviors. This is a class of behaviors that includes pair bonding, grooming, huddling, and play (Carter 1998; Insel and Winslow 1998; Kendrick 1997; Young et al. 2001). Administering oxytocin to adults of many species increases social contact and preference for affiliation with other adults and with infants (Insel 1992). Recent work indicates that oxytocin may promote similarly prosocial behaviors in humans. It has been shown to increase interpersonal trust when administered prior to an investing game (Kosfeld et al. 2005) and to increase generosity when administered prior to an ultimatum game (Zak et al. 2007). Endogenous increases in oxytocin have also been shown to predict increased generosity in the context of an investing game (Zak et al. 2005).

Oxytocin may enhance the processing of positive socioemotional cues, which may pertain to its effects on prosocial and affiliative behaviors. A positive socioemotional cue, such as a happy facial expression, signals the expresser's lack of threat and desire for affiliation (Hess et al. 2000). Thus, a positive facial expression may increase the appearance of trustworthiness (Oosterhof and Todorov 2009; Todorov 2008). In support of this contention, when a computer algorithm is used to exaggerate features associated with trustworthiness in neutral facial expressions, the probability that such expressions will be classified as happy is increased (Todorov 2008). This suggests that determinations of trustworthiness may be related to the detection of subtle elements of a happy expression in a face. Oxytocin's facilitation of interpersonal trust and prosocial interactions

could therefore reflect the fact that it enhances sensitivity to signs of trustworthiness, such as subtle signs of positive facial expressions.

Determining whether oxytocin alters the recognition of emotional facial expressions is critical to understanding its neurocognitive effects. Many prior studies have demonstrated that the accurate identification of specific emotional facial expressions can serve as an indicator of socioemotional functioning, psychiatric or neurological disorders, and the integrity of neural structures that subserve emotion processing (Adolphs et al. 1999; Calder et al. 2000; Corden et al. 2006; Hennenlotter et al. 2004; Marsh et al. 2007; Marsh and Blair 2008).

Three previous studies have assessed the effect of oxytocin on the processing of happy facial expressions (Di Simplicio et al. 2008; Guastella et al. 2008, 2009). Guastella et al. (2009) used a variation of a "popout" task, in which subjects were asked to detect a cartoon line drawing of a happy face among neutral or angry cartoon faces, and found no superiority in detecting happy expressions following oxytocin administration. However, in a separate study, Guastella and colleagues found that oxytocin improved face identity recognition, particularly for faces displaying happy expressions (Guastella et al. 2008). Di Simplicio and colleagues conducted a well-validated emotion recognition task with photographs of emotional expressions and found changes in response biases to neutral and surprise expressions but no indications of superior processing of happy expressions. However, this may in part relate to their relatively small sample size (N=29) or the inclusion of only male subjects. Rodent studies suggest that oxytocin's effects are enhanced by interaction with estrogens (Champagne et al. 2001; McCarthy et al. 1996), and recent neuroimaging studies in humans suggest that oxytocin enhances activity in neural regions involved in processing emotional facial expressions in women but reduces activity in these regions in men (Domes et al. 2007a, 2009).

Given the inconclusive results of previous research on the impact of oxytocin processing on happy expressions, we examined the impact of administering 24 international units (IU) oxytocin or placebo to 50 healthy volunteers, including 21 females, who completed a morphed facial expression recognition task. We predicted that oxytocin would be associated with specific enhancements of the recognition of happy facial expressions but not other expressions.

Materials and methods

Participants

Fifty healthy volunteers (29 males, 21 females, M age= 26.41 years, range=20–40 years) participated in this study. All participants gave informed written consent and were paid for their participation. A psychologist evaluated each participant using the Standard Clinical Interview for Diagnostic and Statistical Manual of Mental Disorders-IV, and a physician conducted a medical history and a physical exam that included blood, urine, and EKG screening. Exclusion criteria included current or past major affective disorder, anxiety disorder, psychotic disorder, substance dependence, anorexia nervosa, bulimia, or IQ less than 80. All participants were free of psychotropic medications and hormonal supplementation. Female enrollment was limited to those not taking hormonal contraceptives, and all females were tested during the follicular phase of their menstrual cycle (approximately days 6 through 12) to minimize variance in responding, following indications of interactions between oxytocin and endogenous estrogen (Razzoli et al. 2003). Ovulation testing beginning the day of testing confirmed that female participants were tested prior to ovulation.

