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Dissociable Effects of Oxytocin on Subjective Reward Evaluation and Facial EMG Activity

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Abstract (ENG)

Oxytocin is frequently described as enhancing social reward processing. The present study tested the hypothesis that oxytocin selectively increases subjective liking of social touch without a corresponding change in physiological hedonic responses. In a randomized, within-subject pharmacological design, 15 female participants completed two experimental sessions with intranasal oxytocin and placebo. During each session, they received social rewards (interpersonal touch at slow, medium, and fast stroking velocities) and nonsocial rewards (palatable drinks at different reward levels). Linear mixed-effects models revealed a robust Drug × Reward Type crossover on subjective liking: oxytocin increased liking for food while decreasing liking for social touch, opposite to the prediction of a selective social enhancement. Within the touch domain, a strong speed gradient (slow > medium > fast) was replicated, and oxytocin's reduction of touch liking was numerically attenuated at medium speed, but no individual speed contrast reached significance. In the food domain, oxytocin's tendency to increase liking was uniform across reward levels. By contrast, oxytocin did not reliably affect zygomaticus EMG in any condition, and trial-wise EMG activity did not consistently track subjective liking in either reward domain. These findings indicate a dissociation between oxytocin's effects on evaluative experience and facial motor expression. This pattern is consistent with componential and constructionist views of emotion, suggesting that oxytocin primarily influences evaluative appraisal.

Keywords: oxytocin, social reward, interpersonal touch; subjective liking, facial EMG; reward processing

Abstract (GER)

Oxytocin wird häufig als Verstärker sozialer Belohnungsverarbeitung beschrieben. Die vorliegende Studie prüfte die Hypothese, dass Oxytocin selektiv die subjektive Liking-bewertung sozialer Berührung erhöht, ohne entsprechende Veränderungen physiologischer hedonischer Reaktionen zu bewirken. In einem within-subject pharmakologischen Design absolvierten die 15 Teilnehmerinnen zwei experimentelle Sitzungen mit intranasalem Oxytocin bzw. Placebo. Die Teilnehmerinnen erhielten soziale Belohnungen (interpersonelle Berührung mit unterschiedlichen Streichgeschwindigkeiten) sowie nicht-soziale Belohnungen (wohlschmeckende Getränke). Lineare Mixed-Effects-Modelle zeigten eine ausgeprägte Drug × Reward Type Crossover-Interaktion auf das subjektive *Liking*: Oxytocin erhöhte Liking für Nahrungsbelohnungen, während es *Liking* für soziale Berührung verringerte entgegen der Vorhersage einer selektiven sozialen Verstärkung. Im Berührungsbereich wurde ein deutlicher Geschwindigkeitsgradient (langsam > mittel > schnell) repliziert, und die durch Oxytocin bedingte Abnahme der Berührung *Liking* war bei mittlerer Geschwindigkeit numerisch abgeschwächt, jedoch erreichte kein einzelner Geschwindigkeitskontrast Signifikanz. Im Nahrungsbereich war die Tendenz von Oxytocin, das Liking zu erhöhen, über alle Belohnungsstufen hinweg einheitlich. Im Gegensatz dazu beeinflusste Oxytocin die EMG‑Aktivität des Musculus zygomaticus in keiner Bedingung zuverlässig, und die Trial‑weise EMG‑Aktivität bildete das subjektive *Liking* in keinem der beiden Belohnungsdomänen konsistent ab. Diese Befunde weisen auf eine Dissoziation zwischen den Wirkungen von Oxytocin auf evaluative Erfahrung und Gesichtsmotorik hin. Dieses Muster ist mit komponenten- und konstruktivistischen Emotionstheorien vereinbar und legt nahe, dass Oxytocin primär die evaluative Bewertung beeinflusst.

Schlüsselwörter: Oxytocin, soziale Belohnung, interpersonelle Berührung; subjektives Liking, Gesichtselektromyographie (EMG); Belohnungsverarbeitung.

Introduction

Affective states are typically conceptualized as multi-component phenomena involving subjective experience, behavioral expression, and physiological activation (Barrett et al., 2017). Some classical affect theories assume that these components operate as coordinated outputs of a unified internal state (Ekman et al., 1999; Keltner et al., 2019). Within this view, an emotion is seen as a biologically organized response program: once it is triggered, the experiential feeling, facial expression, and physiological activation should theoretically covary because they originate from the same underlying process (Keltner et al., 2019). Consequently, physiological measures have often been interpreted as reliable readouts of emotional experience (Cacioppo et al., 1986; Larsen et al., 2003).

However, empirical findings accumulated over several decades challenge the strong covariance assumption (Mauss et al., 2024). Studies comparing experiential reports, facial behavior, and autonomic responses show that these components correlate only modestly (Mauss et al., 2003; 2004). Some typical co-occurrences have been established, for example anger and blood pressure increase (Evers et al., 2014), but trial-by-trial coupling within individuals is frequently weak, unstable, or absent (Evers et al., 2014). The functionalist theories of emotion mentioned in the first paragraph assume a unitary, synchronised package of affective experience, but the latter set of presented findings view affective components as only partially coordinated (Mauss et al., 2005; 2024; Evers et al., 2014).

The degree of coordination (or cohesion) varies across contexts and measurement domains (Evers et al., 2014). Associations between subjective experience and overt behavior tend to be stronger than those between experience and physiological activity (Grossman et al., 2001). The facial expressions do sometimes track reported affect, but autonomic and somatic responses often diverge from conscious experience (Panksepp et al., 2007; Barrett, 2016). It is furthermore important to note that this variability is systematic and context-dependent (Barrett et al., 2019). Aspects like task structure, attentional focus, and situational meaning all influence whether components converge or dissociate during emotional responding (Evers et al., 2014).

These observations have motivated a shift from unitary emotion models toward component-based views (Barrett, 2006). One notable alternative to the functionalist view that presupposes coordination is the constructivist approach. It goes a step further and proposes that emotional states arise from partially independent processes, specifically interoception, conceptualization, and behaviors (Barrett, 2017). These components do not necessarily activate together, therefore this approach considers physiological activation as a contributor to the experience of emotion, but does not determine its experiential quality (Reisenzein et al., 2013; Barrett, 2017).

Having outlined the two opposing poles of the topic, the following work adopts the integrative framework, so a combination of both constructivist and functionalist perspectives, as the theoretical foundation and reconciles the polar opposite views presented above (Mauss et al., 2024). Present integrative frameworks reconcile these positions by proposing that the coupling of emotional components depends on regulatory goals and situational demands before all else (Mauss et al., 2024). When rapid action is required, coordination may increase, whereas in socially or cognitively complex situations the components can decouple (Mauss et al., 2024). Thus, coherence is treated as an empirical variable rather than a defining property of emotion (Mauss et al., 2024). This has methodological implications: physiological signals should not be treated as automatic proxies for subjective feeling (Löken et al., 2009). Changes in facial or autonomic activity do not necessarily reflect changes in experienced pleasantness (Reisenzein et al., 2013); and each component must be measured separately and their relationship tested empirically. The issue is particularly relevant in reward research, where hedonic responses may manifest as bodily reactions or conscious evaluations that do not align. Evaluating concordance between subjective liking and physiological expression thus shifts from assumption to a testable question.

Liking

Reward processing can be measured at different levels, and relevant to the present project is the distinction between *subjective liking* (i.e. reported experiencing of pleasantness) and the *objective liking,* which is reflected in measurable physiological affective reactions, such as fascial muscle activity (Berridge et al., 2008). Subjective liking represents an evaluative

judgement rather than a direct sensory readout (Barrett, 2016). When people report how pleasant something feels, in addition to reporting the interoceptive signals, they also integrate a perceptual input, cognitive appraisal, expectations, and situational aspects (Barrett, 2016; Walker et al., 2017). Hence, two identical stimuli can be experienced differently depending on how they are categorized and understood by the individual (Walker et al., 2017). Attention also strongly contributes to this evaluative process; monitoring or assigning relevance to a stimulus alters perceived pleasantness (Walker et al., 2017; 2022). The context of an emotional episode further shapes hedonic evaluation (Evers et al., 2014). The social setting, expectations about the stimulus, and concurrent cognitive goals modify the interpretation of reward (Evers et al., 2014). This variability suggests that conscious liking depends to a certain degree on situational interpretation, while contextual modulation mainly influences evaluation and not the basic somatic responses.

Physiological expressions of liking operate under different constraints. Facial activity (e.g., zygomaticus contraction) reflects rapid affective motor output that often precedes conscious evaluation (Levenson et al., 2014). These responses depend more on sensorimotor processing and less on higher-order interpretation than subjective ratings (Levenson et al., 2014).

As a consequence, subjective and objective indices of liking do not consistently converge (Barrett et al., 2016; 2019). Individuals may report enjoyment without strong facial activation, particularly when expression is socially regulated or attention is directed toward internal evaluation (Levenson et al., 2014; Barrett et al., 2019). Conversely, affective motor responses can occur in the absence of strong conscious pleasantness (Levenson et al., 2014). The divergence might capture different levels of processing within the reward system and complicates the interpretation of reward effects. Accordingly, subjective ratings index the evaluative interpretation, whereas physiological responses index embodied affect, and their correspondence must be empirically established.

The role of oxytocin in Liking of rewards

Oxytocin is an evolutionarily conserved hypothalamic neuropeptide that influences cognitive, emotional, and social processes (Yao et al., 2025). If subjective liking depends partly on stimulus interpretation, then a neuromodulator known to bias social information processing should

potentially influence evaluative judgments rather than peripheral affective output. Oxytocin provides a means to examine this prediction, as it has been consistently shown to increase salience of social cues (Shamay-Tsoory et al., 2016), increase attention to socially meaningful cues (Yao et al., 2025), change how social information is attended to and interpreted (Yao et al., 2022) and help synchronize bodily states in similar social contexts (Mu et al., 2016).

