The Influence of Oxytocin on Risk-Taking in the Balloon Analogue Risk Task Among Women with Bulimia Nervosa and Binge Eating Disorder

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Abstract

Previous theoretical models of bulimia nervosa (BN) and binge eating disorder (BED) have implicated cross-domain risk-taking behaviour as a significant maintenance factor in both disorders. The current study sought to test this hypothesis by administering the Balloon Analogue Risk Task (BART) to 25 women with BN or BED and 27 healthy comparison women without history of an eating disorder. Furthermore, we tested the effect of a divided dose of 64IU oxytocin on risk-taking behaviour in the BART. Contrary to our hypothesis, women with BN or BED did not exhibit baseline differences in performance on the BART in the placebo condition (t = 1.42, df = 50, p = .161, d = 0.39). Oxytocin did not have a main effect on performance in the BART (F = 0.01, df = 1, p = .907, $\eta_{2partial} < .001$); however, there was an interaction such that participants in the BN/BED participant group, compared to the healthy comparison group, demonstrated safer behaviour on the BART specifically in the oxytocin condition, but not in the placebo condition (F = 4.29, df = 1, p = .044, $\eta_{2partial}$ = .082). These findings cast doubt on the common assumption that individuals with BN and BED exhibit greater risk-taking behaviour in all domains and add to evidence that oxytocin plays a functional role in modulating behaviours which entail trade-offs between reward approach and risk in humans. We recommend that future dose-response studies further investigate the effect of oxytocin on reward approach behaviour in women with recurrent binge eating behaviour and the clinical significance of this effect.

Keywords: Bulimia nervosa; binge eating disorder; oxytocin; risk-taking

Introduction

Recurrent loss-of-control binge eating characterises the DSM-5 eating disorders bulimia nervosa (BN) and binge eating disorder (BED) [1]. Binge eating behaviour is associated with significant distress, guilt, and shame [1-3], and detracts from the overall quality of life of affected individuals [4].

Furthermore, populations with recurrent binge eating behaviour, including those with BN and BED, have been found to exhibit heightened levels of risk-taking behaviour, as evidenced by the high comorbidity of BN and BED with substance abuse disorders and self-harm behaviour [5, 6]. The role of impulsivity in binge eating behaviour has been well-studied, and has been proposed to account for higher levels of risk-taking behaviour in populations with recurrent binge eating [7] However, there is evidence to suggest that both generalised reward approach processes and impulsivity contribute to trans diagnostic risk-taking behaviour, and that each set of processes is both conceptually and functionally distinct.

In the domain of adolescent risk-taking behaviour, for example, it has been observed that adolescents exhibit heightened levels of risk-taking in a virtual driving task when observed by peers versus when completing the task alone [8]. These increases in risk-taking behaviour were found to be associated with heightened BOLD responses in the ventral striatum and orbitofrontal cortex, two regions strongly associated with reward processing [9]. No difference in BOLD response was observed in prefrontal "cognitive control circuits" between conditions [8]. Whilst care must be taken when making inferences from neuroimaging data to the structure of cognitive architecture, these data are at least compatible with the hypothesis that risk-taking is driven by a dual process incorporating the conflicting tendencies for both reward approach and danger avoidance.

The separability of reward-seeking and disinhibition in driving risk-taking behaviour is also supported by previous literature finding that levels of impulsivity and generalised reward-seeking follow separate development curves throughout adolescence and early adulthood [10]. Indeed, it has been proposed that the convergence of high levels of reward-seeking with high levels of impulsivity account for the greater vulnerability to risk-taking behaviour observed in adolescents [10].

However, the role of reward-seeking, versus impulsivity, in driving risk-taking behaviour has received relatively less attention in empirical literature pertaining to adults with recurrent binge eating behaviour. Nonetheless, both conceptual and empirical formulations of risk-taking suggest that reduced reward-seeking should have the consequent effect of also reducing risk-taking behaviour [11].

