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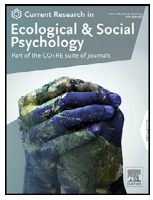

Oxytocin and emotion recognition: Investigating the possible roles of facial synchrony and eye gaze

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ABSTRACT

The neuropeptide oxytocin (OT) has been shown to influence social cognition, including better recognition of emotion in faces. One potential way in which OT improves emotion recognition is by increasing the correspondence between a perceiver's own facial activity and observed facial expressions. Here we investigate whether increased facial synchrony while viewing facial expressions increases emotion recognition, and whether this effect is moderated by OT. Change in visual attention as captured by eye-gaze is another way in which OT might improve emotion recognition. We also examine visual attention to observed expressions, and whether this is influenced by OT. One hundred and four male undergraduates took part in a double-blind, randomized, between-subjects study in which they self-administered either a placebo (PL) or 24 IU of OT before viewing dynamic facial expressions of emotion, during which their facial activity and eye-gaze were measured, before answering questions on emotion recognition and affiliation. It was hypothesized that participants in the OT condition would exhibit more facial synchrony than would those in the PL condition, and that OT would influence time spent looking at the eye region of target faces. Consistent with previous research, participants in the OT condition were marginally but significantly better at emotion recognition than those in the PL condition. However, participants in the OT condition displayed less facial synchrony for fearful expressions, and there was no effect of OT on measures of eye-gaze. These results suggest that OT does not improve emotion recognition through increased facial synchrony or changing visual attention.

1. Introduction

The neuropeptide oxytocin (OT) has been found to play a complex, important role in various aspects of social cognition (Van IJzendoorn and Bakermans-Kranenburg, 2012). A reliable finding is that OT increases emotion recognition (Leppanen et al., 2017; Shahrestani et al., 2013), although the mechanisms responsible for this are unclear. A candidate mechanism is the degree of corresponding facial activity between actor and observer. In the broader emotion literature, there is some evidence that facial synchrony of emotional expressions enhances emotion recognition (Stel et al., 2016). Several studies (Korb et al., 2016; Pavarini et al., 2019; Trilla et al., 2020) have examined OT effects on facial synchrony, finding mixed results. Another candidate mechanism is visual attention, the idea being that increased attention to certain regions of the face improves emotion recognition (e.g., Klin et al., 2002). Although several studies have investigated whether OT influences eye-gaze (Domes et al., 2007; Guastella et al., 2008; Hubble, Daughters et al., 2017), variations in methodology present mixed findings. In the present study we investigated the influence of OT on emotion recognition, facial synchrony, and eye-gaze, and whether improvements in emotion recognition are linked to facial synchrony or eye-gaze.

Synchrony between individuals and within groups is suggested to confer social benefits, such as smoother social interaction and group cohesion. Given OT's role in supporting adaptive social behaviour, research has investigated whether OT facilitates social synchrony. Developmental studies have demonstrated that endogenous OT concentrations synchronise across a young family dyad/triad and that OT was positively associated with social interaction, communication and the synchronising of affect, touch and gaze (Apter-Levi et al., 2014; Feldman et al., 2010, 2011; Gordon et al., 2010). In adults, research has demonstrated that synchronous social interactions are associated with an increase in endogenous OT (Spengler et al., 2017) and that intranasal administration of OT led to increased postural synchrony (for healthy volunteers) during social interaction (Ramseyer et al., 2020). Indeed, neuroscience studies suggest that OT enhances processing of social synchrony stimuli (Levy et al., 2016) and increases inter-brain synchrony

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during a coordination task (Mu et al., 2016). Thus, research suggests that OT facilitates various types of social synchrony.

More specifically, however, emotion researchers have proposed that facial mimicry – spontaneous synchrony of facial expressions – can aid in the recognition of emotions (Hatfield et al., 1993; Stel et al., 2016). Consistent with such theories, it has been shown that blocking the ability to spontaneously mimic the emotional expressions of others results in poorer emotion recognition (Oberman et al., 2007; Rychlowska et al., 2014). However, evidence that facial mimicry increases emotion recognition is less abundant; for example, in one study participants' spontaneous mimicry of dynamic emotional expressions was not found to facilitate emotion recognition (Hess and Blairy, 2001).

Several studies have investigated whether OT influences facial synchrony in response to emotional stimuli. Spengler et al. (2017) found that participants who had received OT were judged (relative to placebo) as displaying more intense facial expressions of happiness and fear. Participants were instructed by word cue to produce emotion displays that were later rated for intensity by a different group of participants; there was no measure of facial activity. Woolley et al. (2017) found that OT tended (p = .06) to increase participants' facial responsiveness to emotional photographs. However, because the photographs did not depict facial expressions of emotions, the researchers were not able to assess facial synchrony or emotion recognition. In more relevant studies, (Korb et al., 2016) participants were presented with dynamic expressions of adults and infants expressing anger and happiness. It was found that OT increased facial mimicry of infant anger, and increased the reported intensity of angry expressions. Pavarini et al. (2019) presented their participants with dynamic facial expressions of happiness, sadness, fear and anger, finding that OT tended (p = .06) to increase mimicry of sad facial expressions. However, it should be noted that there was no reliable mimicry of fear and anger, and the authors were therefore limited to analyzing the effect of OT on happy and sad facial expressions. Finally, Trilla et al. (2020) found no effect of OT on facial mimicry of dynamic facial expressions of happiness and anger. However, none of these studies included a direct measure of emotion recognition, so it was not possible for the researchers to test the relationship between OT, facial synchrony, and emotion recognition.

