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Oxytocin promotes action prediction☆

Jessica Burgstaller*, Markus Paulus, Michaela Pfundmair

Ludwig-Maximilians-University of Munich, Germany

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ABSTRACT

The neuropeptide oxytocin (OT) has been suggested to facilitate social cognition and behavior. As predicting others' behavior is at the core of human social-cognitive abilities and is indispensable for successful social interaction, we hypothesized that OT would increase action prediction. To test this hypothesis, 61 male and female healthy participants self-administered OT or placebo intranasally and their anticipatory eye-movements were recorded using eye-tracking techniques. We found that the ability to predict others' future actions was enhanced following OT treatment. This effect was mediated by the time to the first anticipatory eye-movement suggesting that improved action prediction might operate by increased attention to social cues. These findings provide direct evidence for the role of OT in promoting perception and processing of social cues.

1. Introduction

The neuropeptide oxytocin (OT) plays a crucial role in social cognition. Research has revealed that OT increases gaze to the eye region (Guastella et al., 2008) and enhances the understanding of others' perspective (Ditzen et al., 2009). It also improves recognition memory for faces but not for nonsocial stimuli (Rimmele et al., 2009), and facilitates the ability to recognize emotions (Schulze et al., 2011). But how exactly does OT lead to this social advantage? One of the most popular current theories suggests that OT promotes orienting to social cues (Bartz et al., 2011; Shamay-Tsoory and Abu-Akel, 2016): OT is thought to alter perceptual salience and processing of social cues through its interaction with the dopaminergic system, thereby promoting the allocation of attentional resources to social stimuli (Bartz et al., 2011). However, an unresolved question is whether OT has an effect on social-cognitive abilities beyond simple targeting of social cues.

Humans and other species have evolved the very useful ability to predict others' future behavior (Falck-Ytter et al., 2006; Flanagan and Johansson, 2003) and the better the action prediction, the larger the advantage (Krogh-Jespersen et al., 2015). Action prediction plays a crucial role in language processing and learning (Elman, 2009; Maia, 2009) as well as in purely social tasks (Bar, 2009; Enns and Lleras, 2008). The ability to predict others' actions is at the core of human social-cognitive abilities as it allows us to adequately and successfully interact with others (Sebanz et al., 2006). Joint attention forms the basis of social interactions: sharing the same perceptual input and directing attention to the same events facilitates the representations of others' action goals and promotes the ability to predict action outcomes (Vesper et al., 2016). If OT indeed increases social understanding beyond simple targeting, it should also help to understand and predict other persons' behavior.

Only one previous study has investigated the possible impact of OT on action prediction (Pfundmair et al., 2017). In this, OT had no effect on the action prediction performance. However, participants received no particular instruction to anticipate actions by gaze. To test the relationship between OT and action prediction more clearly, the authors recommended involving an explicit instruction in future research.

The current study is the first to explicitly investigate whether OT improves the ability to actually predict the behavior of other individuals. To this end, we modified recent paradigms (Paulus, 2011) and tracked participants' eye-movements to assess their ability to anticipate a person's future action after administration of OT or placebo.

2. Methods and materials

2.1. Participants and design

A total of 61 participants (31 female, 30 male; mean age = 26.69 years, $SD = 7.30$) were randomly assigned to receive either OT ($n = 30$) or placebo ($n = 31$) in a double-blind procedure. Exclusion criteria included a diagnosis of major depression, bipolar, panic and psychotic disorders, substance dependence, epilepsy, or (if female) pregnancy. Participants were instructed to abstain from alcohol

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* Corresponding author at: Department of Psychology, Ludwig-Maximilians-University of Munich, Leopoldstr. 13, 80802 Munich, Germany.
E-mail addresses: j.burgstaller@campus.lmu.de (J. Burgstaller), markus.paulus@lmu.de (M. Paulus), michaela.pfundmair@psy.lmu.de (M. Pfundmair).

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and caffeine on the day of testing, and from food and drink, except water, for 2 h before drug administration. The study was approved by the local ethics committee.

2.2. Procedure and materials

After written informed consent was obtained, participants received 24 I.U. of OT (Syntocinon Spray, Defiante; three puffs per nostril) or a placebo (sodium chloride solution). After 40 min, they started the action prediction task. Then, participants completed a standardized questionnaire with 10 positive (α = 0.85) and 10 negative affect items (α = 0.75; Watson et al., 1988) on 1 = *not at all* to 5 = *very much* response scales to control for the participants' affective state (as similarly done in Pfundmair et al., 2017). Debriefing followed after unrelated tasks.

2.3. Stimuli

The action prediction task consisted of 31 videos in random order that show a person facing downward (2 s), lifting the head to greet the participant (2 s), and facing either to the left or to the right (3 s) to look at a green or red apple, see Fig. 1. Gaze direction of the actor and position of the apples appeared randomly. Participants were explicitly instructed to fixate the person's face at the beginning of every video sequence and to anticipate the actor's gaze direction to one of the apples before the action could be realized in the video. Stimuli were presented on a computer monitor. Participants' eye gaze was tracked by a Tobii TX 300 Eye Tracker. The Tobii Fixation Filter was used as fixation classifier with a velocity threshold of 35 pixels/window and a distance threshold of 35 pixels. Each image had two designated Areas of Interest (AOI)—the right and left apple. Only the first fixation from the actor's face to one of the AOIs was analyzed. Correct or incorrect trials were scored manually. Participants could reach a score from 0 to 31 mistakes. Time was analyzed from the beginning of the video to the first fixation to one of the AOIs.