A between-groups, double-blind, placebo-controlled design was used. Participants were randomly assigned to self-administer an intranasal dose of 24 IU oxytocin or saline solution placebo. Participants' ages and intelligence, as measured by the Wechsler Abbreviated Scale of Intelligence (Wechsler 1999), were matched across conditions (Table 1).

Oxytocin preparation

The oxytocin spray was formulated by the National Institutes of Health's Clinical Center Pharmacy from the powder version of the drug (Spectrum Pharmaceuticals, Irvine, CA, USA). The solution was prepared by combining 35.2 mg of oxytocin (568 U) with 300 mL of a 0.9% sodium chloride solution and adjusting the pH with 10× diluted acetic acid (final pH=4.01). The filtered and sterile solution was then distributed in individual vials (1.5 mL each). These vials were frozen, then thawed, and refrigerated (4°C) on the day of the study. A clinician prepared the nasal spray by

Table 1 Comparison of participants in oxytocin and placebo conditions

	Oxytocin	Placebo	P
N	24	26	–
Males:females	14:10	15:11	>0.10
Age (SD)	26.2 (4.9)	26.6 (5.0)	>0.10
IQ (SD)[a]	114.9 (9.4)	115.8 (10.9)	>0.10

[a] IQ data were not available for two participants in the placebo group and four participants in the oxytocin group

transferring the oxytocin or placebo from the vial into the nebulizer. The nebulizer was primed and provided to the participants, who self-administered the nasal spray while being monitored by a clinician and an experimenter.

Procedure

This research was approved by the Institutional Review Board at the National Institute of Mental Health, and all participants' written informed consent was obtained prior to the study's commencement. Participants were tested in private or semiprivate rooms in the Clinical Center of the National Institutes of Health. Upon arrival, participants completed baseline measures of adverse symptoms including abdominal, neurological, dermatological, and cardiac symptoms. They also completed visual analog scales measuring alertness, anxiety, irritability, boredom, calmness, excitement, happiness, tension, tiredness, sadness, and friendliness.

Subsequently, participants received oxytocin or placebo in four puffs delivered to alternating nostrils at 30–45 s intervals. Thirty-five minutes following administration of drug or placebo, participants completed the emotion recognition task. A clinician assessed heart rate and blood pressure before and after behavioral testing and immediately prior to discharge (after the emotion recognition task, participants completed additional behavioral tasks which will not be described here). Prior to discharge, participants also completed follow-up measures of adverse symptoms and mood.

The facial expression recognition task featured six basic emotions (anger, disgust, fear, happiness, sadness, and surprise) from the well-validated pictures of facial affect set (Ekman and Friesen 1976). The task used in this study is derived from a task described previously (Blair et al. 2001; Marsh and Blair 2008) but which was modified in keeping with a task described by Harmer et al. (2003). In the task, participants viewed static expressions of the six basic emotions. Each face had been morphed with a neutral expression from the same exemplar in 10% increments so that the expressions varied in emotional intensity from 100% (0% neutral) to 10% (90% neutral). Participants saw 360 expressions total (6 expressions × 6 exemplars × 10 intensity levels) presented in random order (i.e., rather than seeing each face morph from 10% to 100%). Each expression appeared for 500 ms and was followed by a response choice screen that required participants to make a forced choice among six possible responses: anger, disgust, fear, happiness, sadness, and surprise. Participants' responses were self-paced. After the participant responded, a fixation cross (250 ms) appeared, followed by the next expression. Response selections and response latencies were recorded.