One laboratory task measuring risk-taking behaviour is the Balloon Analogue Risk Task (BART) [14]. In the BART, participants aim to maximise a virtual "reward" in a game-like task that entails gambling earnings made within each trial as participants continue to seek greater overall reward. Therefore, the risk posed by continued responding taps into the ratio of participants' tendency for reward approach versus punishment sensitivity [15, 16]. Studies recruiting large community samples have found greater risk-taking behaviour on the BART among disinhibited, as opposed to restrained, eaters [17, 18], although this effect appears to be moderated by prior food consumption [18] and exposure to food images [17].

Studies administering the BART in clinical eating disorder populations, however, have not yielded a clear pattern of results. Manasse, Forman, Ruocco, Butryn, Juarascio and Fitzpatrick [19], for example, found no differences on the BART between obese individuals with and without BED. Neveu, Fouragnan, Barsumian, Carrier, Lai, Nicolas, Neveu and Coricelli [20] found that individuals with BN tend to exhibit less risky behaviour in the BART following

exposure to food, versus neutral, images, but did not exhibit overall differences in behaviour compared to control participants. The study conducted by Neveu, Fouragnan [20], however, was limited by low sample size, and the study conducted by Manasse and colleagues [19] administered only 10 trials in the BART, while the BART was originally validated across 30 trials of balloons with the same probability of explosion. Therefore, limiting the task to 10 trials also limited power to detect differences between individuals with and without binge eating behaviour.

On the whole, however, the general pattern of responding on the BART in samples with subclinical binge eating behaviour has indicated greater levels of risk-taking behaviour, which is in line with studies finding greater risk-taking tendencies on other measures in populations with clinical levels of binge eating behaviour [7]. In the current study, we therefore sought to investigate whether participants with clinical levels of recurrent binge eating behaviour would, indeed, be found to exhibit greater risk-taking tendencies on the BART given the greater sample size [20] combined with a greater number of BART trials compared to previous investigations [19].

Subsequently, it was of interest to examine whether the hypothesised risk-taking tendencies in women with recurrent binge eating could be reduced via modulation of underlying reward-seeking. Intranasal oxytocin supplementation has emerged as a new investigational approach to manage hedonic and over-eating behaviour in healthy and overweight men [21-24] and in BN [25]. While oxytocin may partially impact food intake via the integration of central and peripheral homeostatic satiety signals [26], an increasing body of evidence suggests that the effects of oxytocin on feeding are also mediated by the modulation of reward processes [21, 23, 24]. For example, the fact that oxytocin has been found to significantly curb eating of palatable food in sated healthy normal-weight men, but not homeostatic eating

in fasted conditions, suggests that exogenous oxytocin administration has a stronger effect on reward-driven, as opposed to homeostatic eating [21, 22, 24].

With regards to the mechanism of effect of oxytocin on reward processing, it may be the case that exogenous oxytocin administration modulates dopaminergic functioning in mesolimbic regions. This hypothesis is supported by a range of pre-clinical studies, which have indicated that oxytocin directly stimulates dopamine release within the striatum, and reduces the likelihood of conditioned place preference to morphine in opioid-tolerant rats after a period of withdrawal [27]. A recent review of the myriad direct and indirect effects of oxytocin in modulating opioid seeking and withdrawal effects has further highlighted the role of oxytocin in modulating reward-related central functions of noradrenaline, methamphetamine, serotonin, and glutamate [28].

In humans, 24IU intranasal oxytocin administration has been found to increase blood-oxygenated-level dependent (BOLD) response to images of high, versus low, calorie foods within the ventromedial prefrontal cortex, supplementary motor area, ventrolateral prefrontal cortex, and anterior cingulate cortex of healthy men [23]. Of functional significance, the oxytocin-induced enhanced BOLD response in the right ventrolateral prefrontal cortex when viewing high- versus low-calorie food images was inversely correlated with the consumption of sweet ingredients in a breakfast meal. While hypotheses stemming from these findings are still speculative, it may be the case that oxytocin enhances cognitive control over hedonic eating behaviour. In a similar study conducted in healthy adult women, the authors found a trend-level effect of 24IU oxytocin administration in successfully supporting the intentional reduction of food craving in response to food images [29]. On the whole, previous preliminary evidence has therefore supported a role for oxytocin in modulating reward processing. However, it is not yet clear to what extent oxytocin modulates eating behaviour or general

reward approach behaviours in the context of risk-taking tendencies in women with recurrent loss-of-control binge eating [25, 30].