The social salience hypothesis posits that oxytocin increases the attentional weighting of socially relevant stimuli (Shamay-Tsoory et al., 2016). This enhanced relevance can modify evaluative judgments without altering sensory reward value, leading to increased perceived pleasantness through meaning attribution rather than intensified hedonic processing (Yao et al., 2025).

Evidence from both animal and human studies suggests that oxytocin acts as a neuromodulator that influences behavior indirectly through interaction with classical neurotransmitters and other peptide systems (Yao et al., 2025). Both central receptor activity and peripheral pathways, especially those involving the vagus nerve, contribute to its effects (Yao et al., 2025). The authors of this review propose a hierarchical account in which oxytocin first enhances attention to socially salient stimuli and then modulates cognitive, emotional, and reward processing in a manner that is both context- and person-dependent (Yao et al., 2025). Through this interconnected cluster of effects oxytocin supports social bonding, understanding, cooperation, and cohesion.

At the neural level, intranasal oxytocin modifies activity within circuits linking affective appraisal and bodily regulation, including reduced amygdala responses to social stimuli and altered coupling with brainstem regions involved in autonomic output (Yao et al., 2018). In parallel, oxytocin is released during affiliative interactions such as social touch and engages mesolimbic reward pathways, including ventral tegmental and striatal regions implicated in hedonic experience (Kirsch et al., 2005).

Evaluation of modulation need not produce proportional physiological change: oxytocin can shift perceived pleasantness through reinterpretation while somatic affective responses remain stable. Therefore, oxytocin provides a candidate mechanism for dissociating evaluative experience from motor expression of affect.

Rewards

Touch

Reward stimuli can differ in both sensory pleasantness and in the degree to which their value depends on social interpretation (Kraus et al., 2023). Some rewards, such as food, can be evaluated largely on the basis of sensory and homeostatic properties (Peciña et al., 2006). Others, such as interpersonal touch, might additionally require some inference about social intention, affiliative meaning, and interpersonal context, along with the simple activation of CT-afferent fibers (Chen et al., 2020). Although both categories can be experienced as pleasant, they rely on partially different psychological processes during evaluation.

Social touch consists of a dimension that is context-dependent: identical stimulation can feel pleasant, neutral, or aversive depending on interpersonal meaning (Chen et al., 2023). Its value therefore relies on social interpretation rather than on the physical properties alone (Chen et al., 2023). In contrast, food rewards are typically evaluated more directly through gustatory and somatosensory features, with comparatively limited dependence on social inferences in controlled laboratory settings (Peciña et al., 2006).

Oxytocin is a suitable candidate to test this distinction. Rather than uniformly enhancing reward processing, oxytocin alters attention to social cues and the interpretation of interpersonal signals (Yao et al., 2025; Chen et al., 2023). Because of this, it should preferentially affect evaluations that depend on social inference. Social touch therefore provides a condition in which oxytocin-dependent modulation is theoretically expected, whereas food rewards provide a domain in which evaluation relies less on social meaning.

Food

Food rewards are primarily processed through gustatory and metabolic valuation systems that estimate nutritive and sensory value based on taste, texture, and internal state (Peciña, 2006; Sato et al., 2021). Their pleasantness is related to chemo-sensory properties and homeostatic

relevance, engaging neural circuits involved in energy balance and sensory pleasure (Sato et al., 2021). Even if expectations and context can influence food evaluation, its hedonic appraisal in controlled laboratory conditions depends less on interpreting another agent's intentions and more on direct sensory–interoceptive integration (Sato et al., 2019). For this reason, food provides a reward type in which experienced pleasantness can be compared to social touch while minimizing the contribution of social meaning construction, allowing separation of general reward evaluation from socially mediated evaluation.

Comparing these reward categories is a starting point for investigating oxytocin's possible role. If oxytocin acts as a general hedonic enhancer, then changes should be observable across both social and non-social rewards. Conversely, if oxytocin modulates interpretative components of liking, its influence should be selective for socially meaningful stimuli (Chen et al., 2020). Examining both reward domains therefore allows dissociating general reward effects from social-specific modulation and explores whether oxytocin alters reward experience itself or the construction of its meaning.

Facial Electromyography

Facial electromyography (EMG) provides a sensitive measure of subtle facial muscle activity associated with affective processing (Larsen et al., 2003). In the present study, activity of the *zygomaticus major* (ZM) muscle was recorded as an index of positive affective expression. Increases in zygomaticus activation have been consistently linked to positive emotional valence and appetitive responses, often occurring rapidly and outside conscious control (Sato et al., 2020). For this reason, facial EMG is commonly used to capture automatic affective reactions that may not be fully reflected in explicit reports (Winkielmann, 2005).

It might be tempting to jump to understanding facial EMG as a direct measure of subjective liking; but in actuality it reflects the motor output associated with affective processing (Ree et al., 2019). The relationship between zygomatic activity and conscious evaluation is probabilistic: activation may accompany positive experience, yet its presence or absence cannot be equated with liking itself (Winkielmann, 2005). This makes EMG suitable for testing whether physiological expression and subjective evaluation are tightly coupled or partially independent components of reward responses (Winkielmann, 2005). Additionally, the interpretation of EMG

signals relies on relative change rather than absolute amplitude (Winkielmann, 2005). Because baseline muscle tone varies across individuals and contexts, the affective meaning is established by comparing activity during stimulus presentation to a pre-stimulus delivery baseline (Winkielmann, 2005).

Aim of study

The present project examines whether oxytocin modulates the relationship between subjective evaluation and physiological expression of reward. Contemporary models of emotion propose that experience and physiological components are only partially coupled (Mauss et al., 2024); therefore, a manipulation affecting interpretative processing may alter subjective liking without proportional changes in physiological expression. Because oxytocin biases attention and appraisal of socially relevant cues, it provides a suitable test of this possibility (Chen et al., 2020).

The study is based on data from a larger pharmacological project that additionally included a mu-opioid antagonist (naltrexone) condition. The present thesis narrows the focus on the oxytocin versus placebo comparison to assess whether oxytocin reorganizes affective responding or generally amplifies hedonic processing. Including both social and non-social rewards therefore provides the necessary contrast to evaluate whether oxytocin reorganizes affective components specifically in socially constructed experiences.

Research Question and Hypotheses

After having completed a thorough literature search and filling out a research log on the aforementioned elements, the formulated research question reads: “Does oxytocin influence subjective liking reports and does that change stay coherent to bodily expression? ”

In derivation of this, the following hypothesis have been formulated in order to be tested:

H1: Does oxytocin selectively increase subjective liking of social touch relative to non-social food reward?

1a: Oxytocin vs. placebo increases subjective Liking ratings for social touch more than for food rewards

1b: The effect of oxytocin is strongest on subjective Liking for the slow touch speed

H2: Oxytocin increases subjective liking of social touch without a corresponding increase in zygomaticus EMG activity

2a: Oxytocin does this especially for the slow touch compared to other reward levels

2b: Oxytocin affects subjective liking and zygomaticus EMG in different directions

H3: Under Oxytocin compared to placebo, trial-wise zygomaticus EMG is a significant predictor of subjective liking ratings

3b: The effect is strongest for the slow touch level.

Methods

The present thesis focuses on the relationship between subjective liking reports and physiological affective expression during reward processing under oxytocin compared to placebo. Although the larger pharmacological project additionally included other drug conditions and outcome measures, the analyses reported here are restricted to the oxytocin (OXY) manipulation and to behavioral and facial EMG responses. Additional experimental variables are therefore only described only briefly where necessary for understanding the procedure.

Sample

The acquired sample consists of fifteen female participants who completed both pharmacological sessions (OXY and PLC) of the within-subject design. All participants were right-handed. Participants were recruited from a university population and participated voluntarily. Inclusion criteria required good physical and mental health. Exclusion criteria comprised current neurological or psychiatric disorders, regular medication affecting the nervous system, substance

abuse, and pregnancy. Participants were screened prior to participation to ensure eligibility according to the standardised protocol of the larger pharmacological project.

Procedure

Participants completed two laboratory sessions under double-blinded conditions, receiving intranasal oxytocin in one session or placebo in the other. The order of administration was counterbalanced across participants. Sessions were separated by a washout interval of approximately 14 days to prevent carry-over effects. Upon arrival, participants were screened for compliance with pre-session requirements and subsequently self-administered the nasal spray under experimenter supervision. Following administration, a waiting period of approximately 60 minutes allowed the substance to reach effectiveness.

After the absorption period, participants performed the reward task while facial EMG activity was recorded continuously. Each session consisted of four experimental blocks: two blocks presenting social reward (affective touch) and two blocks presenting non-social reward (food). Each block contained 20 trials, resulting in 80 trials per session.

In the touch condition, participants received gentle stroking stimulation delivered at three predefined velocities (slow with 6cm/s, medium with 21 cm/s, fast 27cm/s). In the food condition, participants received liquid consumable stimuli at three levels of palatability (milk, mixed drink, chocolate milk) measured by the sugar content of the drink. Trial order within blocks was pseudorandomized.

On each trial, the stimulus was presented and participants subsequently rated its pleasantness on a continuous scale ranging from −100 to +100. Facial EMG activity of the zygomaticus major muscle was recorded during stimulus presentation to capture physiological affective responses. This trial-wise structure enabled analysis of both mean condition effects and within-participant relationships between subjective evaluation and physiological expression

Reward stimuli

The reward task was performed during continuous recording of facial electromyography and consisted of two reward domains presented in alternating blocks: a social reward and a

non-social reward. Each reward domain included three stimulus levels differing in expected pleasantness. The non-social reward consisted of liquid food stimuli delivered as milk (low desirability), a mixed drink (medium desirability), and chocolate milk (high desirability). The social reward consisted of interpersonal stroking touch delivered at three velocities: slow (high desirability), medium (medium desirability), and fast (low desirability).

The order of reward blocks was counterbalanced across participants. Across the two pharmacological sessions, this resulted in repeated trial-wise observations for both reward categories and all stimulus levels. In the present thesis, both reward domains are analyzed to contrast socially mediated reward evaluation with non-social reward processing and to test whether oxytocin effects are specific to socially meaningful stimuli.