Analyses of behavioral data

Participants' emotion recognition accuracy in the morphed facial expression task was assessed using the unbiased hit rate analysis (Marsh et al. 2007; Wagner 1997). The procedure determines accuracy by assessing both raw accuracy, or how frequently a stimulus is identified compared to how often it appears (hits divided by the number of stimuli of that type), and differential accuracy, or how frequently a response category is used correctly compared to how often it is used (hits divided by the total number of uses of that type of response). Then the difference between the resulting value and the accuracy that would be expected by chance is computed. The resulting value, being a proportion, is then arcsin-transformed. Thus, all accuracy scores used in the analysis represented that which would be expected above the accuracy that would be expected due to guessing.

Performance differences among groups were assessed using a repeated-measures analysis of variance (ANOVA). Between-group factors were pharmacological challenge group (oxytocin, placebo) and participant gender, and the dependent variables were accuracy levels for the six expressions. Significant interactions were followed up with pairwise comparison tests. We predicted that a significant group × expression interaction would emerge, following the hypothesis that oxytocin would enhance the recognition of happy facial expressions but not other expressions. A similar ANOVA was conducted to assess differences in response latencies across expressions.

Results

Mood and physiological results

Independent sample t tests were conducted to compare systolic and diastolic blood pressure readings across conditions and to compare self-reported negative and positive mood. No significant differences in systolic or diastolic blood pressure were recorded at any time point prior to or following the administration of active drug or placebo (P's> 0.10). No significant differences in positive or negative mood were observed across conditions (P's>0.10).

Morphed facial expression task results

Identification accuracy

The predicted interaction between pharmacological challenge condition and expression was found ($F(5, 230)=2.83$, $P<0.05$, partial $\eta^2=0.06$), suggesting that oxytocin's effects vary across expressions. Planned independent samples t

tests confirmed that the only expression for which recognition rates were significantly affected by oxytocin was happiness ($t(48)=2.11$, $P<0.05$, $r=0.29$; Table 2). A nonsignificant improvement was also found for surprise expressions ($t(48)=1.69$, $P<0.10$, $r=0.24$).

The cell values at each time point were insufficiently large to support an unbiased hit rate analysis for each time point. Thus, we inspected accuracy rates at each intensity level using raw percent accuracy scores, which are not corrected for response biases or false alarms. Inspection of accuracy rates across intensity levels indicates that the effects of oxytocin were the strongest for happy expressions of moderate intensity (Fig. 1), with peak differences between groups appearing at approximately 40% ($t(48)=1.75$, $P<0.05$), 50% ($t(48)=1.68$, $P<0.05$), and 80% intensity ($t(38)=1.55$, $P<0.10$; P values one-tailed).

Improved recognition of happy expressions was not due to response bias toward selecting positive response choices (the unbiased hit rate corrects for any such tendency). The number of times participants in both groups selected "happy" as their response was compared, and the mean number of selections of "happy" did not significantly differ across groups ($P>0.20$).

No significant main effect was found for pharmacological challenge condition across the six expressions ($F(1, 46)=1.73$, $P>0.10$). A main effect of expression was found ($F(5, 230)=90.34$, $P<0.001$, partial $\eta^2=0.66$), replicating the common finding that the accuracy with which the six expressions are identified varies across expression. As is typically true, happiness was correctly identified most frequently, and disgust was correctly identified least frequently.

Reaction times

Reaction times were assessed using the same technique as for accuracy scores, except that the data comprised the time each participant required to identify each emotional expression. Only the latency of correct responses was analyzed. For reaction time data, no significant main effects or interactions were found for correct recognition of the six facial expressions (all P's>0.05). A post hoc analysis revealed a nonsignificant improvement in the latency of happiness recognition, however, such that participants who received oxytocin recognized happiness more quickly ($M=964.1$ ms, SD=248) than participants who received placebo ($M=1{,}096.1$ ms, SD=334; $t(48)=1.58$, $P=0.12$).

Gender

Previous studies have found gender to modulate the effects of pharmacological challenges on facial expression recognition (Harmer et al. 2003), and oxytocin's effects on behavior may be enhanced by its interaction with sex hormones like estrogens (Champagne et al. 2001; McCarthy et al. 1996). Our analyses revealed no significant main effect of gender or interactions between gender and expression or pharmacological challenge condition (P's>0.05). Males and females viewing happiness expressions showed improved response accuracies of similar magnitudes (0.10 and 0.12, respectively) following the administration of oxytocin.