Synchrony between individuals is also associated with increased affiliation (Hess and Fischer, 2013; Lakin et al., 2003; Van Der Schalk et al., 2011). Relatedly, it has also been found that OT increases prosocial, affiliative behavior (De Dreu and Kret, 2016). This raises the possibility that facial synchrony is the mechanism through which OT increases affiliation. Indeed, Pavarini et al. (2019) hypothesized that the effect of OT on spontaneous mimicry would only occur when mimicry indicated an affiliative response (i.e., that OT would only increase mimicry of happy and sad facial expressions). However, because they found no mimicry of fear or anger, this remains an open question and will therefore be examined in the present study.

Research on face processing has shown that the eye region of the face contains important information about emotional expressions, and that expression differences in the eye region can be used to distinguish different emotions (Schyns et al., 2007, 2009). The social salience hypothesis of oxytocin (Bartz et al., 2011; Shamay-Tsoory and Abu-Akel, 2016) suggests that OT influences social cognition by increasing the salience of social cues, and it has been hypothesized that OT increases eye-gaze because the eyes become a particularly salient source of social information. In turn, increased visual attention to the eye region of faces may be another way in which OT facilitates emotion recognition. Several studies have investigated this hypothesis but inconsistencies in methodology and results make it difficult to draw strong conclusions. Several studies suggest that OT is associated with increased eye-gaze when engaging in real-life social interaction (Auyeung et al., 2015), viewing social video clips (Hubble et al., 2017), dynamic facial expressions (Domes et al., 2013), and static images of faces (Andari et al., 2010; Guastella et al., 2008) and dyads (Eckstein et al., 2019). However, other studies have found no effect of OT on eye-gaze when viewing static (Hubble, Daughters et al., 2017) or dynamic (Lischke et al., 2012) facial expressions of emotion. Furthermore, although these studies have implications for the relation between OT, eye-gaze, and emotion recognition, this relation was not explicitly tested in all studies. Moreover, of the studies that did directly measure emotion recognition, in one there was no effect of OT on eye-gaze (Lischke et al., 2012) and in another it was found that OT increased eye-gaze but that increased gaze was not related to emotion recognition (Hubble et al., 2017). Given the conflicting evidence to date, the current study sought to directly test the relationship between OT, visual attention to the eye region, and emotion recognition.

In summary, in the present study we investigated two potential mechanisms through which OT might influence emotion recognition: facial synchrony and eye-gaze. First, we aimed to replicate the finding from previous research that OT increases emotion recognition. Secondly, we hypothesized that OT would increase facial synchrony of emotional expressions, and that this would be moderated by emotion. Thirdly, given the mixed findings to date, we explored the effect of OT on eye-gaze (as measured by the amount of time spent looking at the eye region, and how quickly participants looked at the eye region). Fourthly, we hypothesized that OT would increase ratings of intensity of emotional expressions (in line with findings from Korb et al., 2016), and feelings of affiliation with the target (in line with predictions from Pavarini et al., 2019).

2. Material and Methods

2.1. Participants and Ethics

One hundred and four male Cardiff University undergraduates (M_{age} = 19.90, SE = 2.26) participated in the study, which was approved by the relevant institutional ethics committee and adhered to the Declaration of Helsinki. Given the recent controversy regarding statistical power and the validity of early OT findings (Walum et al., 2016), we decided to recruit a larger sample size than a similar study (Korb et al., 2016), in which there were 60 participants in a between-subjects design. We aimed to recruit 120 participants, although ultimately 104 participants took part. Participants who were psychology students were recruited via an online system; participants from other schools were recruited via an email advertisement. All participants were required to pass a medical screening and provided written informed consent before taking part in the study and were fully debriefed and provided a signed statement of health before leaving the testing facility. Participants were not allowed to take part if they had a history of cardiovascular disease, or neurological or mental health disorders. They were asked to avoid alcohol consumption 24 hours prior to their session, and to avoid smoking and caffeine consumption in the preceding 2 hours. Female participants were not recruited due to evidence that OT concentrations interact with the menstrual cycle (Salonia et al., 2005). Participants who were psychology students were awarded course credits; participants from other schools received £20.

2.2. Design

We used a randomized, double-blind, placebo-controlled, mixed design, in which the factors were Drug (OT vs PL, between-subjects) and Emotion (happy, sad, angry, fearful). Participants were randomly allocated to either the OT or PL conditions and were then shown stimulus faces expressing happiness, sadness, anger and fear.

2.3. The Facial Synchrony Task

Stimuli were taken from the Amsterdam Dynamic Facial Expression Set (ADFES; (Van Der Schalk et al., 2011)), a validated stimulus set of short video clips showing neutral faces developing over time into one of nine discrete emotions. For the purposes of this study, participants were shown video clips of four different North-European actors (two males,

two females), facing forward, depicting four basic emotions: happy, sad, fear, and anger. The original video clips were edited such that each clip was four seconds long. For the purposes of analysis, the first second of the video was discarded because during this second the stimuli displayed a neutral face, and thus no active facial synchrony could be assessed. Analyses were therefore carried out on the final three seconds which captured the stimuli morphing into a full intensity expression. Participants were shown each emotion display eight times (twice for each actor), which was presented as two blocks of 16 pseudorandomized trials. Trials were pseudorandomized to ensure that participants did not see successive clips in which different actors posed the same expression. The order of blocks was randomized.

A trial consisted of a black screen for 500ms, followed by a white fixation cross on a black background for 500ms (the cross was counterbalanced to appear on either the left- or right-hand side of the screen to ensure participants were fixated away from the face at onset), then the four second stimulus was presented. After each video, participants were asked: 1) to identify the emotional expression (forced-choice: happy, sad, fear or anger); 2) to rate the intensity of the emotional expression (5-point Likert scale, where 1 was low intensity and 5 was high intensity); 3) to rate their affiliative tendency toward the individual in the clip (the Inclusion of Other in the Self Scale, which ranges from 1 to 7, where 1 represents no affiliation and 7 represents high affiliation; Aron et al., 1992). Participants were allowed to complete responses in their own time. An emotion recognition score (percentage of correct responses), an average intensity score and an average affiliation score were calculated for each participant. The entire task took approximately 15 minutes to complete.