The touching was administered by a same-sex experimenter to minimize sexual connotations and maintain a socially affiliative context. Touch was applied to the participant's right forearm along the radial bone within a predefined 9-cm region by using the index and middle finger and followed a standardized tempo provided through auditory guidance to ensure consistent velocity across trials. The experimenter was instructed to maintain a continuous, comfortable, and rhythmically stable movement throughout stimulus delivery. To provide a smooth tactile sensation and reduce friction, a small amount of cornflour was applied to the skin prior to delivery of rewards.

Dependent variables

Two primary outcome measures were used to assess reward processing: subjective liking and EMG activity of the zygomaticus major muscle. In addition to analyzing each outcome separately, the relationship between subjective liking and EMG activity was examined at the trial level. This allowed assessment of whether experiential and physiological components of reward responding covary and whether this relationship differs across experimental conditions.

Subjective Liking

Subjective liking was assessed on each trial using a continuous rating scale ranging from −100 (very unpleasant) to +100 (very pleasant). This measure indexed the participant's conscious evaluation of the presented stimulus and served as the behavioral indicator of reward experience.

Trial-wise ratings allowed examination of both average condition effects and within-participant variability across stimuli.

Physiological Liking

Physiological affective expression was measured using facial EMG recorded from the zygomaticus major muscle during stimulus delivery. Zygomaticus activation is associated with positive affective reactions and provides an index of automatic facial motor output (Sato, 2020). EMG activity was analyzed relative to baseline of each participant to capture stimulus-related changes in affective expression rather than absolute muscle tone.

Data Analysis

Analyses were performed on trial-level data obtained across both pharmacological sessions (OXY, PLC). Each participant completed four blocks per session (two touch, two food), with twenty trials per block, resulting in repeated observations for each reward category and stimulus level. This structure yielded a hierarchical dataset in which trials were nested within participants. To account for this dependency while maintaining within-subject variability, linear mixed-effects models were used. Model assumptions were evaluated using residual diagnostics. The residuals showed no substantial deviations from normality or homoscedasticity, indicating that the assumptions underlying linear mixed-effects modeling were adequately met.

Separate models were specified for the two dependent variables: subjective liking ratings and zygomaticus EMG activity. Fixed effects included drug condition, reward type (social touch vs food), and stimulus level (three levels per reward type), as well as their interactions. Random intercepts and slopes for participants were included to model individual baseline differences in response tendencies (Bates et al., 2015). These models tested whether oxytocin altered experiential evaluation and physiological expression of reward.

To examine the coherence between affective components, additional models assessed the trial-wise association between EMG activity and subjective liking and whether this relationship differed across drug and reward conditions.

Results

Descriptive statistics

15 participants have completed the within-subject pharmacological study in which they received intranasal oxytocin and placebo in separate sessions. Two additional drug conditions were collected by the overarching project, but will not be analysed here. The dependent variables are: subjective liking ratings, rated on a continuous scale ranging from -100 to +100 and baseline zygomaticus muscle activity (ZM_fc). One extreme EMG trial (ZM_fc = 0.0001) was removed in the filtering stage and the final dataset thus comprised 1773 trials, specifically 880 food observations, 893 touch observations.

All of the analyses comprised linear mixed-effect models and were performed using *R* (Core Team, 2025) and the used packages were *lme4* (Bates et al., 2015). The p-values were obtained via Satterwaithe degrees of freedom as implemented in *lmerTest* (Kuznetsova et al., 2017). The EMG values were z-scored within-subject (M=0, SD=1 pro participant) so that interpretation is facilitated. For each hypothesis, I fitted a model with random intercepts only where participants differ in baseline level and a model that additionally allows the effect of Drug to vary across participants, so adding random slopes for Drug. I compared the two models using a likelihood ratio test and the model that fit significantly better. The *emmeans* package was used to compute post-hoc contrasts and effect sizes (Cohen d).

Model diagnostics were investigated for all employed models. Likelihood ratio tests confirmed that including a by-participant random slope for Drug did significantly improve the fit for all liking models (H1a, $\chi^2(2) = 13.36$, $p = .001$; H1b, $\chi^2(2) = 48.12$, $p < .001$; H1c (exploratory): $\chi^2(2) = 23.40$, $p < .001$; H3, $\chi^2(2) = 13.35$, $p = .001$; H3a, $\chi^2(2) = 49.08$, $p < .001$; H3b, $\chi^2(2) = 23.22$, $p < .001$.) so these were the ones retained. The only exception was the H2 EMG model: when random slopes were added, the model indicated overparametrization or non-identifiable variance, so therefore for H2 the simple random intercept-only model was used. Residual plots for all models showed no systematic deviations from normality or homoscedasticity.

The mean liking rating was 14.22 (*SD* = 56.14, range: −100 to 100). Raw *ZM_fc* values clustered near 1.0 (*M* = 1.0025, *SD* = 0.0457, range: 0.54–1.76). In addition to these overall values, Table 1 shows raw means and standard deviations separately for Drug × Reward Type condition.

Drug	Reward Type	N	Liking Rating		Zygomaticus EMG(z)	
			M	SD	M	SD
Placebo	Food	416	12.14	57.74	−0.027	1.188
	Touch	416	18.72	52.92	−0.034	0.792
Oxytocin	Food	464	20.69	55.29	0.047	1.009
	Touch	477	5.80	57.27	0.008	0.960

Table 1. Descriptive statistics for touch trials by Drug condition and Reward type

Subjective liking

Effects of Oxytocin on Liking Across Reward Types (H1a)

In order to test whether oxytocin selectively increased liking for social touch relative to food reward, a model predicting *Like* from Drug, Reward Type (Touch vs. Food), and their interaction was fitted. A likelihood ratio test indicated that a random-slopes model (including a random slope for Drug for each subject) fitted significantly better than a random-intercept-only model, $\chi^2(2) = 13.36$, $p = .001$, and was therefore retained.

Final model: *Like ~ Drug × RewardType + (1 + Drug | iSubj)*.

The Drug main effect was marginally significant, $\beta = 10.69$, $SE = 5.15$, $t(19.91) = 2.08$, $p = .051$, which indicates a trend for higher liking under OXY than PLA in the food condition (the reference level). The Reward Type main effect was not significant, $\beta = 6.58$, $SE = 3.49$, $t(1743) = 1.88$, $p = .060$. Critically, the Drug × Reward Type interaction was significant, $\beta = -20.71$, $SE = 4.80$, $t(1745) = -4.32$, $p < .001$.

Post-hoc contrasts revealed a crossover pattern: for food trials, OXY tended to increase liking by approximately 10.7 points relative to PLA ($p = .053$, $d = -0.21$), whereas for touch trials, OXY

tended to decrease liking by approximately 10.0 points ($p = .067$, $d = 0.20$). The direction of this interaction was opposite to the prediction of H1a, which hypothesised that OXY would selectively increase touch liking.

AI-assisted coding tools (LeChat, Mistral AI) were used to support the generation and debugging of *R* code for statistical visualization.

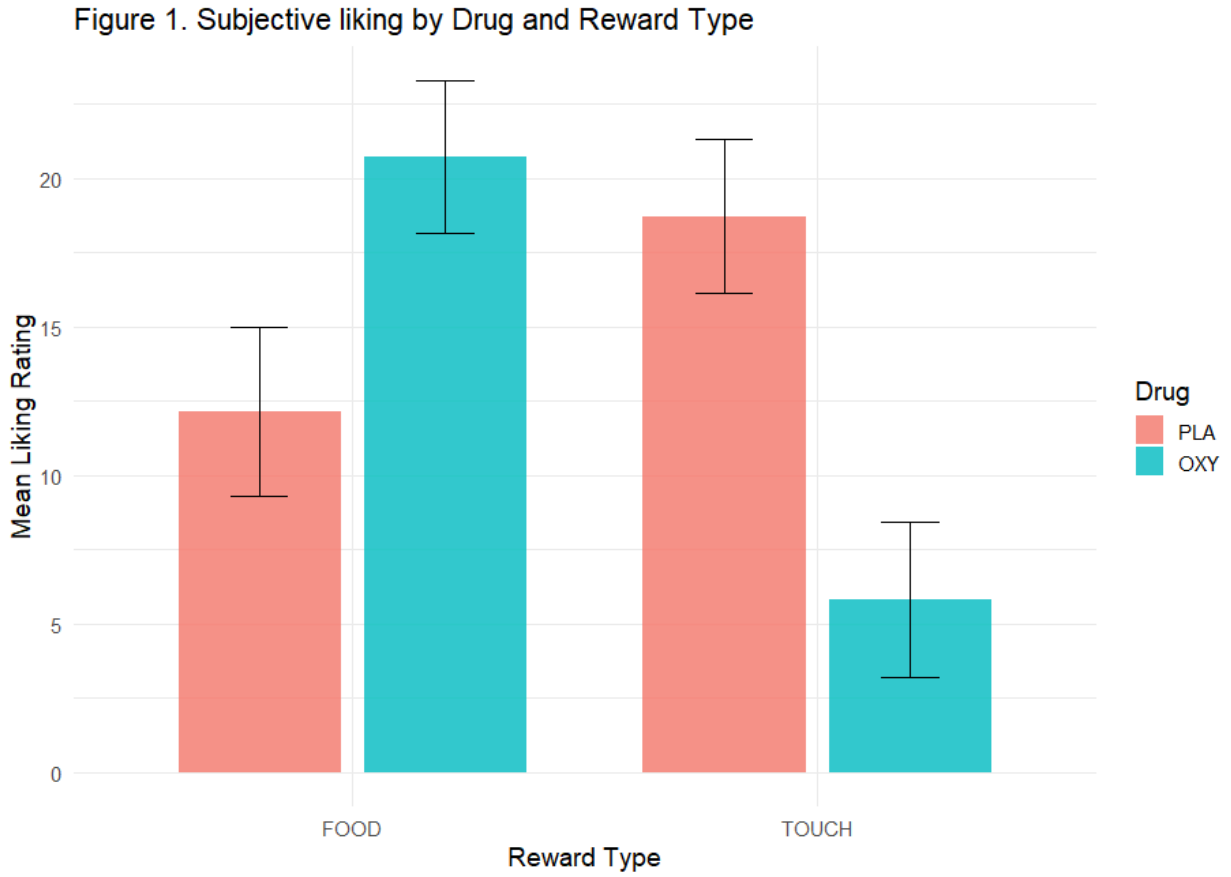

Figure 1. Mean subjective liking ratings for food and touch rewards under placebo and oxytocin, with 95% confidence intervals. Oxytocin increases liking for food but decreases liking for touch, yielding a Drug × Reward Type crossover pattern (H1a).