In the current study, we sought to compare the performance of women with clinical levels of recurrent binge eating on the BART to that of control women without previous history of an eating disorder. Furthermore, we also aimed to investigate the differential effect of intranasal oxytocin on risk-taking in the BART in women with BN and BED compared to healthy controls. Based on theoretical models suggesting the existence of cross-domain risk-taking [31], we hypothesised that women with BN and BED would demonstrate greater baseline risk-taking behaviour on the BART in the placebo condition, relative to women without previous history of an eating disorder. Additionally, given previous research indicating that oxytocin induces a down-regulation of reward seeking in men, we hypothesised that a divided dose of 64IU intranasal oxytocin, versus placebo, would be associated with reduced risk-taking behaviour in the BART in women, and that this effect would be stronger in women with BN and BED due to higher trait levels of risk-taking behaviour.

Methods

Participants

Fifty-two women participated in the current study. Given that recurrent binge eating behaviour was the primary trait of interest in the current study, and that populations with BN and BED are both characterised by recurrent loss-of-control binge eating behaviour, we therefore recruited a heterogeneous sample of women who met criteria for either disorder. Twenty-five women met DSM-5 criteria for BN or BED at the time of the study and twenty-seven comparison women had no history of an eating disorder and no current psychiatric disorder [1]. Participants were recruited via the internal research circular at King's College London, the website for the UK eating disorders charity Beat, and through flyers posted on

community bulletin boards. By chance, an unequal number of participants with BN (n = 20) versus BED (n = 5) volunteered to take part in the study during the recruitment period. Ethical approval for the current study was granted by the London – Camberwell St Giles NHS Research Committee (reference: 14/LO/2115).

Inclusion criteria for the study were as follows: age between 18 and 40 years old, English fluency, and right-handedness (due to an MRI scan which was conducted within the battery of tasks). Exclusion criteria included pregnancy, severe psychiatric comorbidity (*e.g.*, current or previous history of substance abuse disorder, psychosis), currently smoking > 5 cigarettes per day (past 6 months), consuming > 21 units of alcohol per week, uncompensated general medical conditions that could alter eating habits (*e.g.*, diabetes, hypothyroidism), history of a neurological condition (*e.g.*, epilepsy), a significant visual impairment not corrected by eyewear, currently suffering from a cold or flu (as this can affect nasal absorption of the oxytocin), contraindication to MRI scans, and current intake of medication that might potentially interact with oxytocin (*e.g.*, Prostaglandins).

Eligibility for the current study was determined through a phone screening, which included an interview using the eating disorders module of the Structured Clinical Interview for DSM-5 – Research Version (SCID) [1]. Phone screenings were conducted by MSc and PhD students who had received training in the correct use of SCID for DSM-5.

Seven participants in the BN/BED participant group self-reported at least one comorbid psychiatric disorder: 5 women had comorbid depression, 4 women had borderline personality disorder, 4 women had comorbid generalised anxiety disorder, 1 woman had obsessive-compulsive disorder, 1 woman had social anxiety, and 1 woman had an autism spectrum disorder. At the time of the study, 7 women were taking an antidepressant, 1 woman was taking an antipsychotic drug, and 1 woman was taking a mood stabiliser. Participants with BN and

BED reported an average binge eating frequency of 14.14 episodes over the past 28 days (*SD* = 9.88). The women with BN endorsed an average frequency of self-induced vomiting equal to 10.40 occasions over the past 28 days (*SD* = 13.61), an average laxative abuse frequency of 5.13 occasions over the past 28 days (*SD* = 8.35), an average frequency of "hard exercise intended to control weight or shape" equal to 7.31 occasions over the past 28 days (*SD* = 8.57), and one participant reported using diuretic pills on 4 occasions over the past 28 days.