Discussion

The results of the current study demonstrate that oxytocin increases healthy adults' sensitivity to positive emotional expressions. Participants who received oxytocin identified happy expressions more accurately than those who received placebo. This group difference was not attributable to differences in gender, response latency, mood, or response biases toward selecting the "happy" response option.

Previous research examining the impact of oxytocin on the processing of happy facial expressions has yielded somewhat inconclusive results. Guastella et al. (2008) found that oxytocin increases memory for the identity of faces first seen showing happy expressions. However, in a separate study, Guastella et al. (2009) found no increased popout effect for cartoon line drawings of happy expressions following oxytocin administration. Moreover, Di Simplicio et al. (2008) concluded that oxytocin had "no effect on facial expression recognition accuracy" (p 245) but that it does slow reaction time to correctly identify fearful facial expressions and reduces the misclassification of positive or ambiguous emotions as negative ones. Our results are consistent with Guastella et al. (2008), less consistent with those of Di Simplicio et al. (2008), and inconsistent with those of Guastella et al. (2009). With

Table 2 Comparison of emotional facial expression recognition for participants who received oxytocin and placebo

	Anger	Disgust	Fear	Happiness	Sadness	Surprise
Oxytocin	0.21 (0.02)	0.20 (0.03)	0.22 (0.03)	0.58 (0.04)	0.18 (0.02)	0.28 (0.03)
Placebo	0.17 (0.02)	0.17 (0.03)	0.18 (0.02)	0.45 (0.04)	0.19 (0.02)	0.22 (0.02)
t value (P)	0.78 (0.43)	0.40 (0.69)	0.68 (0.49)	2.11 (0.04)	0.67 (0.51)	1.69 (0.09)

Means and standard error values are provided across intensity levels

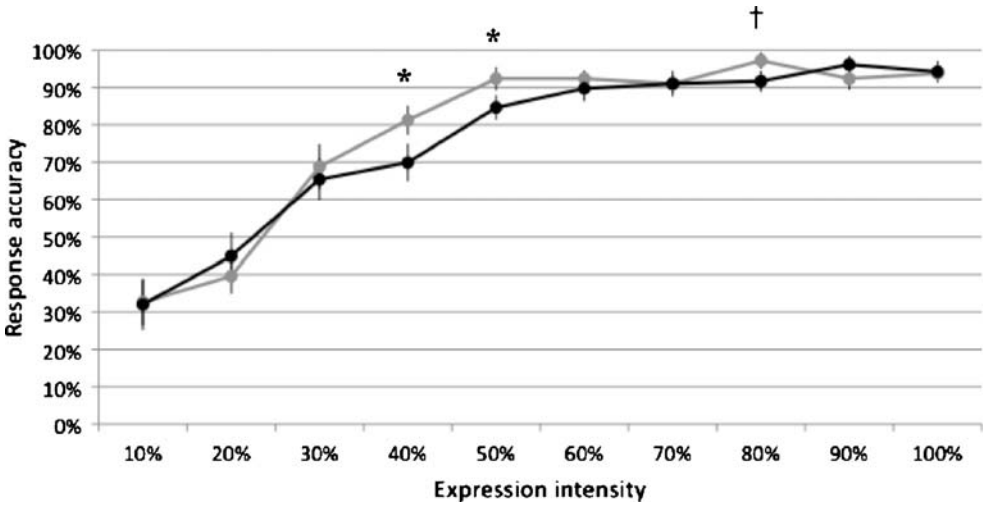

Fig. 1 Accuracy of recognition of happy expressions at ten intensity levels. Note that because the cell values at each time point were insufficiently large to support an unbiased hit rate analysis for each time point, these values reflect percent accuracy rates, which are not corrected for response biases or false alarms. *Dark lines* following oxytocin administration, *light lines* following placebo administration. Values represent means ±1 SEM. *<0.05. †<0.10

reference to the study by Guastella et al. (2009), it is important to note that the effects of "popout" or visual search paradigms rely on visual processing biases, particularly for threatening information, at very early stages of the visual encoding process (Öhman et al. 2001). No clear popout effect emerged for happy faces in this study, which may make the absence of an oxytocin effect less surprising.