Oxytocin and Touch Speed on Touch Liking (H1b)

For the touch condition, a model predicting *Like* from Drug, Speed, and their interaction, corresponding to H1b was fitted to test whether OXY preferentially enhanced liking for slow, CT-optimal touch. The random-slopes model was the significantly better one, with $\chi^2(2) = 48.12$, $p < .001$.

Final model: *Like ~ Drug × Speed + (1 + Drug | iSubj)*.

The Drug main effect was not significant, $\beta = -12.97$, $SE = 7.68$, $t(20.14) = -1.69$, $p = .107$. A strong Speed main effect confirmed the expected scenario: relative to slow touch, medium speed reduced liking by 30.30 points ($p < .001$) and fast speed by 46.33 points ($p < .001$). The Drug × Speed(medium) interaction was significant, $\beta = 13.24$, $SE = 6.44$, $t(864.89) = 2.06$, $p = .040$, whereas the Drug × Speed(fast) interaction was not, $\beta = 1.37$, $SE = 5.88$, $t(873.44) = 0.23$, $p = .816$.

Post-hoc contrasts for all speed levels did not reach significance: slow speed PLA − OXY = 12.97, $d = 0.37$, $p = .108$; medium speed PLA − OXY = −0.27, $d = -0.008$, $p = .973$; fast speed PLA − OXY = 11.61, $d = 0.33$, $p = .129$. The significant Drug × Speed (medium) interaction indicates that oxytocin's negative impact on touch liking was weaker at medium speed. However, since none of the individual speed comparisons were statistically significant, hypothesis H1b was not supported and OXY did not specifically increase liking for slow touch.

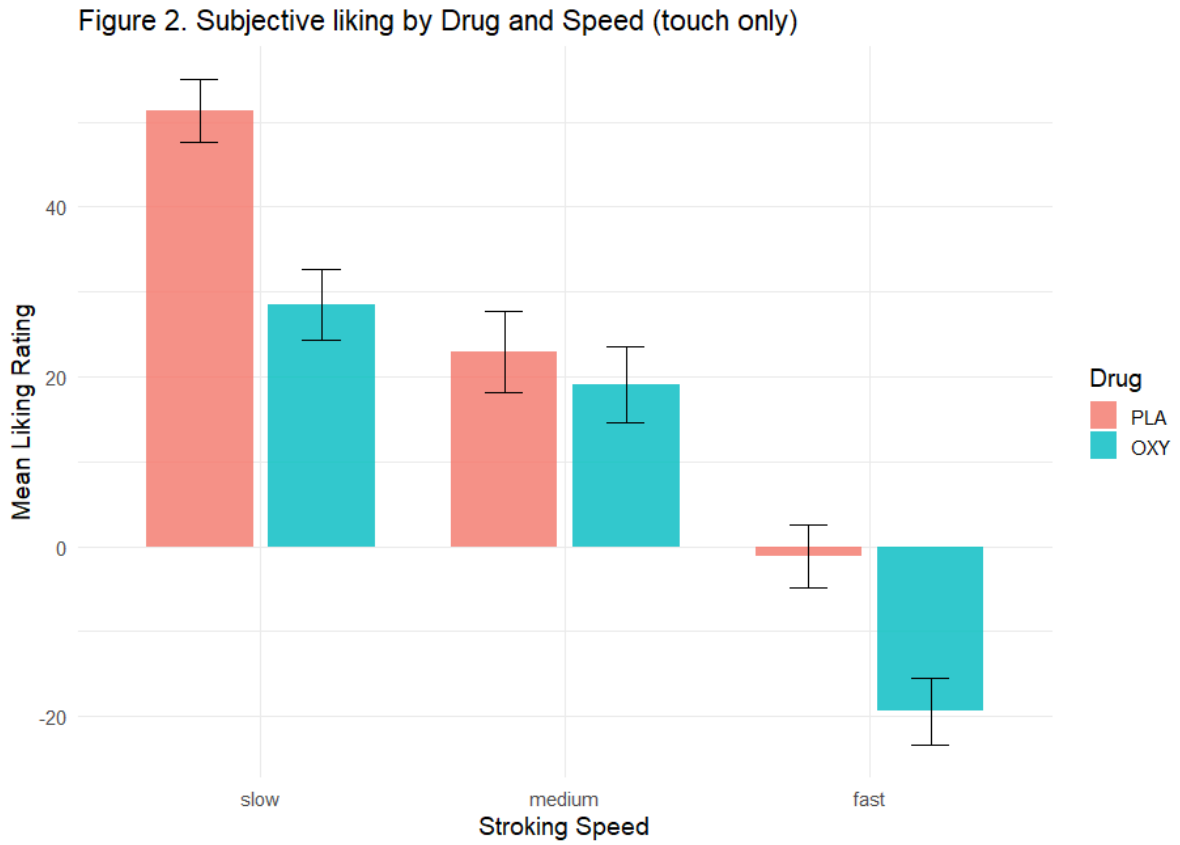

Figure 2. Subjective liking by Drug and Stroking Speed (touch only). Mean subjective liking ratings for slow, medium, and fast touch under placebo and oxytocin , with 95% confidence intervals. Liking decreases with increasing stroking speed, and oxytocin tends to reduce liking at slow and fast speeds, with no clear enhancement at slow touch (H1b).

Exploratory Analysis: Oxytocin and Reward Level on Food Liking

Because of the unexpected direction of the Drug × Reward Type interaction, where oxytocin increased rather than decreased food liking, the exploratory follow-up analyses were conducted within the food condition to examine if OXY's effect varied across reward levels, in a parallel manner to the touch-specific analyses above. The random-slopes model was significantly better, $\chi^2(2) = 23.40$, $p < .001$.

Final model: *Like ~ Drug × LevDel + (1 + Drug | iSubj)*.

A strong reward-level (i.e. chocolate milk, mix chocolate-milk, plain milk) main effect was observed: relative to plain milk, the mix reward increased liking by 57.87 points ($p < .001$) and chocolate milk by 69.89 points ($p < .001$). The Drug main effect was not significant, $\beta = 7.83$, $SE = 7.71$, $t(18.28) = 1.01$, $p = .324$. Neither Drug × Reward-Level interaction term reached significance: Drug × LevDel(25), $\beta = -9.17$, $SE = 7.07$, $t(860.83) = -1.30$, $p = .195$; Drug × LevDel(100), $\beta = 2.68$, $SE = 6.84$, $t(859.70) = 0.39$, $p = .695$.

Post-hoc contrasts at each reward level were non-significant: LevDel = plain milk PLA − OXY = −7.82, $d = -0.20$, $p = .327$; LevDel = mix PLA − OXY = 1.35, $d = 0.03$, $p = .873$; LevDel = chocolate milk PLA − OXY = −10.50, $d = -0.27$, $p = .210$. Oxytocin's tendency to increase food liking (which was also observed in H1a) was uniform across reward levels and did not reach significance at any individual level. The null Drug × LevDel interaction contrasts with the significant Drug × Speed interaction in touch, suggesting that OXY's modulation of food liking is a general upward shift rather than being reward-level dependent.

Effects of Oxytocin on Zygomaticus EMG Across Reward Types (H2)

For the H2 EMG analysis, I initially specified a model predicting within-subject z-scored zygomaticus EMG (zscoreZM_fc) from Drug, Reward Type, and their interaction,while also including random slopes for Drug by subject. This model produced a singular (boundary) fit, indicating negligible between-subject variance in the Drug effect on EMG. Consequently, retained was a random intercept-only model for H2.

Initial model: *zscoreZM_fc ~ Drug × RewardType + (1 + Drug | iSubj)* → singular fit. Therefore the kept model was: *zscoreZM_fc ~ Drug × RewardType + (1 | iSubj)*.

None of the fixed effects reached significance: Drug, $\beta = 0.074$, $SE = 0.067$, $t = 1.11$, $p = .269$; Reward Type, $\beta = -0.007$, $SE = 0.069$, $t = -0.10$, $p = .920$; Drug × Reward Type, $\beta = -0.032$, $SE = 0.095$, $t = -0.34$, $p = .736$.

Post-hoc contrasts also confirmed the null pattern: food PLA − OXY = −0.074, $d = -0.075$, $p = .276$; touch PLA − OXY = −0.042, $d = -0.043$, $p = .530$. Oxytocin had no detectable effect on zygomaticus EMG activity in either reward domain.