Participants self-reported their use of hormonal contraception or the first day of their most recent menstrual period and this information was used to determine menstrual phase at the time of the study for each participant. Twenty-two participants reported taking hormonal contraception at the time of the study. Fifteen women completed the study in the follicular phase of the menstrual cycle and thirteen women completed the study in the luteal phase of the menstrual cycle. Menstrual phase data were missing for two women. Descriptive statistics regarding the age, BMI, and education level of the BN/BED and comparison participant groups are presented in **Table 1**.

Procedure

The current study used a double-blind placebo-controlled crossover design. Each participant attended the laboratory for an initial orientation visit and two experimental visits. Each participant completed an online battery of psychological tests between the orientation visit and the first experimental visit. Two of the tests, the Depression, Anxiety, and Stress Scales and the Eating Disorders Examination – Questionnaire version, will be described in further detail below. During each experimental visit, participants self-administered a divided dose of 64IU intranasal oxytocin or an equal volume of a placebo nasal spray. The order of oxytocin versus placebo administration was pseudo-randomised for each participant, such that the same number of participants received oxytocin on the first, versus the second, visit.

Experimental study visits were held two days apart to ensure that each woman was in the same phase of the menstrual cycle during each visit. Perfusion data analysing the central effects of oxytocin suggest that carryover effects from oxytocin administration on the first experimental visit to the second experimental visit are highly unlikely [32].

The first 40IU dose of intranasal oxytocin, or equal volume of placebo, was administered at approximately 5.50pm during each experimental visit. Participants subsequently underwent an arterial spin labelling (ASL) scan and fMRI scan, in which they were presented with images and flavours of water and chocolate milk. These neuroimaging results are not reported in the current paper. We chose to administer a 40IU dose of oxytocin prior to the fMRI scan in order to replicate the Kim, Eom [25] protocol, which found an effect of oxytocin on eating behaviour in women with BN at this dose. We additionally chose this dose in order to replicate the protocol of a previous study investigating the effects of intranasal oxytocin on cerebral blood perfusion in men [33]. A comparison analysis with the previous ASL data found in men is currently in preparation for publication.

However, previous findings in humans have suggested that peak central effects of 40IU intranasal oxytocin occur 39-51 minutes following administration [32], thus suggesting the need for an additional dose after this time. Therefore, following the conclusion of the fMRI scan, each participant self-administered the remaining 24IU of oxytocin or equal volume of placebo at approximately 7.10pm. Following this second dose of oxytocin each participant completed the Balloon Analogue Risk Task, which is described below. At the conclusion of the study, participants were prompted to indicate whether they had received oxytocin or placebo on that occasion to test the effectiveness of drug blinding. Drug blinding was found to be effective, as participants guessed drug condition correctly on 57 out of the total 104 visits (54.8% of visits), which was not significantly different from chance (p = .377). There was not a significant difference in the frequency of binge eating episodes in the 24-hr period following oxytocin

administration, versus placebo administration, among the participants with BN and BED (see **Supplementary Material**).

The Balloon Analogue Risk Task

The Balloon Analogue Risk Task (BART) is a validated measure of risk taking behaviour, which is presented on a computer [14]. Each participant is presented with a total of 30 balloon trials. During each trial, the participant is informed that each additional click of the computer mouse will add one pump to the balloon, which is associated with an additional virtual £0.05 added to their total task bank. Once the participant believes they have collected enough money for that task trial, they press on a button reading "Collect" to collect their total earnings for that task trial and proceed to the next trial. However, each balloon is programmed to explode after a different random number of pumps. Participants do not collect any money on trials where the balloon explodes before the participant chooses to collect their earnings.