Participants were told that the purpose of the task was to assess how people respond to different individuals. As part of their verbal instructions, participants were asked to pretend the individual in each clip was really present in the room, and to copy what they were doing to the best of their ability. This informed by a pilot study in which we found that the automatic coding software did not record sufficient facial activity under spontaneous mimicry conditions.[1] In line with prior research (Ekman et al., 1981; Hess and Kleck, 1990; Schmidt et al., 2006), the pilot study demonstrated that synchrony instructions increased the amount of facial activity to detectable levels and thereby avoided floor effects. Research has shown that there is no difference in emotion recognition when using instructed versus deliberate mimicry (Blairy et al., 1999; Schneider et al., 2013).[2] Although prior research shows that asking participants to identify emotions increases levels of facial activity (Murata et al., 2016), this is something we could not avoid while addressing our research question. Because the use of the instruction to mimic the stimulus person's expressions means that our outcome variable does not reflect spontaneous mimicry, we refer instead to facial synchrony. Facial synchrony reflects the level of participants' facial activity in the corresponding pre-selected channels shown to be active in the stimuli. The greater the value, the greater the degree of facial synchrony between actor and participant.

[1] In a pilot study we found that the AFFDEX algorithm (see Supplemental Materials *2.3* for details) detected very low levels of facial activity when participants were given no instructions regarding mimicry. There were 29 undergraduate participants in the study, half of whom received deliberate mimicry instructions, while the other half were told to pretend the individual in each clip was really present in the room, that they were engaging in a conversation with them, and to act as naturally as possible (natural reaction instructions). Participants in the deliberate mimicry condition had similar AFFDEX scores as the stimulus faces, while participants in the natural reaction condition had very low AFFDEX scores.

[2] Although one study (Lewis & Dunn, 2017) found differences for individuals high in autistic traits, the current study recruited undergraduate students with a presumably normal distribution of autistic traits.

Table 2
Channels used to assess relevant facial activity for each emotion.

Emotion	Channels
Happy	Mouth Open, Smile, Lip Stretch, Cheek Raise
Anger	Brow Furrow, Lid Tighten, Chin Raise, Lip Suck, Lip Press
Sad	Brow Furrow, Lid Tighten, Chin Raise, Lip Corner
Fear	Brow Raise, Mouth Open, Eye Widen

2.4. Automatic facial coding

The experimental task was presented using iMotions (www.imotions.com), a biometric research platform that can be used to synchronize multiple psychophysical measures. This enabled automated facial coding, eye tracking, and stimulus presentation to be precisely coordinated. Participants' facial activity was recorded via a Logitech HD webcam. The videos were post-processed using the AFFDEX algorithm for automatic facial coding developed by Affectiva Inc. (El Kaliouby and Robinson, 2005; McDuff et al., 2010). AFFDEX is grounded in the Facial Action Coding System (FACS) and provides an output for 20 'channels' based on the FACS action units (Ekman and Friesen, 1975). Participants' facial activity was scored in terms of these 20 'channels' on a scale from 0 to 100 representing the probability that that channel was being expressed (0 – channel not expressed, 100 – channel expressed).

To assess whether participants were copying stimulus expressions reliably, we investigated the degree of correspondence in activity in specific channels between the video stimuli and participants' facial activity. To do this, the ADFES stimuli were processed using AFFDEX. A cut-off AFFDEX score of 20 was used to assess which of the 20 channels was activated in each emotion display and each actor (see Supplemental Material 2 for details). Channels that were activated for each emotion in at least three of the four actors were identified (see Table 2 and Fig. S1 in Supplemental Material 2 for a visual depiction of these channels). Evidence of activation of these specific channels in participants' faces would therefore reflect synchrony with the stimulus expressions.

2.5. Eye tracking

Eye tracking was measured by a portable Tobii x2-60 compact eye-tracker sampling at 60Hz with a screen resolution of 1920 × 1080. An I-VT fixation filter was applied, and data were sampled from both eyes to produce information on eye position and duration. Participants were seated 60-65cm from the screen of the laptop on which the stimuli were presented. They completed a 9-point calibration before the main task. If the calibration quality was poor, the process was repeated. No participants had to complete the calibration more than twice. iMotions provides a percentage score of successfully recorded eye tracking data; 91% of the data was successfully recorded.

Dynamic Areas of Interest (AOIs) were drawn around the actor's eyes and mouth using landmarks on the face. These AOIs were adjusted on a frame-by-frame basis to ensure that as landmarks moved with the developing display, the AOIs continued to capture the relevant information (for example, ensuring that eyebrows were still captured by the AOI for the eyes when these moved upwards in the fearful expression). Metrics were then exported for Dwell Time (as a percentage of time the participants were fixated in an AOI while the stimulus was on the screen) and time-to-first-fixation (TTFF), in terms of milliseconds from stimulus onset to first fixation in an AOI.

2.6. Protocol

After settling into the testing facility, participants self-administered 24 IU (three 4 IU puffs per nostril) of synthetic OT or an independently manufactured placebo (PL) nasal spray in line with recent guidelines (Guastella et al., 2013) and under the supervision of the experi-

menter. Both sprays were manufactured by St Mary's Pharmaceutical Unit, Cardiff (http://www.wales.nhs.uk/sites3/home.cfm?orgid=828). A medical doctor was available during administration and for the following 15 minutes in case of an adverse reaction. Participants completed several measures (including personality measures and intelligence assessments) during the 30-minute waiting period (Daughters et al., 2015; Gossen et al., 2012) before completing two 15-minute face-processing tasks. Approximately one hour after administration, participants completed the facial synchrony task. Previous research demonstrates that OT concentrations are still elevated 100 minutes after administration (Daughters et al., 2015), so participants would still have been under the influence of the nasal sprays during the facial synchrony task. At the end of the study all participants were fully debriefed.