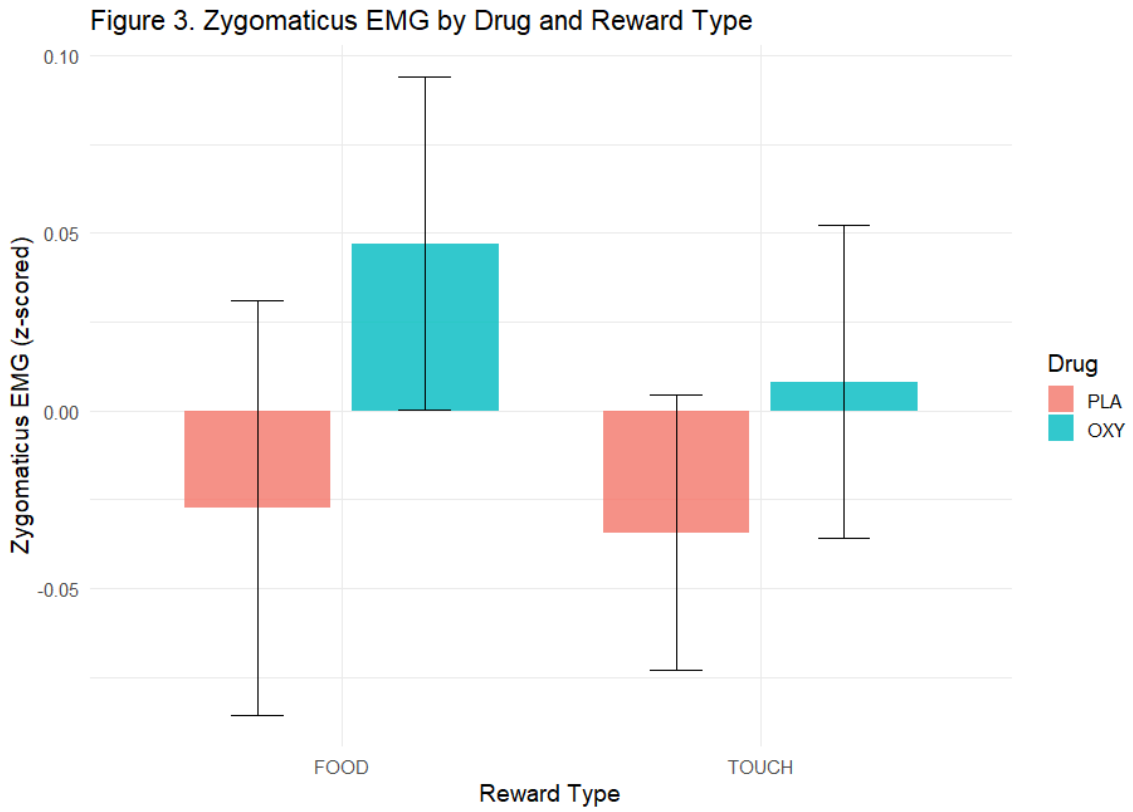

Figure 2. Mean z-scored zygomaticus EMG activity for food and touch rewards under placebo and oxytocin, with 95% confidence intervals. EMG responses show no pronounced differences between Drug or Reward Type conditions.

Trial-wise coupling between zygomaticus EMG and subjective liking (H3)

In order to examine whether trial-level ZM muscle activity predicted liking and whether this coupling was moderated by oxytocin and Touch vs. Food reward, a three-way interaction model was fitted. A likelihood ratio test confirmed that including random slopes for each participant for Drug significantly improved model fit, $\chi^2(2) = 13.35$, $p = .001$, and was thus retained.

Final model: *Like ~ Drug × zscoreZM_fc × RewardType + (1 + Drug | iSubj)*.

The main effect of *zscoreZM_fc* was not significant, $\beta = -2.22$, $SE = 2.09$, $t(1741.52) = -1.06$, $p = .288$, indicating no overall EMG–liking coupling. The Drug × *zscoreZM_fc* interaction was marginally significant, $\beta = 5.38$, $SE = 3.12$, $t(1740.11) = 1.72$, $p = .086$, suggesting a trend toward stronger EMG–liking coupling under OXY. The *zscoreZM_fc* × Reward Type interaction

was not significant, $\beta = 2.01$, $SE = 3.76$, $t(1741.06) = 0.53$, $p = .594$. The three-way Drug × *zscoreZM_fc* × Reward Type interaction was also not significant, $\beta = -5.26$, $SE = 5.03$, $t(1740.78) = -1.05$, $p = .296$.

Figure 3. Trial-wise EMG–Liking Coupling by Drug Condition

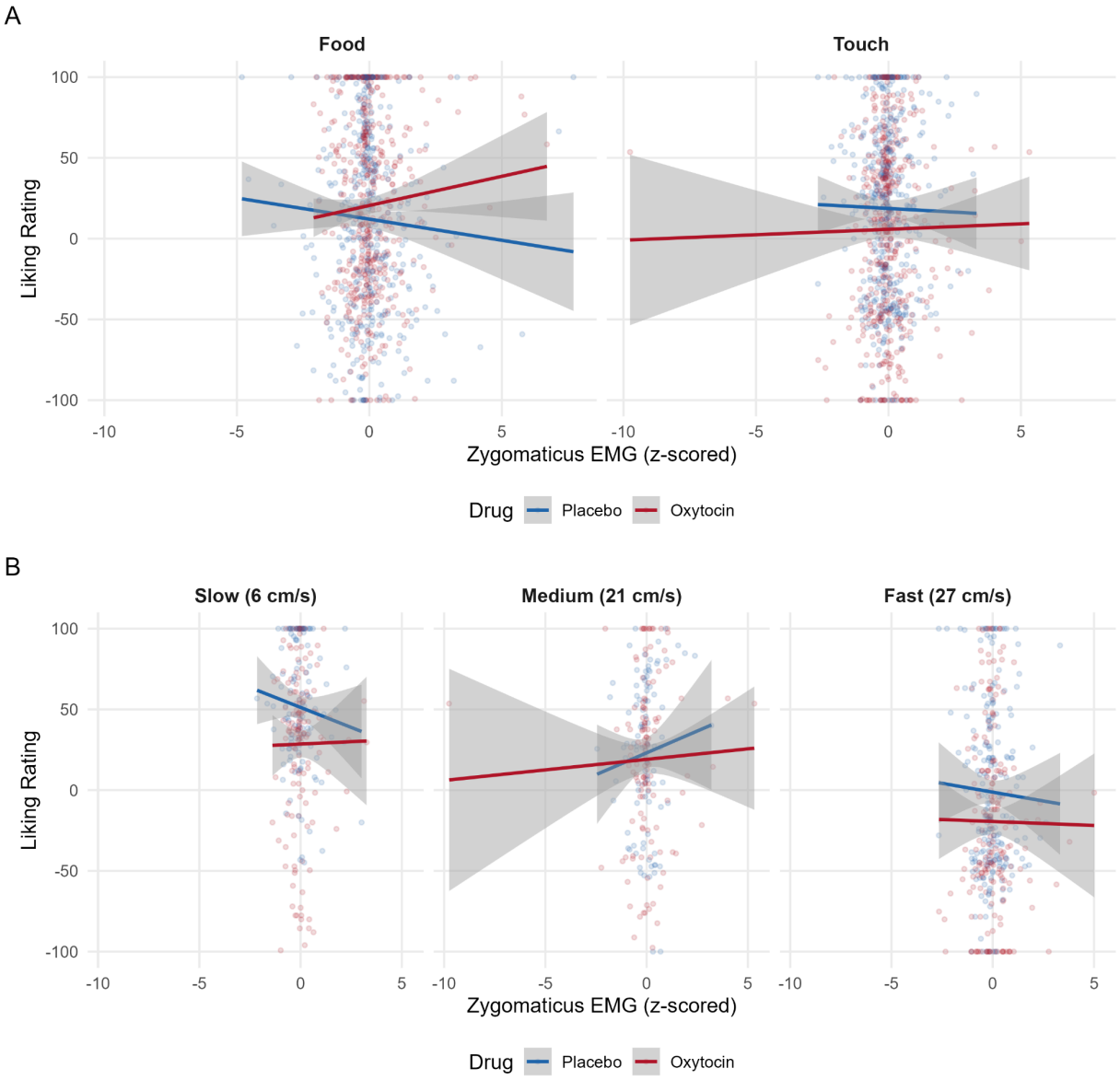

Figure 3. Zygomaticus EMG (z-scored) plotted against subjective liking for food and touch trials, with separate regression lines for placebo and oxytocin. Lines depict model-based fits illustrating the absence of a reliable EMG–Liking coupling or Drug moderation in either reward domain.

EMG–Liking Coupling Across Stroking Speeds (H3b)

For touch trials specifically, I fitted a model examining the three-way interaction of Drug, zscoreZM_fc, and Speed. A likelihood ratio test confirmed that random slopes for Drug significantly improved fit, $\chi^2(2) = 49.08$, $p < .001$.

Final model: *Like ~ Drug × zscoreZM_fc × Speed + (1 + Drug | iSubj).*

The main effect of zygomaticus activity was not significant, $\beta = 0.78$, $SE = 4.25$, t (857.24) = 0.18, p = .855. None of the EMG-related interactions were significant: Drug × zscoreZM_fc, β = 2.21, $SE = 5.96$, t(857.18) = 0.37, p = .710; Drug × zscoreZM_fc × Speed(medium), $\beta = -2.73$, $SE = 7.90$, $t(858.24) = -0.35$, $p = .730$; Drug × zscoreZM_fc × Speed(fast), $\beta = -5.83$, $SE = 7.25$, t(857.03) = −0.80, p = .422. Zygomaticus EMG activity did not predict trial-wise liking, and neither Drug nor Speed moderated this relationship. H3 and H3b were therefore not supported.

Exploratory Analysis: EMG–Liking Coupling Across Food Reward Levels

Comparatively to H1, but within food trials, a parallel model examined the three-way interaction of Drug, *zscoreZM_fc*, and reward level. The likelihood ratio test confirmed that random slopes for Drug significantly improved fit, $\chi^2(2) = 23.22$, $p < .001$.

Final model: *Like ~ Drug × zscoreZM_fc × LevDel + (1 + Drug | iSubj).*

The main effect of *zscoreZM_fc* was marginally significant, $\beta = -4.18$, $SE = 2.48$, $t(852.30) = -1.68$, $p = .093$, suggesting a weak negative EMG–liking coupling in food trials. The Drug × *zscoreZM_fc* interaction was not significant, $\beta = 6.05$, $SE = 3.75$, $t(849.49) = 1.61$, $p = .107$. The *zscoreZM_fc* × LevDel interaction was marginally significant, $\beta = 0.072$, $SE = 0.038$, $t(854.23) = 1.89$, $p = .059$, hinting that EMG–Liking coupling may strengthen at higher reward levels. The three-way Drug × *zscoreZM_fc* × LevDel interaction was not significant, $\beta = -0.083$, $SE = 0.058$, $t(852.52) = -1.44$, $p = .151$. Overall, the food-specific EMG–Liking coupling analysis mirrored the null pattern observed for touch.