The BART yields three measures of risk-taking tendency: the adjusted average pump count, total pump count, and total explosion count. The adjusted average pump count is sensitive to general risk-taking tendency on trials without a balloon explosion, as the pump count for trials in which the balloon explodes are excluded from the adjusted average pump count measure. A greater adjusted average pump count therefore indicates greater risk-taking tendency. The total number of balloon explosions captures continued risk-taking tendency after experiencing previous "punishment" for that risk-taking behaviour (in the form of prior balloon explosions). The adjusted average pump count is generally considered superior to the total pump count, which has an artificial ceiling on pumps imposed on trials in which the balloon does explode, thus potentially artificially suppressing variance between individuals' performance [14]. In line with standard administration of the BART, the total pump count will therefore not be considered in the current paper [14]. As both adjusted average pump count and

total number of balloon explosions both tap into general risk-taking tendency, these measures are positively correlated with each other (r = .91) [14, 34]. However, previous work has found interpersonal differences in responding to "win" versus "loss" trials, depending on whether the balloon exploded in the previous trial. Specifically, compared to adults, adolescents are more sensitive to the previous trial's outcome, responding with more pumps after win trials and fewer pumps after loss trials [35]. Additionally, men are more likely to continue to respond with a greater number of pumps after loss trials [36]. Given that the total number of balloon explosions taps into continued risk-taking following previous loss trials, there is evidence to suggest that total number of balloon explosions additionally captures risk tolerance following previous loss, which is not captured by the adjusted average pump count. Accordingly, we have operationalised our hypotheses regarding risk-taking tendency in the BART in terms of both the adjusted average pump count and total number of balloon explosions.

Psychometric Tests

Depression, Anxiety, and Stress Scales. The Depression, Anxiety, and Stress Scales, 21-item version (DASS) is a short measure of negative emotions experienced over the course of the past week for the individual [37]. Each item is presented as a 4-point Likert scale, anchored as 0 ("Did not apply to me at all"), 1 ("Applied to me some degree, or some of the time"), 2 ("Applied to me to a considerable degree or a good part of the time"), and 3 ("Applied to me very much or most of the time"). The total score for each subscale of the 21-item DASS is calculated by summing participants' responses to the items for each subscale and multiplying this sum by two. Higher scores for each subscale therefore indicate greater levels of depression, anxiety, and stress, respectively. Each subscale of the DASS was associated with very good or excellent internal consistency reliability in the current study: Depression subscale $\alpha = 0.96$; Anxiety subscale $\alpha = 0.88$; Stress subscale $\alpha = 0.93$. The DASS-21 exhibits good discriminant and convergent validity, when results are compared against other psychometric measures of

depression and anxiety [38]. Descriptive statistics associated with the DASS for each participant group are presented in **Table 2**.

Eating Disorder Examination – Questionnaire Version. The Eating Disorder Examination – Questionnaire Version (EDE-Q) is a self-report questionnaire measuring eating disorder psychopathology and the frequency of eating disorder behaviours [39]. The psychopathology section of the EDE-Q contains four subscales presented in the form of a 7-point Likert scale: a Restraint subscale, an Eating Concern subscale, a Weight Concern subscale, and a Shape Concern subscale. The Likert scale prompts participants to report on how many days they exhibited each item of eating disorder psychopathology, in which response to each item are anchored from 0 ("No days") to 6 ("Every day"). Each subscale of the EDE-Q was associated with excellent internal consistency reliability in the current sample: Restraint subscale $\alpha = 0.92$; Eating Concern subscale $\alpha = 0.93$; Shape Concern subscale $\alpha = 0.97$; Weight Concern subscale $\alpha = 0.94$. The EDE-Q is associated with acceptable criterion validity, with significantly different mean scores for each subscale among individuals with, versus without, a current eating disorder [40]. Descriptive statistics associated with the EDE-Q subscales for each participant group are reported in **Table 3**.

Statistical Analyses

All analyses were conducted in IBM SPSS Statistics version 24. Differences in performance on the BART in the placebo condition between women in the BN/BED group and comparison women were analysed using Student's *t*-test. The effects of oxytocin and eating disorder status on the adjusted average pump count and total balloon explosions in the BART were analysed with 2 x 2 mixed-design ANOVAs. The independent variables for each analysis were eating disorder status (healthy control versus BN/BED) and drug condition (placebo versus oxytocin).