With respect to the findings of Di Simplicio et al. (2008), it is notable that whereas we observed that oxytocin improved the recognition of happy expressions, Di Simplicio and colleagues found that oxytocin reduced the misclassification of positive or ambiguous emotions (particularly surprise and neutral expressions) as negative ones. By contrast, we did not observe any group differences in response biases for selecting any of the emotional labels. This suggests that participants who received oxytocin not only showed improved accuracy for recognizing happiness (particularly at moderate intensity levels) but also showed fewer false alarms or incorrect attributions of happiness to other expressions. However, interpretation of false alarm data is inherently difficult for forced-choice response formats, as participants may try to compensate for underuse of particular response categories by guessing.

The group differences in identification of happiness that was observed in the current study might have been affected by two factors. First, Di Simplicio and colleagues included only male participants, unlike the current study. Although we did not observe a statistically significant gender interaction, oxytocin may affect females differently than males, in accordance with evidence from rodent studies that oxytocin interacts with gonadal hormones in influencing social behavior (Champagne et al. 2001; McCarthy et al. 1996; Razzoli et al. 2003). Moreover, recent neuroimaging studies suggest that in women, oxytocin may increase activity in neural regions involved in processing emotional facial expressions (such as the amygdala and inferior temporal cortex) but that it may reduce activity in these regions in men (Domes et al. 2007a, b, 2009). Second, our study employed a larger sample size than did Di Simplicio and colleagues. Had we analyzed only the data from the 29 males in our study (equivalent to the sample used by Di Simplicio and colleagues), we would not have found a significant group effect for emotion recognition following oxytocin administration. Other methodological differences, such as the fact that Di Simplicio and colleagues dropped the data from the lowest-intensity expressions before calculating their analyses and the fact that they used d' to assess accuracy rather than the unbiased hit rate, may have also affected the determination of group differences in recognition accuracy.[1]

It should be noted also that Di Simplicio et al. (2008) reported a significant emotion × intensity × group effect for reaction time. This interaction was driven by the oxytocin group being slower than the placebo group at recognizing fearful faces for the 40% and 70% intensities. This was not seen in the current study despite our larger N and our inclusion of females. Further work will be necessary to examine whether oxytocin's effects are specific to positive emotions, as suggested by our findings, those findings of Guastella et al. (2008), and the misclassification data of Di Simplicio et al. (2008), or whether they also generalize to other emotions like fear.

[1] Reanalyzing our data using the methods of Di Simplicio and colleagues—removing responses to 10% and 20% intensity expressions and calculating d' using the number of hits for each expression, the number of false alarms, the number of targets, and the number of distractors and the formula: Pr = (number of hits + 0.5/number of targets +1) − (number of false alarms + 0.5/number of distractors +1)—also failed to yield significant results. The resulting group × emotion interaction was $F(5, 230)=0.43$, *ns*, and the group comparison for happy expressions was $t(48)=1.56$, $P=0.12$ (two-tailed). This suggests that the difference in results between the two studies may reflect differences in the sensitivity of the analysis strategies.

Given our current results, findings of Di Simplicio et al. (2009) that oxytocin reduced the misclassification of positive or ambiguous emotions as negative ones, and findings of Guastella et al. (2008) that oxytocin increases memory for the identity of faces first seen showing happy expressions, we assume that oxytocin effectively increases the representational strength of faces displaying happy expressions. Facial expression naming and facial identity memory and naming are, of course, different processes. But it is important to note that oxytocin has not been demonstrated to generally affect either process; rather, its effects are specific to positive emotional expressions. So although face memory and emotion identification are distinct processes, we assume that both are influenced by the representational strength of the facial expression stimulus and that oxytocin can modulate either process if positive emotional expressions like happiness are present. To the extent that happy expressions are associated with social approach and affiliation, this interpretation is corroborated by the findings of Unkelbach et al. (2008). In this study, the cognitive accessibility of positive words related to sex and relationships (e.g., love) was selectively facilitated by oxytocin.