Summary of results

The most notable finding was a significant Drug × Reward Type crossover interaction on subjective liking ($p < .001$): oxytocin tended to increase liking for food but decrease liking for social touch, a pattern which is opposite to the prediction of H1. Within the touch condition, a strong speed gradient was confirmed (slow > medium > fast, with all $p < .001$). The significant Drug × Speed (medium) interaction ($p = .040$) indicated that oxytocin's reduction of touch liking was attenuated at medium speed, but no individual speed contrast has reached significance. Thus, H1b was not supported. Exploratory follow-up analyses in the food condition showed that oxytocin's tendency to increase food liking was uniform across reward levels (Drug × reward level: all ps > .195). Oxytocin did not affect zygomaticus EMG activity in any condition. Oxytocin changed how much people reported they liked the stimuli, but it did not alter their EMG responses. This pattern offers only partial support for H1 and H2, and the change went in the opposite direction to what was predicted. At the trial level, EMG did not predict liking in either the food or touch tasks, and this null EMG–Liking link was not influenced by Drug, Reward Type, Speed, or reward level. As a result, H3 and its exploratory extensions were not supported.

Discussion

The principal aim of this master thesis is to add to a bigger study of a research group led by Univ. Prof. Dr. Giorgia Silani examining oxytocinergic and opioidergic action and interaction during social reward processing in humans.

The present thesis has investigated reward processing within a multi-component framework of emotions, distinguishing between subjective liking and physiological affective expression. Oxytocin was used as a means to examine modulation because it is proposed to influence appraisal of socially meaningful stimuli rather than hedonic processing per se (Froemke et al., 2021). The responses to social touch were compared with non-social food rewards for determining whether any effects were specific to socially constructed reward. This daughter study has tested whether oxytocin altered the coupling between subjective experience and facial EMG activity. The central question was therefore whether oxytocin, which according to the literature acts on modulating especially ambiguous social stimuli (Shamay-Tsoory et al., 2016), can influence affective responding to reward deliveries and its relationship to subjective and physiological components.

Across both reward domains, the stimulus intensity has influenced strongly the subjective liking ratings: touch and food stimuli with higher desirability were consistently evaluated as more pleasant than lower-desirability stimuli. In contrast, zygomaticus EMG activity showed little systematic variation across reward levels. Trial-wise analyses revealed no reliable association between facial activation and reported pleasantness. Thus, subjective experience and physiological expression did not covary in a stable manner within the present paradigm.

This pattern indicates that the two measures captured related but separable aspects of affective processing (Mauss, 2024). The data therefore support models proposing partial independence of emotional components, in which conscious evaluation arises from interpretative processes that are not necessarily mirrored in peripheral motor output (Mauss et al., 2024). In this context, the facial EMG activity cannot be treated as a direct proxy of hedonic experience. Here, it would be best considered as one possible expression channel whose relation to subjective liking depends on situational and cognitive factors. Overall, the findings are consistent with constructionist and

componential accounts of emotion, suggesting that reward experience reflects an integration of multiple processes rather than a single unified output (Villringer et al., 2025).

Across analyses, oxytocin did not produce the expected selective modulation of social reward processing. Instead, it yielded a robust Drug × Reward Type crossover in subjective liking: oxytocin tended to increase liking for food while decreasing liking for social touch. This pattern is opposite to the hypotheses' prediction. Several interpretations are possible. The effects of oxytocin are known to be strongly context-dependent and typically emerge when social stimuli require interpretation under uncertainty (Elias et al., 2022). In the present paradigm, the affiliative meaning of the touch stimulus was stable and predictable, potentially reducing the need for oxytocin-mediated modulation for the touch trials. Repetitive stimulation and familiarity with the toucher may also have led to ceiling-level social interpretation, limiting the opportunity for oxytocin to influence appraisal. Under such conditions, oxytocin might not alter reward evaluation itself but instead it modulates processing primarily when social relevance must be inferred or updated (Elias et al., 2022).

Including a food reward condition served as a comparison for interpreting oxytocin effects. Due to both touch and food stimuli being experienced as pleasant and varied systematically in desirability, they allowed assessment of general reward processing independent of social meaning (Yao et al., 2025). Although oxytocin altered subjective liking, its effects were opposite in direction for food and touch and were not accompanied by corresponding changes in zygomaticus EMG. This non-parallel pattern argues against a simple, overall and undifferentiated amplification of hedonic evaluation or response tendencies and does not support the idea that oxytocin selectively boosts socially mediated reward in this case. Instead, the fact that oxytocin changed participant's liking ratings but did not change EMG suggests that the mismatch between subjective experience and facial activity mainly reflects how affective responses are organized: oxytocin seems to act more on evaluative appraisal than on peripheral motor expression (Elias et al., 2022).

The weak correspondence between facial EMG activity and subjective liking suggests that evaluative experience and motor expression reflect partially distinct processes (Winkielman et al., 2005). Subjective ratings depend on appraisal, integrating sensory input with contextual

interpretation and expectations, whereas zygomaticus activation represents an embodied motor output which can occur independently of conscious evaluation (Winkielman et al., 2005). In this sense, evaluation and expression operate at different functional levels: one reflects interpretative judgment, the other action-related physiological preparation.

From a broader perspective, the findings align with models proposing that affective experience arises from weighting and interpretation of internal and external signals (Barrett, 2017). Predictive and constructionist accounts posit that the brain infers affective meaning by combining sensory input with prior knowledge, which may produce a coherent subjective experience even when peripheral motor responses remain minimal (Barrett, 2016; Mauss et al., 2025). Accordingly, facial EMG should be considered as one possible channel of affective expression rather than a reliable indicator of experienced pleasure.

Several limitations should be considered when interpreting the present findings. Although the study included a large number of trial-level observations, the sample size at the participant level was modest. This aspect limits generalizability and sensitivity to smaller pharmacological effects. In addition, subjective ratings may have been influenced by expectations, task beliefs, or habituation due to the repetitive and structured nature of the paradigm. The experimental setting also reduces ecological validity, as laboratory-administered touch differs from naturally occurring affiliative interactions and may attenuate contextual influences on reward valuation. Furthermore, the sample consisted primarily of WEIRD participants, which constrains broader cultural inference (Heinrich et al., 2010).

Despite these limitations, the findings provide some insight into the organization of affective responding. Subjective experience and physiological expression behaved as partially independent components. Taken together, the absence of selective or differential oxytocin effects suggests that oxytocin does not strongly or directly modulate social reward responses under stable and predictable conditions. Instead, affective evaluation appears to be shaped by interpretative processes that may operate independently of peripheral motor expression (Elias et al., 2022). The present findings contribute to understanding the architecture of affective responding by demonstrating that subjective experience and physiological expression can vary independently within the same reward experience. Even when stimuli differed clearly in perceived pleasantness,

facial EMG activity did not reliably track these changes. This supports models in which emotional episodes arise from partially separable components rather than a single unified output (Barrett et al., 2006; Nath et al., 2020). Accordingly, peripheral physiological measures should not be treated as direct indicators of hedonic experience, particularly in structured laboratory tasks where appraisal processes may dominate evaluation.

Future research should examine affective responding in a more naturalistic social interaction context, where the meaning of touch emerges dynamically instead of being predetermined by the experimental context (e.g. no CT-optimal speed; different contexts for reward delivery, etc.). Introducing uncertainty or ambiguity about social intent may be particularly informative, as oxytocin effects are expected to depend on the need to interpret and update social meaning. Additionally, individual differences such as attachment style or certain traits may moderate pharmacological influences and could help explain variability across participants.

Methodologically, one must combine multiple physiological measures (e.g., autonomic, behavioral, and neural indices) to provide a comprehensive characterization of affective components. Relying on a single peripheral measurement is therefore lacking in the extent to which it can reveal information about hedonic processing. Only such multi-component approaches may clarify how experiential, expressive, and regulatory processes interact and under which conditions neuromodulators influence their integration.

Conclusion

The present study investigated whether oxytocin selectively modulates social reward processing and can alter the relationship between subjective experience and physiological expression. Using a within-subject design, responses to social touch and non-social food rewards were assessed through trial-wise liking ratings and facial electromyography of the zygomaticus muscle. Across reward types, stimulus intensity reliably influenced subjective liking, whereas physiological expression showed comparatively little variation and did not consistently track reported pleasantness. These findings indicate that affective experience and motor expression function as partially independent components rather than a unified output. Facial EMG therefore reflects one channel of affective expression but cannot be treated as a direct proxy for hedonic experience within structured reward paradigms.

Oxytocin did not produce the hypothesized selective increase of social reward evaluation, nor did it modify zygomaticus EMG activity or strengthen the trial-wise coupling between subjective and physiological measures. Instead, it produced a clear crossover effect on liking by increasing ratings for food in a similar way across all reward levels. This pattern points to a domain-specific and directionally unexpected modulation of evaluative appraisal. Together, these results suggest that, under stable and predictable conditions, oxytocin does not directly amplify social reward value and leaves the relationship between subjective experience and facial motor output largely unchanged.

In summary, the findings support constructivist models of emotion and highlight the importance of distinguishing evaluative and expressive processes in the study of reward. They further suggest that oxytocin's influence on social behavior is likely contingent on contextual demands for interpretation rather than a uniform enhancement of affiliative experience.

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Supplementary material

Description of a trial

Each trial follows a fixed sequence of events. First, participants see an image indicating the potential reward (either high or low) for 2 seconds. Next, they rate how much they *want* that announced reward using a continuous scale ranging from “not at all” to “very much” (maximum 4 seconds, self-paced within that window).