2.7. Data analysis

For all analyses, where the assumption of sphericity was not met, Greenhouse-Geisser corrections were applied. For main effects, pairwise comparisons were carried out and were Bonferroni-corrected. Interaction effects were decomposed using simple effects analysis and all comparisons were Bonferroni-corrected. Effect sizes are reported as partial eta squared, where 0.02 represents a small effect size, 0.13 represents a medium effect size, and 0.26 represents a large effect size (Draper, 2002). All analyses were carried out using SPSS 25 (IBMCorp, 2017).

2.7.1. Emotion recognition

A 2 (Drug: OT/PL, between subjects) x 4 (Emotion: happy/sad/anger/fear, within subjects) mixed-model Analyses of Variance (ANOVA) was carried out on emotion recognition accuracy scores.

2.7.2. Facial synchrony

Four mixed-model ANOVAs, one for each of the four emotions, were carried out to assess whether participants' synchrony differed across channels, over time, and between drug conditions. Correlations were also calculated to assess the relation between facial synchrony and emotion recognition, and between facial synchrony and affiliation.

2.7.3. Eye-gaze

Two 2 (Drug: OT/PL, between-subjects) x 4 (Emotion: happy/sad/anger/fear, within-subjects) x 2 (AOI: eyes/mouth, within-subjects) mixed-model ANOVAs were carried out on percentage dwell time and TTFF. The data violated the assumption of normality and were therefore log transformed (which reduced skewness to acceptable levels) prior to analysis. For ease of interpretation, untransformed means and SEs are reported below. Correlations were calculated to assess the relations among drug condition, dwell time/TTFF, and emotion recognition.

2.7.4. Intensity and affiliation

Two 2 (Drug: OT/PL, between-subjects) x 4 (Emotion: happy/sad/anger/fear, within-subjects) mixed-model Analyses of Variance (ANOVA) were carried out on emotion intensity ratings and affiliation scores.

3. Results

3.1. Emotion recognition

In line with predictions, there was a significant main effect of Drug, $F(1, 100) = 4.501$, $p = .036$, $\eta_p^2 = .043$ (see Fig. 1), such that participants in the OT condition identified more emotions correctly ($M = 95.688$, $SE = .329$) compared to participants in the PL condition ($M = 94.531$, $SE = .382$). A significant main effect of emotion also revealed that happy ($M = 99.880$, $SE = .123$), angry ($M = 99.029$, $SE = .450$), and fearful ($M = 99.029$, $SE = .333$) facial expressions were correctly identified to a greater extent than sad ($M = 82.500$, $SE = .939$) expressions, $F(3, 300) = 232.819$, $p < .001$, $\eta_p^2 = .700$. There was no significant interaction between Drug and Emotion ($F(1.62, 162.13) = .749$, $p = .448$, $\eta_p^2 = .007$).

3.2. Facial synchrony

3.2.1. Anger

A 5 (Channel: brow furrower/lid tightener/chin raiser/lip sucker/lip presser, within-subjects) x 3 (Time: 1st second/2nd second/3rd second, within-subjects) x 2 (Drug: OT/PL, between-subjects) was carried out on participants' facial activity while viewing angry expressions. Participants showed more activation in the brow furrower ($M = 13.453$, $SE = 1.016$) and lid tightener ($M = 12.670$, $SE = 1.047$) channels compared to the chin raiser ($M = 5.361$, $SE = .656$), lip presser ($M = 4.247$, $SE = .615$), and lip sucker ($M = 3.814$, $SE = .598$), $F(4, 408) = 43.137$, $p < .001$, $\eta_p^2 = .297$. Participants showed the most facial activity during the 3rd second ($M = 21.480$, $SE = 1.320$), compared to the 2nd second ($M = 1.805$, $SE = .215$) and the least activation in the 1st second ($M = .442$, $SE = .122$), $F(2, 204) = 256.427$, $p < .001$, $\eta_p^2 = .715$, reflecting the dynamic nature of the stimuli morphing from neutral to the expression. There was a no main significant effect of Drug ($F(1, 102) = .585$, $p = .446$, $\eta_p^2 = .006$). Finally, there was a significant interaction between Channel and Time, $F(8, 816) = 46.787$, $p < .001$, $\eta_p^2 = .314$, such that there was no significant difference in activation between the channels during the 1st second and by the 3rd second brow furrow and lid tighten shown significantly greater activation compared to chin raiser, which showed statistically similar activation to lip press, which showed statistically similar activation to lip suck. All remaining interactions were non-significant (Channel x Drug: $F(2.445, 249.416) = .331$, $p = .761$, $\eta_p^2 = .003$; Time x Drug: $F(1.011, 103.163) = .215$, $p = .647$, $\eta_p^2 = .002$; Channel x Time x Drug: $F(2.440, 248.888) = .258$, $p = .815$, $\eta_p^2 = .003$).