3. Results

To test OT's potential to improve action prediction, several independent two-sample *t*-tests were conducted. Participants in the OT condition ($M = 1.27$, $SD = 2.85$) made significantly fewer mistakes than participants in the placebo condition ($M = 4.03$, $SD = 4.65$) when trying to predict the gaze-direction with their first anticipatory eye-movement, $t(59) = 2.79$, $p = .007$, $d = 0.71$, 95%CI = [0.19,1.23]. Notably, the time to the first anticipatory eye-movement was also significantly different between participants in the OT ($M = 5.70$, $SD = 0.47$) and placebo ($M = 5.44$, $SD = 0.49$) condition, $t(59) = -2.13$, $p = .037$, $d = 0.54$, 95%CI = [−0.03,1.05].

To determine whether the time to the first anticipatory eye-movement mediated the relationship between OT and number of mistakes,

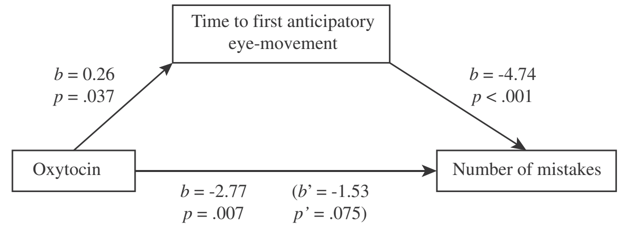

Fig. 2. Results of the mediation analysis: Participants under OT needed more time for their first anticipatory eye-movement and this led to fewer mistakes in action prediction.

we conducted a mediation analysis using the Process tool by Hayes (2012). Bias corrected bootstrapping with 5000 samples was conducted and substance was dummy coded (1 = OT and −1 = placebo). The total effect proved to be significant, $b = -2.77$, $SE = 0.99$, $t(59) = -2.79$, $p = .007$, indicating fewer mistakes in the OT group compared to the placebo group. The direct effect was not statistically different from zero, $b = -1.53$, $SE = 0.84$, $t(59) = -1.81$, $p = .075$, but the indirect effect was, 95% CI = [−2.60, −0.34]: Time to the first anticipatory eye-movement was increased in the OT group and this, in turn, translated to fewer mistakes, $z = -1.96$, $p = .049$, see Fig. 2.

Participants' affective state was independent of substance administration: Participants in the OT condition ($M = 3.33$, $SD = 0.71$) did not differ in their positive affect from participants in the placebo condition ($M = 3.52$, $SD = 0.53$), $t(59) = 1.24$, $p = .222$, $d = 0.32$, 95%CI = [−0.19,0.82]. The same holds true for negative affect in the OT ($M = 2.13$, $SD = 0.60$) and placebo condition ($M = 2.39$, $SD = 0.48$), $t(59) = 1.88$, $p = .066$, $d = 0.48$, 95%CI = [−0.03,0.99].

4. Discussion

The current study revealed that OT improves the ability to predict others' actions: Participants who were administered OT made fewer mistakes in their anticipatory eye-movements to the gaze-direction of the actor than participants who were administered a placebo. Moreover, OT delayed the time-point of the first anticipatory eye-movement which mediated the effect of OT on action prediction. This indicates that OT promotes increased attention to social cues resulting in successful action prediction. The participants' affective state could not provide an explanation of the effect.

Consistent with the idea of the social salience hypothesis (Bartz et al., 2011; Shamay-Tsoory and Abu-Akel, 2016), OT seems to promote perception and processing of social cues. This effect seems to exceed simple targeting of social cues as it is related to enhanced social understanding. Going one step further, one might even speculate that this kind of increased social information processing might underlie social behaviors promoted by OT (e.g., in-group cooperation, De Dreu et al., 2010, or conformity, Stallen et al., 2012): Only if individuals can make

Fig. 1. Selected frames from the stimuli. The first picture shows the first frame of the video when the actor is facing downward. Participants were instructed to fixate the actor's face when she lifts the head in the second picture. The third picture shows the action, looking to one of the apples, that participants were instructed to anticipate.

correct predictions about someone's future behavior, the social environment provides enough information to eliminate ambiguity and to promote socially adequate effects.

Recently, critical voices have casted doubt on the conventional doses, time frame of application (Leng and Ludwig, 2016), and effect of intranasally applied OT pointing to a publication bias in OT research (Lane et al., 2016). It should be noted that the current study is the first to explicitly investigate the impact of OT on action prediction, precluding a publication bias. However, due to low power in most studies, OT effects are easily overestimated (Walum et al., 2016). Moreover, null results (Lane et al., 2016) and replication failures (Nave et al., 2015; Radke and de Bruijn, 2015) have been reported repeatedly in the past. Thus, further research relying on additional methods is warranted to substantiate our finding of an association between OT and action prediction.

Taken together, our results show that one consequence of OT's effect on increased social attention is enhanced action prediction, pointing to an increased social understanding. This finding might have implications to understand the hormone's role in human's social behavior.

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