After the wanting rating, participants complete a 4-second effort phase. During this period, they squeeze a dynamometer with their right hand. The amount of force they apply influences the probability of receiving the previously announced reward. Visual feedback is provided while they exert effort. Subsequently, a second image appears for 2 seconds, informing them about the reward outcome. The obtained reward can be high, low, or if insufficient effort is exerted it will be very low. Greater exerted force increases the likelihood of receiving the initially announced reward. This is followed by a 6-second preparation phase before reward administration, then 7 seconds of actual reward delivery. Afterward, there is a 6-second rest period. Finally, participants rate how much they *like* the reward they just received using a continuous scale (4 seconds). In food-related blocks, an additional rinsing procedure is included: 5 seconds of preparation followed by 7 seconds of rinsing. Throughout the entire task, EMG is recorded from the corrugator supercilii and zygomaticus major muscles. EMG activity is analyzed separately for reward anticipation and reward consumption phases.

Tables and figures

Descriptive statistics by Drug and Speed (Touch only trials)

Drug	Speed	N	Liking Rating		Zygomaticus (z)	
			M	SD	M	SD
Placebo	Slow (6 cm/s)	113	51.33	38.66	−0.023	0.779
	Medium (21 cm/s)	97	22.92	46.87	−0.034	0.786
	Fast (27 cm/s)	206	−1.15	53.21	−0.041	0.805
Oxytocin	Slow (6 cm/s)	148	28.56	50.75	0.016	0.691
	Medium (21 cm/s)	128	19.08	50.73	0.009	1.279

Descriptives by Drug and Reward Level (Food Trials only)

Drug	Speed	N	Liking Rating		Zygomaticus (z)	
			M	SD	M	SD
Placebo	Milk	186	−19.57	51.45	0.047	1.118
	Mix	106	29.00	43.12	−0.085	1.024
	Chocolate	124	45.30	52.96	−0.090	1.405
Oxytocin	Milk	186	−3.80	56.10	0.035	0.942
	Mix	128	24.69	44.05	0.033	0.954
	Chocolate	150	47.66	49.42	0.073	1.133

Estimated Marginal Means (SE) for Liking by Drug and Reward type

	PLA	OXY
Food	9.29 (7.59)	19.98 (6.38)
Touch	15.87 (7.59)	5.84 (6.36)

Estimated Marginal Means (SE) for Liking by Drug and Speed (Touch only)

	PLA	OXY
Slow (6 cm/s)	42.3 (11.0)	29.4 (11.1)
Medium (21 cm/s)	12.0 (11.1)	12.3 (11.1)
Fast (27 cm/s)	−4.0 (10.8)	−15.6 (11.0)

Estimated Marginal Means (SE) for Liking by Drug and Reward Level (Food only)

	PLA	OXY
Milk	−24.1 (8.75)	−16.3 (10.00)
Mix	33.7 (9.09)	32.4 (10.10)
Chocolate milk	45.8 (8.97)	56.3 (10.10)

H1a: Does OXY selectively increase touch liking over food? Model: Like ~ Drug × RewardType + (1 + Drug | iSubj)

Effect	ß	SE	t	df	p
Drug (OXY)	10.69	5.15	2.08	19.91	.051
RewardType (TOUCH)	6.58	3.49	1.88	1743	.060
Drug × RewardType	−20.71	4.80	−4.32	1745	**<.001** ***

Post-hoc: Food: OXY +10.7 pts (p = .053, d = 0.21) | Touch: OXY −10.0 pts (p = .067, d = 0.20)

H1b: Is OXY effect strongest for slow touch? Model: Like ~ Drug × Speed + (1 + Drug | iSubj)

Effect	ß	SE	t	df	p
Drug (OXY)	−12.97	7.68	−1.69	20.14	.107

Speed medium	−30.30	4.86	−6.23	864.90	<.001 ***
Speed fast	−46.33	4.21	−11.02	869.82	<.001 ***
Drug x speed (medium)	13.24	6.44	2.06	864.89	.040 *
Drug x speed (fast)	1.37	5.88	0.23	873.44	.816

Post-hoc: Slow: PLA−OXY = 13.0 (p = .108, d = 0.37) | Med: −0.3 (p = .973, d = −0.008) | Fast: 11.6 (p = .129, d = 0.33)

H2: Does OXY affect liking but NOT EMG? Model: zscoreZM_fc ~ Drug × RewardType + (1 + Drug | iSubj)

Effect	ß	SE	t	p
Drug (OXY)	0.074	0.067	1.11	.269
RewardType (TOUCH)	−0.007	0.069	−0.10	.920
Drug × RewardType	−0.032	0.095	−0.34	.736

Post-hoc: Food: d = −0.075 (p = .276) | Touch: d = −0.043 (p = .530)

H3: Does trial-wise EMG predict liking, moderated by Drug? Model: Like ~ Drug × zscoreZM_fc × RewardType + (1 | iSubj)

Effect	ß	SE	t	df	p
zscoreZM_fc	−2.23	2.10	−1.06	1751	.289
Drug × ZM_fc	5.43	3.15	1.73	1751	.085
ZM_fc × RewardType	2.21	3.79	0.58	1751	.560
Drug × ZM_fc × RewardType	−5.48	5.07	−1.08	1751	.280

Summary table:

Hypo-thesis	Prediction	Result	P (key test)	Verdict
H1a	OXY ↑ touch liking > food	OXY ↑ food, ↓ touch (opposite)	<.001	Opposite direction
H1b	OXY effect strongest at slow	OXY ↓ slow/fast, null at medium	.040 (med interact.)	Not supported
H2	OXY affects liking not EMG	Liking: yes; EMG: no	.736 (EMG interaction)	Partial support
H3	EMG predicts liking, Drug mod.	No coupling	.289 (ZM), .085 (Drug×ZM)	Not supported
H3b	Coupling strongest slow touch	No coupling at any speed	all >.36	Not supported