3.2.2. Happy

A 4 (Channel: mouth open/smile/lip stretcher/cheek raiser, within-subjects) x 3 (Time: 1st second/2nd second/3rd second, within-subjects) x 2 (Drug: OT/PL, between-subjects) was carried out on participants' facial activity while viewing happy expressions. Participants showed more activation in the mouth open channel ($M = 25.494$, $SE = 1.161$), than in the smile channel ($M = 20.857$, $SE = .836$), than in the lip stretcher ($M = 16.641$, $SE = 1.011$), than in the cheek raiser ($M = 7.817$, $SE = .619$), $F(3, 306) = 104.131$, $p < .001$, $\eta_p^2 = .505$. Again, participants showed the most facial activity during the 3rd second ($M = 48.301$, $SE = 1.825$), compared to the 2nd second ($M = 4.168$, $SE = .284$) and the 1st second ($M = .638$, $SE = .152$), $F(2, 204) = 682.491$, $p < .001$, $\eta_p^2 = .870$. There was a no significant main effect of drug, $F(1, 102) = 1.373$, $p = .244$, $\eta_p^2 = .013$. Again, there was a significant interaction between channel and time, $F(6, 612) = 91.123$, $p < .001$, $\eta_p^2 = .472$, such that although the increase in participants' facial activity over time was significant for the mouth open, smile and lip stretcher channels, the cheek raiser channel showed statistically similar activation for the 1st and 2nd seconds. All remaining interactions were non-significant (Channel*Drug: $F(1.780, 181.564) = .105$, $p = .879$, $\eta_p^2 = .001$; Time*Drug: $F(1.018, 103.879) = 1.590$, $p = .210$, $\eta_p^2 = .015$; Channel*Time*Drug: $F(1.870, 190.710) = .212$, $p = .794$, $\eta_p^2 = .002$).

3.2.3. Sad

A 4 (Channel: brow furrower/lip corner puller/chin raiser/lid tightener, within-subjects) x 3 (Time: 1st second/2nd second/3rd second, within-subjects) x 2 (Drug: OT/PL, between-subjects) was carried out on participants' facial activity while viewing sad expressions. Participants showed more activation in the brow furrower ($M = 8.685$, $SE = .894$) and lid tightener ($M = 8.324$, $SE = .924$) channels, than in the lip corner puller ($M = 6.289$, $SE = .638$) and chin raiser ($M = 6.240$, $SE = .692$)

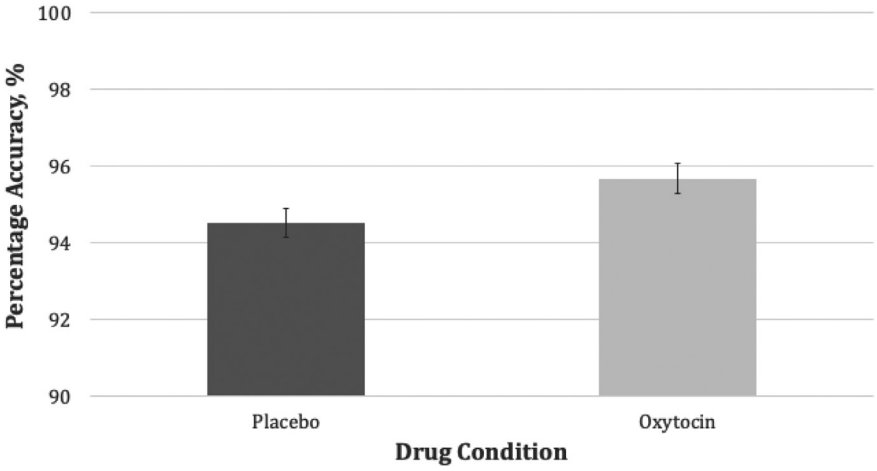

Fig. 1. Emotion recognition accuracy as a function of Drug (± 1 SE)

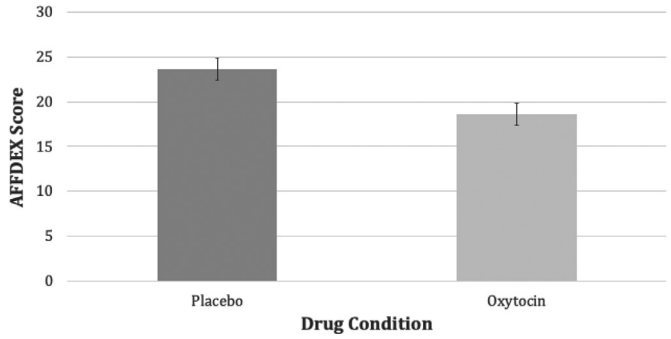

Fig. 2. Facial activation in response to fearful expressions as a function of Drug (± 1 SE)

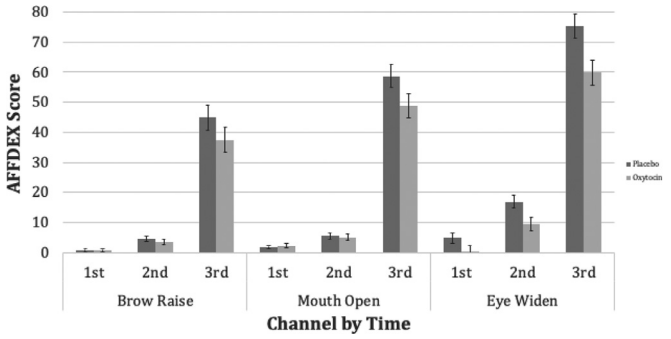

Fig. 3. Facial activation in response to fearful expressions as a function of Drug, Channel, and Time (± 1 SE)

channels, $F(2.441, 248.955) = 3.026$, $p = .040$, $\eta_p^2 = .029$. Again, participants showed the most facial activity during the 3rd second ($M = 18.965$, $SE = 1.157$), compared to the 2nd second ($M = 2.712$, $SE = .282$) and the 1st second ($M = .476$, $SE = .158$), $F(2, 204) = 254.834$, $p < .001$, $\eta_p^2 = .714$. There was a no significant main effect of Drug, $F(1, 102) = 1.152$, $p = .286$, $\eta_p^2 = .011$. All interactions were non-significant (Channel x Time: $F(2.315, 236.138) = 1.938$, $p = .139$, $\eta_p^2 = .019$; Channel x Drug: $F(2.441, 248.955) = .499$, $p = .645$, $\eta_p^2 = .005$; Time x Drug: $F(1.032, 105.299) = 1.239$, $p = .270$, $\eta_p^2 = .012$; Channel x Time x Drug: $F(2.315, 236.138) = .254$, $p = .807$, $\eta_p^2 = .002$).