An alternate interpretation of the present findings is that oxytocin improved recognition of positive cues due to the relative ease with which the happy expression is processed. Although this cannot be discounted, it is important to note that while happiness is consistently seen to be the easiest basic emotional expression to recognize across studies, group differences in happiness recognition are very rarely observed (Adolphs and Tranel 2004; Calder et al. 2003; Marsh and Blair 2008).

The present results also suggest a possible mechanism by which oxytocin may facilitate prosocial and affiliative behavior: by increasing sensitivity to signs of trustworthiness. A smile indicates that the expresser is trustworthy—that he or she seeks affiliation and does not present a threat (Hess et al. 2000). Accordingly, recent research suggests that subtle signs of happiness predict whether a face will appear trustworthy (Oosterhof and Todorov 2009; Todorov 2008). Neutral faces that engender the appearance of trustworthiness appear to simulate a happy expression. This is demonstrated by manipulating neutral expressions to make them appear more trustworthy, which results in the generation of faces that are perceived as happy (Todorov 2008). These findings indicate that sensitivity to trustworthiness in a face is related to the ability to detect subtle signs of happiness. Oxytocin, by increasing sensitivity to happiness cues, may thereby facilitate interpersonal trust. It should be noted that recent research has suggested that oxytocin may also enhance less positive forms of social behavior, such as envy and schadenfreude (Shamay-Tsoory et al. 2009). However, the effects of oxytocin on processing nonverbal visual cues seem to pertain predominantly to the detection of positive cues.

Oxytocin is produced in hypothalamic nuclei that project to subcortical structures involved in regulating social behavior, including the amygdala and striatum (Baumgartner et al. 2008; Ferguson et al. 2002; Sofroniew 1983; Uvnäs-Moberg 1997; Winslow and Insel 2002). Receptors in these structures are thought to play an important role in oxytocin's effects on social behavior. For example, high levels of trust in adults who receive oxytocin are associated with reduced activity in the amygdala and striatum (Baumgartner et al. 2008). Sensitivity to trustworthy faces, which are characterized by elements of happy expressions, is associated with increased amygdala activation relative to neutral faces, although this activation is much less than activation in response to untrustworthy faces (Todorov 2008). That administering oxytocin alters responses to happy expressions, which are perceived as trustworthy, supports the possibility that oxytocin's effects on the processing of cues relevant to positive emotion and trustworthiness may be related to the modulation of amygdala activity.

The present findings suggest potential clinical applications for oxytocin. Social anxiety disorders are characterized by enhanced sensitivity to threatening social cues (Joormann and Gotlib 2006; Straube et al. 2005), and individuals diagnosed with social phobia are less accurate than controls at identifying happiness expressed in the face (Simonian et al. 2001) and the voice (Quadflieg et al. 2007). Oxytocin, by increasing sensitivity to other individuals' positive affect, might improve symptoms in patients with social anxiety disorders. Although autism spectrum disorders are distinct from social anxiety disorders, they are also characterized by impaired social cue processing and impaired formation of affiliative bonds (Kirsch et al. 2005; Young 2001). Preliminary evidence suggests that oxytocin may reduce autistic individuals' impairments at reading face-based social cues (Domes et al. 2007b). Detecting others' positive social cues more effectively may not itself ameliorate symptoms of social anxiety or autism, but future researchers may wish to assess whether oxytocin's role in identifying positive social cues is relevant to the treatment of these disorders.

Conclusions

This study investigated the relationship between acute oxytocin administration and sensitivity to emotional facial expressions in healthy adults. In keeping with prior evidence that oxytocin enhances sensitivity to positive social and emotional cues, we found that oxytocin administration resulted in specific improvements in identifying happy facial expressions. This result was unrelated to

response biases, mood, or differences in response latency. We hypothesize that oxytocin's enhancement of the detection of subtle positive socioemotional cues may be relevant to oxytocin's ability to increase social trust and affiliation and reduce social anxiety.

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