R script

```
library(readxl); library(writexl); library(ggplot2); library(patchwork)
library(lme4); library(lmerTest); library(dplyr); library(emmeans)

data_folder <- "C:/Users/annam/Desktop/MA DATA/EMG"
all_files <- list.files(path = data_folder,
  pattern = "^SUB_\\d+_Session\\d+_BSL3_fc2sd\\.xlsx$", full.names = TRUE)

cols_to_keep <- c("iSubj","iSess","Group","Type","iBlock","iTrial","RankAnn",
  "RankDel","LevAnn","LevDel","Want","Effort","Like","ZM_fc","ZM_rx","CS_fc","CS_rx")
sheets_to_read <- c("Mean_FOOD","Mean_TOUCH")

all_data <- list(); counter <- 0; errors <- c()
for (filepath in all_files) {
  fname <- basename(filepath)
  for (sheet in sheets_to_read) {
    df <- tryCatch(read_excel(filepath, sheet = sheet),
      error = function(e) { return(NULL) })
    if (is.null(df)) { errors <- c(errors, paste(fname, sheet)); next }
    missing_cols <- setdiff(cols_to_keep, names(df))
    if (length(missing_cols) > 0) for (mc in missing_cols) df[[mc]] <- NA
    df <- df[, cols_to_keep, drop = FALSE]
     df$Sheet <- sheet; df$SourceFile <- filepath  counter <- counter + 1; all_data[[counter]] <-
df}}
```

```
MAnew20mar <- do.call(rbind, all_data)

unblind <- read_excel("C:/Users/annam/Desktop/MA DATA/Unblinding – master students_NEW.xlsx")

names(unblind)[names(unblind) == "SUB...2"] <- "iSubj"

names(unblind)[names(unblind) == "SESSION 1"] <- "S1"

names(unblind)[names(unblind) == "SESSION 2"] <- "S2"

names(unblind)[names(unblind) == "SESSION 3"] <- "S3"

names(unblind)[names(unblind) == "SESSION 4"] <- "S4"

drug_wide <- unblind[, c("iSubj","S1","S2","S3","S4")]

drug_long <- tidyr::pivot_longer(drug_wide, cols = S1:S4,

  names_to = "Sess", values_to = "DrugCode")

drug_long$iSess <- as.integer(sub("S","",drug_long$Sess))

drug_long$Drug <- ifelse(drug_long$DrugCode == 2,"OXY",

                  ifelse(drug_long$DrugCode == 4,"PLA",NA))


MAnew20mar <- merge(MAnew20mar,

  drug_long[, c("iSubj","iSess","DrugCode","Drug")],

  by = c("iSubj","iSess"), all.x = TRUE)

MAnew20mar <- MAnew20mar[MAnew20mar$Drug %in% c("OXY","PLA"), ]

write_xlsx(MAnew20mar, "C:/Users/annam/Desktop/MA DATA/EMG/MAdata_rebuilt.xlsx")


p1a <- ggplot(MAnew20mar,aes(x = Like)) +

  geom_histogram(aes(y = ..density..), bins = 40, fill = "steelblue", alpha = .6) +
```

```
  geom_density(linewidth = .8) + theme_minimal()
p1b <- ggplot(MAnew20mar,aes(x = Like, fill = Drug)) +
  geom_density(alpha = .4) + facet_wrap(~RewardType) + theme_minimal()
p2a <- ggplot(MAnew20mar,aes(x = Want)) +
  geom_histogram(aes(y = ..density..), bins = 40, fill = "darkorange", alpha = .6) +
  geom_density(linewidth = .8) + theme_minimal()
p2b <- ggplot(MAnew20mar,aes(x = Want, fill = Drug)) +
  geom_density(alpha = .4) + facet_wrap(~RewardType) + theme_minimal()
p3a <- ggplot(MAnew20mar,aes(x = Effort)) +
  geom_histogram(aes(y = ..density..), bins = 40, fill = "forestgreen", alpha = .6) +
  geom_density(linewidth = .8) + theme_minimal()
p3b <- ggplot(MAnew20mar,aes(x = Effort, fill = Drug)) +
  geom_density(alpha = .4) + facet_wrap(~RewardType) + theme_minimal()
(p1a | p1b) / (p2a | p2b) / (p3a | p3b)

MAnew20mar$iSess_c <- as.numeric(MAnew20mar$iSess) -
  mean(as.numeric(MAnew20mar$iSess))

MAnew20mar$z_CS_fc <- ave(MAnew20mar$CS_fc, MAnew20mar$iSubj,
  FUN = function(x) scale(x))
MAnew20mar$z_CS_rx <- ave(MAnew20mar$CS_rx, MAnew20mar$iSubj,
  FUN = function(x) scale(x))
```

```
H1a <- lmer(Like ~ Drug * RewardType + (1 | iSubj), data = MAnew20mar)
H1b <- lmer(Like ~ Drug * Speed + (1 | iSubj),
  data = subset(MAnew20mar, RewardType == "TOUCH"))

p_resfit_a <- ggplot(data.frame(fitted = fitted(H1a), resid = resid(H1a)),
  aes(x = fitted, y = resid)) +
  geom_point(alpha = .2) + geom_hline(yintercept = 0, color = "red") +
  geom_smooth(method = "loess", se = FALSE, color = "blue") +
  theme_minimal()
p_qq_a <- ggplot(data.frame(resid = resid(H1a)), aes(sample = resid)) +
  stat_qq() + stat_qq_line(color = "red") + theme_minimal()
p_resfit_b <- ggplot(data.frame(fitted = fitted(H1b), resid = resid(H1b)),
  aes(x = fitted, y = resid)) +
  geom_point(alpha = .2) + geom_hline(yintercept = 0, color = "red") +
  geom_smooth(method = "loess", se = FALSE, color = "blue") +
  theme_minimal()
p_qq_b <- ggplot(data.frame(resid = resid(H1b)), aes(sample = resid)) +
  stat_qq() + stat_qq_line(color = "red") + theme_minimal()
ggsave("C:/Users/annam/Desktop/MA DATA/plot_H1_diagnostics.png",
  plot = (p_resfit_a | p_qq_a) / (p_resfit_b | p_qq_b),
  width = 12, height = 10, dpi = 150)

H2a_zm <- lmer(zscoreZM_fc ~ Drug * RewardType + (1 + Drug | iSubj),
```

```
  data = MAnew20mar)
emm_H2 <- emmeans(H2a_zm, ~ Drug | RewardType)
p_resfit_h2 <- ggplot(data.frame(fitted = fitted(H2a_zm), resid = resid(H2a_zm)),
  aes(x = fitted, y = resid)) +
  geom_point(alpha = .2) + geom_hline(yintercept = 0, color = "red") +
  geom_smooth(method = "loess", se = FALSE, color = "blue") +
  theme_minimal()
p_qq_h2 <- ggplot(data.frame(resid = resid(H2a_zm)), aes(sample = resid)) +
  stat_qq() + stat_qq_line(color = "red") + theme_minimal()
ggsave("C:/Users/annam/Desktop/MA DATA/plot_H2_diagnostics.png",
  plot = p_resfit_h2 | p_qq_h2, width = 12, height = 5, dpi = 150)

H3 <- lmer(Like ~ Drug * zscoreZM_fc * RewardType + (1 + zscoreZM_fc | iSubj),
  data = MAnew20mar)
touch <- subset(MAnew20mar, RewardType == "TOUCH")
H3a <- lmer(Like ~ Drug * zscoreZM_fc * Speed + (1 + zscoreZM_fc | iSubj),
  data = touch)
p_resfit_h3 <- ggplot(data.frame(fitted = fitted(H3), resid = resid(H3)),
  aes(x = fitted, y = resid)) +
  geom_point(alpha = .2) + geom_hline(yintercept = 0, color = "red") +
  geom_smooth(method = "loess", se = FALSE, color = "blue") +
  theme_minimal()
p_qq_h3 <- ggplot(data.frame(resid = resid(H3)), aes(sample = resid)) +
```

```
  stat_qq() + stat_qq_line(color = "red") + theme_minimal()
p_resfit_h3a <- ggplot(data.frame(fitted = fitted(H3a), resid = resid(H3a)),
  aes(x = fitted, y = resid)) +
  geom_point(alpha = .2) + geom_hline(yintercept = 0, color = "red") +
  geom_smooth(method = "loess", se = FALSE, color = "blue") +
  theme_minimal()
p_qq_h3a <- ggplot(data.frame(resid = resid(H3a)), aes(sample = resid)) +
  stat_qq() + stat_qq_line(color = "red") + theme_minimal()
ggsave("C:/Users/annam/Desktop/MA DATA/plot_H3_diagnostics.png",
  plot = (p_resfit_h3 | p_qq_h3) / (p_resfit_h3a | p_qq_h3a),
  width = 12, height = 10, dpi = 150)

H3_ri <- lmer(Like ~ Drug * zscoreZM_fc * RewardType + (1 | iSubj),
  data = MAnew20mar, REML = FALSE)
H3_rs <- lmer(Like ~ Drug * zscoreZM_fc * RewardType + (1 + Drug | iSubj),
  data = MAnew20mar, REML = FALSE)
anova(H3_ri, H3_rs)

desc_drug_reward <- MAnew20mar %>%
  group_by(Drug, RewardType) %>%
  summarise(N = n(),
    M_Like = round(mean(Like, na.rm = TRUE), 2),
    SD_Like = round(sd(Like, na.rm = TRUE), 2),
```

```
    M_ZM = round(mean(zscoreZM_fc, na.rm = TRUE), 3),
    SD_ZM = round(sd(zscoreZM_fc, na.rm = TRUE), 3),
    .groups = "drop")
desc_drug_speed <- touch %>%
  group_by(Drug, Speed) %>%
  summarise(N = n(),
    M_Like = round(mean(Like, na.rm = TRUE), 2),
    SD_Like = round(sd(Like, na.rm = TRUE), 2),
    M_ZM = round(mean(zscoreZM_fc, na.rm = TRUE), 3),
    SD_ZM = round(sd(zscoreZM_fc, na.rm = TRUE), 3),
    .groups = "drop")
mean_like <- mean(MAnew20mar$Like); sd_like <- sd(MAnew20mar$Like)
mean_ZM <- mean(MAnew20mar$ZM_fc); sd_ZM <- sd(MAnew20mar$ZM_fc)

food <- subset(MAnew20mar, RewardType == "FOOD")
food$LevDel <- factor(food$LevDel)

desc_food <- food %>%
  group_by(Drug, LevDel) %>%
  summarise(N = n(),
    M_Like = round(mean(Like, na.rm = TRUE), 2),
    SD_Like = round(sd(Like, na.rm = TRUE), 2),
    M_ZM = round(mean(zscoreZM_fc, na.rm = TRUE), 3),
```

```
    SD_ZM = round(sd(zscoreZM_fc, na.rm = TRUE), 3),
    .groups = "drop")


H1c_ri <- lmer(Like ~ Drug * LevDel + (1 | iSubj),
  data = food, REML = FALSE)
H1c_rs <- lmer(Like ~ Drug * LevDel + (1 + Drug | iSubj),
  data = food, REML = FALSE)
H1c_final <- lmer(Like ~ Drug * LevDel + (1 + Drug | iSubj), data = food)
emm_h1c <- emmeans(H1c_final, ~ Drug | LevDel, lmerTest.limit = 5000)
H3b_ri <- lmer(Like ~ Drug * zscoreZM_fc * LevDel + (1 | iSubj),
  data = food, REML = FALSE)
H3b_rs <- lmer(Like ~ Drug * zscoreZM_fc * LevDel + (1 + Drug | iSubj),
  data = food, REML = FALSE)
H3b_final <- lmer(Like ~ Drug * zscoreZM_fc * LevDel + (1 + Drug | iSubj),
  data = food)


p_h3 <- ggplot(MAnew20mar,
  aes(x = zscoreZM_fc, y = Like, color = Drug)) +
  geom_point(alpha = .15, size = 1) +
  geom_smooth(method = "lm", se = TRUE, linewidth = 1) +
  facet_wrap(~ RewardType,
    labeller = labeller(RewardType = c("FOOD" = "Food","TOUCH" = "Touch"))) +
  scale_color_manual(values = c("PLA" = "#2166AC","OXY" = "#B2182B"),
```

```
    labels = c("PLA" = "Placebo","OXY" = "Oxytocin")) +
  labs(x = "Zygomaticus EMG (z-scored)", y = "Liking Rating", color = "Drug") +
  theme_minimal(base_size = 13) +
  theme(legend.position = "bottom",
    strip.text = element_text(face = "bold", size = 12),
    panel.grid.minor = element_blank())

touch$Speed <- factor(touch$Speed,
  levels = c("slow","medium","fast"),
  labels = c("Slow","Medium","Fast"))

p_h3a <- ggplot(touch,
  aes(x = zscoreZM_fc, y = Like, color = Drug)) +
  geom_point(alpha = .15, size = 1) +
  geom_smooth(method = "lm", se = TRUE, linewidth = 1) +
  facet_wrap(~ Speed) +
  scale_color_manual(values = c("PLA" = "#2166AC","OXY" = "#B2182B"),
    labels = c("PLA" = "Placebo","OXY" = "Oxytocin")) +
  labs(x = "Zygomaticus EMG (z-scored)", y = "Liking Rating", color = "Drug") +
  theme_minimal(base_size = 13) +
  theme(legend.position = "bottom",
    strip.text = element_text(face = "bold", size = 12),
    panel.grid.minor = element_blank())
```

```
combined <- p_h3 / p_h3a +
  plot_annotation(tag_levels = "A",
    title = "Figure 3. Trial-wise EMG–Liking Coupling by Drug Condition",
    theme = theme(plot.title = element_text(face = "bold", size = 14, hjust = 0)))

ggsave("Figure3_H3_EMG_Liking.png", combined,  width = 10, height = 10, dpi = 300)
```