3.2.4. Fear

Finally, a 3 (Channel: brow raiser/mouth opener/eye widener, within-subjects) x 3 (Time: 1st second/2nd second/3rd second, within-subjects) x 2 (Drug: OT/PL, between-subjects) was carried out on participants' facial activity while viewing fear expressions. Participants showed more activation in the eye widener channel ($M = 27.784$, $SE = 1.486$), than in the mouth opener ($M = 20.345$, $SE = 1.115$), than in the brow raiser ($M = 15.315$, $SE = 1.176$), $F(2, 204) = 30.951$, $p < .001$, $\eta_p^2 = .233$. Again, participants showed the most facial activity during the 3rd second ($M = 54.147$, $SE = 2.086$), compared to the 2nd second ($M = 7.484$, $SE = .642$) and the 1st second ($M = 1.814$, $SE = .424$), $F(2, 204) = 621.378$, $p < .001$, $\eta_p^2 = .859$. Importantly, there was a significant main effect of Drug (see Fig. 2), $F(1, 102) = 8.310$, $p = .005$, $\eta_p^2 = .075$, such that participants in the OT condition ($M = 18.629$, $SE = 1.259$) showed less facial activity compared to those in the PL condition ($M = 23.667$, $SE = 1.212$).

There was a significant interaction between Channel and Time, $F(4, 408) = 22.420$, $p < .001$, $\eta_p^2 = .180$, such that there was no significant difference in activation between the channels during the 1st second and by the 3rd second eye widener showed significantly more activation compared to mouth opener, which showed significantly more activation compared to brow raiser (in line with the main effect of channel). There was also a significant interaction between Time and Drug, $F(1.05, 106.55) = 4.908$, $p = .027$, $\eta_p^2 = .046$, such that the effect of drug was significant in the 3rd second, but not in the 2nd or 1st seconds (see Fig. 3). There was no significant interaction between channel and drug, $F(1.923, 196.135) = 2.322$, $p = .103$, $\eta_p^2 = .022$, and the 3-way interaction was also non-significant, $F(2.072, 211.306) = .183$, $p = .840$, $\eta_p^2 = .002$.

3.2.5. Facial synchrony correlations

To avoid a large number of correlations, and therefore an increased risk of type I error, the average facial activity across the relevant channels for each emotion during the final second (3rd second) of the stimuli were correlated against the average emotion recognition score for each emotion. The final second of the stimuli was chosen because the consistent main effect of time across emotions demonstrated that this was when participants facial synchrony was highest, and therefore most likely to correlate with the relevant outcomes. In the PL condition, there was a significant negative correlation between facial synchrony for angry expressions and anger recognition, $r(52) = -.317$, $p = .022$. There were no significant correlations in the OT condition.

Similarly, to avoid a large number of correlations, and therefore an increased risk of type I error, the average facial activity across the relevant channels for each emotion during the final second (3rd second) of the stimuli were correlated against the average affiliation score for each emotion. There were no significant correlations between facial synchrony and affiliation in either the PL or OT conditions.

3.3. Eye-gaze

3.3.1. Dwell time

Participants spent longer ($M = 51.941$, $SE = 1.290$) looking at fearful facial expressions, compared to sad ($M = 46.426$, $SE = 1.531$) expressions, which in turn were looked at longer than angry ($M = 29.551$, $SE = 1.202$) and happy ($M = 27.980$, $SE = 1.112$) expressions, $F(3, 276) = 406.488$, $p < .001$, $\eta_p^2 = .815$. Participants also spent longer looking at the eyes ($M = 50.145$, $SE = 2.441$) than at the mouth ($M = 27.805$, $SE = .948$), $F(1, 92) = 61.691$, $p < .001$, $\eta_p^2 = .401$. There was a significant Emotion by AOI interaction, $F(3, 276) = 187.566$, $p < .001$, $\eta_p^2 = .671$, such that although participants spent more time looking at the eyes than the mouth for all emotions, the proportion of time spent looking at the mouth was greater for fear and sad facial expressions, compared to angry and happy expressions. There was no main effect of Drug ($F(1, 92) = .008$, $p = .931$, $\eta_p^2 = .001$) and there were no significant interactions involving Drug (Emotion x Drug: $F(2.746, 252.599) = .781$, $p = .495$, $\eta_p^2 = .008$; AOI x Drug: $F(1, 92) = .448$, $p = .505$, $\eta_p^2 = .005$; Emotion x AOI x Drug: $F(2.549, 234.468) = .519$, $p = .640$, $\eta_p^2 = .006$).

3.3.2. TTFF

Participants were faster to look at fearful ($M = 990.084$, $SE = 36.122$) and sad ($M = 1023.122$, $SE = 43.474$) facial expressions, than at happy expressions ($M = 1518.739$, $SE = 62.123$), which in turn were looked at faster than angry expressions ($M = 1713.871$, $SE = 51.416$), $F(3, 276) = 203.271$, $p < .001$, $\eta_p^2 = .688$. Participants were faster to look at the eyes ($M = 588.741$, $SE = 74.453$) than at the mouth ($M = 2034.168$, $SE = 74.453$), $F(1, 92) = 808.926$, $p < .001$, $\eta_p^2 = .898$. There was also a significant Emotion by AOI interaction, $F(3, 276) = 203.283$, $p < .001$, $\eta_p^2 = .688$, such that participants were faster to look at the eyes of fearful ($M = 2.395$, $SE = .055$) compared to happy ($M = 2.525$, $SE = .056$) facial expressions (there were no differences with the other two expressions: sad [$M = 2.442$, $SE = .056$], angry [$M = 2.455$, $SE = .052$]); participants were also faster to look at the mouth for sad ($M = 1453.684$, $SE = 58.862$) and fearful ($M = 1463.706$, $SE = 54.298$) expressions compared to happy ($M = 2346.028$, $SE = 102.729$) and angry ($M = 2873.253$, $SE = 103.128$) ones, with the latter two expressions also differing significantly. There was no main effect of Drug ($F(1, 92) = .525$, $p = .470$, $\eta_p^2 = .006$) and there were no significant interactions involving Drug (Emotion x Drug: $F(2.513, 231.202) = 1.938$, $p = .135$, $\eta_p^2 = .021$; AOI x Drug: $F(1, 92) = .526$, $p = .470$, $\eta_p^2 = .006$; Emotion x AOI x Drug: $F(2.513, 231.219) = 1.937$, $p = .135$, $\eta_p^2 = .021$).

3.3.3. Eye-gaze correlations

In the PL condition, there was a trend for longer looking at the eye region of sad expressions to be associated with poorer recognition of sad expressions, $r(47) = -.282$, $p = .055$; conversely, there was a trend for faster looking at the eye region of sad expressions to be associated with better recognition of sad expressions, $r(47) = .276$, $p = .060$. All remaining correlations were non-significant.

In the OT condition, there was a trend for longer looking at the mouth region of sad expressions to be associated with better recognition of sad expressions, $r(47) = .281$, $p = .056$. All remaining correlations were non-significant.

3.4. Intensity and affiliation

3.4.1. Emotion intensity ratings

There was no main effect of Drug ($F(1, 100) = .865$, $p = .355$, $\eta_p^2 = .009$) and no interaction between Drug and Emotion ($F(2.73, 273.12) = .156$, $p = .912$, $\eta_p^2 = .002$). However, there was a main effect of Emotion, $F(3, 300) = 164.957$, $p < .001$, $\eta_p^2 = .623$, with happy ($M = 3.807$, $SE = .055$) and fearful ($M = 3.755$, $SE = .056$) facial expressions being rated as more intense, compared to sad ($M = 2.941$, $SE = .055$) and angry ($M = 2.955$, $SE = .053$) expressions.

3.4.2. Affiliation ratings

There was no main effect of Drug ($F(1, 100) = .058$, $p = .810$, $\eta_p^2 = .001$), and no interaction between Drug and Emotion ($F(2.04, 203.93) = .622$, $p = .541$, $\eta_p^2 = .006$, but there was a main effect of Emotion, $F(3, 300) = 106.248$, $p < .001$, $\eta_p^2 = .515$, with participants reporting more affiliation in relation to happy ($M = 4.383$, $SE = .147$) facial expressions, compared to sad ($M = 3.158$, $SE = .123$), fearful ($M = 3.080$, $SE = .126$), and angry ($M = 2.928$, $SE = .122$) ones. Affiliation was also significantly lower in response to angry expressions than to sad ones.

4. Discussion

We replicated the finding that participants exposed to OT were better at identifying emotional expressions, compared to control participants. This is worth highlighting because of the nature of the emotion recognition task used here. Rather than static photographs of expressions, or a morphed series of static expressions, which are often used in OT research on emotion recognition (Domes et al., 2007; Domes et al., 2014; Guastella et al., 2010; Hubble, Daughters et al., 2017), we used a well validated set of dynamic expressions much closer in nature to the expressions encountered in everyday social interaction. It is well established that dynamic information is important in recognizing emotional expressions (Krumhuber et al., 2013) and therefore unsurprising that participants in both conditions achieved overall recognition scores exceeding 90%. Nevertheless, participants in the OT condition were significantly more accurate than those in the PL condition.

We investigated the effect of OT on facial synchrony and eye-gaze, with a view to examining whether any increases in facial synchrony or eye-gaze induced by OT help to explain why OT enhances emotion recognition. For all four stimulus expressions, there were significant increases in participants' facial activity over time. The fact that there were consistently significant effects of time on measures of participants' facial behavior shows that the instruction to copy the stimulus facial expressions was effective, given that the measures were tailored to reflect the facial behavior of the stimuli. This establishes the conditions under which we could examine whether increased facial synchrony has an impact on emotion recognition, and whether this was influenced by OT administration. There was no evidence that facial synchrony was enhanced by OT. Indeed, contrary to our prediction, participants in the OT condition showed significantly *less* facial synchrony when viewing fearful expressions, compared to their counterparts in the PL condition. Finally, there were no significant correlations between the extent of facial synchrony and emotion recognition in the OT condition.

Several studies have examined the effect of OT on facial synchrony (Korb et al., 2016; Pavarini et al., 2019; Trilla et al., 2020). Korb and colleagues found that OT increased synchrony of frowning in response to angry infant expressions; Pavarini and colleagues found that OT increased synchrony with sad expressions; however, Trilla and colleagues found no effect of OT on facial synchrony. The present results therefore add to this mixed set of findings. Although all three previous studies found some null effects of OT on facial synchrony, none found that OT induced *decrease* in synchrony, as we did here for fearful expressions. The fear-specific effect of OT is consistent with a number of previous studies (Fischer-Shofty et al., 2010; Hubble et al., 2017; Lischke et al., 2012) and is relevant to anxiolytic and approach-avoidance theories of OT, which propose that OT reduces natural aversion to fearful stimuli, thereby facilitating their processing, and in turn, increasing approach-related behaviors (Domes et al., 2007; Kemp and Guastella, 2011). It may be that participants in the OT condition of the present study were able to process the fearful stimuli without copying the expression to the same extent. Alternatively, if OT facilitates processing of fearful expressions, it may be that participants felt greater empathy for the actor, which in some way inhibited their ability to copy fearful facial expressions to the same extent as other emotions. Prior research suggests, however, that OT does not have a reliable effect on empathy (Leppanen et al., 2017), suggesting that the first explanation may be more likely.

Although Korb et al. (2016) suggested that their findings provided evidence that facial synchrony mediates the effects of OT on emotion recognition, the fact that they did not include a direct measure of emotion recognition limits the ability to draw such a conclusion. The fact that we (like Trilla et al., 2020) found that OT either did not enhance facial synchrony or, in the case of fear expressions, resulted in a decrease in facial synchrony, and found no significant correlations between facial synchrony and emotion recognition, may suggests that OT does not enhance emotion recognition by increasing facial synchrony. However, the fact that Korb et al. (2016) employed spontaneous facial mimicry, whereas our participants were instructed to copy the stimuli, makes it difficult to compare the findings directly. Given these differences, future research is required to establish whether OT reliably influences facial synchrony in response to emotional expressions.

Another possible explanation for the impact of OT on emotion recognition is that it increases attention to the eye-region of the face, which in turn enhances emotion recognition. We found no effect of OT on the amount of time participants spent looking at the eye region of target faces, or on the speed within a given epoch with which they attended to the eye region of these faces. Although care should be taken when interpreting null effects, previous research found mixed evidence that OT influences visual attention to the eyes, with some studies finding significant effects (Andari et al., 2010; Auyeung et al., 2015; Domes et al., 2013; Eckstein et al., 2019; Guastella et al., 2008; Hubble, Daughters et al., 2017) and others (Hubble et al., 2017; Lischke et al., 2012) finding no effect. These studies employed a wide variety of methodologies. In studies finding no effect of OT, one used static photographs of emotional expressions (Hubble et al., 2017), and another used dynamic video clips of faces changing from neutral to an emotional expression (Lischke et al., 2012). The method used in the present study is therefore most similar to that used by Lischke and colleagues, who also found that OT had no effect on attention to the eyes. Future research should seek to replicate methodologies used in other previous studies with a view to assessing whether methodological differences help to account for inconsistencies in results. To assess whether visual attention to the eyes was related to emotion recognition, we examined correlations and found that although OT participants who spent longer looking at the mouth region of sad facial expressions recognized such expressions better, all remaining correlations were non-significant. On balance, the present study suggests that the superior emotion recognition of OT participants was not the result of increased visual attention to the eyes.

Finally, we investigated whether OT increased ratings of emotional intensity (as found by Korb et al., 2016) and affiliation towards the target (in line with predictions from Pavarini et al., 2019). There was no significant effect of OT on either measure, nor was there an interaction between OT and emotional expression, suggesting that the superior emotion recognition scores of participants in the OT condition was not the result of increased affiliation with the target.

Although the present study has several strengths, such as the large sample size, the use of dynamic rather than static stimuli, and the simultaneous assessment of facial synchrony and eye-gaze, we also acknowledge some limitations. First, the decision to instruct participants to copy the stimulus facial expressions means that facial responses were not spontaneous, limiting the ecological validity of our findings. This decision was made on the basis of previous literature and pilot data demonstrating that i) the automatic software could not reliably detect participants' spontaneous mimicry; and ii) that there was no effect of this instruction on participants liking ratings or emotion recognition. Ultimately, to avoid floor effects (as was the case in Pavarini et al. (2019), who used the same stimulus set), we chose to add the instruction. Thus the results do not reflect spontaneous facial mimicry of the observed expressions, but rather the extent of synchrony between the channels displayed in the stimuli and the level of activity in the same channels in participants who viewed them. Relatedly, although our results do not support previous research demonstrating an effect of OT on eye-gaze, the use of instructions prevents us from making strong comparisons between our own data and previous studies using a free-viewing paradigm.

Second, although the study recruited a large sample size (n = 104) compared to other OT studies (Korb et al., 2016; Trilla et al., 2020), it is possible the results of the current study were underpowered. In a study published after data collection for the current study was complete, Pavarini et al. (2019) recruited a larger sample (n = 145) and reported some effects of OT. Third, for reasons already explained, all participants in the present study were male, meaning that the results may not be generalizable to female participants. Indeed, it is difficult to draw conclusions about gender effects in OT research because most of the published research has involved male participants. Studies including both men and women have found evidence both for and against the view that gender moderates the effects of OT on behavioral measures (e.g., Daughters et al., 2017; Rilling et al., 2014), meaning that more research is required to assess the generalizability of these findings. Fourth, it is possible that the scale used to capture participants' ratings of emotional intensity was not sensitive enough to detect an effect of OT. Further research is needed to establish whether OT influences the subjective intensity of emotions.

Finally, in keeping with most research on the effects of OT administration, we did not measure participants' endogenous OT concentrations, meaning that we cannot draw any conclusions about the degree to which participants' emotion recognition, facial synchrony, or eye-gaze varied systematically as a function of OT concentrations. In future studies it would be worth assessing whether the effects of OT on emotion recognition, facial synchrony, or eye-gaze vary as a function of endogenous OT concentrations.

5. Conclusions

In conclusion, we investigated whether intranasal administration of OT in healthy male volunteers increased emotion recognition, and whether such an increase was related to participants' facial synchrony or patterns of eye-gaze. As predicted, participants in the OT condition exhibited superior emotion recognition. However, they also showed *less* facial synchrony in response to fearful expressions, and no differences in their eye-gaze, compared to counterparts in the PL condition. Given mixed evidence from previous studies and the use of instructions in the present study, future research will need to use more powerful facial stimuli and/or more sensitive measures of facial activity to address the question of whether OT administration increases emotion recognition through increased facial synchrony of expressions or changes in the way that people attend to faces.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Author contributions

KD: Conceptualization, methodology, software, validation, investigation, formal analysis, resources, data curation, writing – original draft, funding acquisition. **ASRM**: Methodology, resources, writing – review and editing, supervision. **JvdS**: Conceptualization, methodology, resources, writing – review and editing, supervision.

Supplementary materials

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