Results

The data were first inspected for outliers and assumptions of normality. There were no outliers (Z > |3.0|) in the Adjusted Pump Count or Total Explosions variables. Both variables were approximately normally distributed (skew < |2.0|, kurtosis < |9.0|) [41]. Descriptive statistics for the BART data are presented in **Table 4**. Correlations between the adjusted average pump count variable and the total explosion variable within the healthy control group were $r = .87$ ($p < .001$) and $r = .91$ ($p < .001$), for the placebo and oxytocin conditions, respectively. Correlations between the adjusted average pump count variable and the total explosion variable within the BN/BED group were $r = .90$ ($p < .001$) and $r = .95$ ($p < .001$), for the placebo and oxytocin conditions, respectively. Given the high correlation between the adjusted average pump count variable and the total explosion variable and the fact that there were only two main analyses, we deemed it excessively conservative to control for multiple comparisons using a Bonferroni correction due to the high risk of a Type II error [42].

Adjusted Average Pump Count

We tested baseline differences between women with BN/BED and comparison women on the adjusted average pump count using Student's *t*-test. There was no significant difference between the two participant groups on the adjusted average pump count in the placebo condition ($t = 1.11$, $df = 50$, 95% CI [-2.95, 10.29], $p = .270$, $d = 0.31$). We tested the influence of oxytocin and eating disorder status on the adjusted average pump count using a 2x2 mixed-design ANOVA. Participants without history of an eating disorder did not exhibit a significant difference on the average adjusted average pump count variable compared to participants in the BN/BED group ($F = 2.99$, $df = 1$, $p = .090$, $\eta^2_{partial} = .059$). The main effect of drug condition on the adjusted average pump count was also non-significant ($F = 0.02$, $df = 1$, $p = .888$, $\eta^2_{partial} < .001$), as was the Drug Condition*Eating Disorder Status interaction ($F = 0.90$, $df = 1$, $p =$

.348, $\eta_{2partial}$ = .018). A line graph depicting the adjusted average pump count for each participant group and drug condition is depicted in **Supplementary Figure 1**.

Total Explosions

There was no significant difference in balloon explosions between the healthy comparison (HC) and BN/BED participant group in the placebo condition (t = 1.42, df = 50, 95% CI [-0.58, 3.43], p = .161, d = 0.39). We tested the influence of oxytocin and eating disorder status on the total number of balloon explosions using a 2x2 mixed-design ANOVA. The main effect of drug condition on total number of explosions was not significant (F = 0.01, df = 1, p = .907, $\eta_{2partial}$ < .001). Participants in the HC group exhibited a significantly greater number of balloon explosions (F = 4.06, df = 1, p = .050, $\eta_{2partial}$ = .078). There was a significant interaction between drug condition and eating disorder status: the HC group exhibited a numerically greater number of balloon explosions in the oxytocin condition compared to the placebo condition, while participants in the BN/BED group had fewer balloon explosions in the oxytocin condition compared to the placebo condition (F = 4.29, df = 1, p = .044, $\eta_{2partial}$ = .082). A line graph depicting the number of total balloon explosions for each participant group in each drug condition is presented in **Supplementary Figure 2.**

Post hoc *t*-tests revealed that the difference in total balloon explosions between placebo and oxytocin conditions was not statistically significant when the data was isolated among the BN/BED participant group (t = 1.20, df = 23, 95% CI [-0.42, 1.59], p = .241, d = 0.30), nor among the healthy comparison participant group (t = -1.82, df = 25, 95% CI [-1.39, 0.09], p = .081, d = 0.27). However, the difference in balloon explosions between the two groups did depend on drug condition. As stated previously, there was no significant difference in balloon explosions between the HC and BN/BED participant group in the placebo condition (t = 1.42, df = 50, 95% CI [-0.58, 3.43], p = .161, d = 0.39). However, the HC group did have significantly

greater balloon explosions than the BN/BED group in the oxytocin condition (t = 2.50, df = 48, 95% CI [0.51, 4.71], p = .016, d = 0.71). As reported in **Table 5**, there were no significant correlations between depression, anxiety, stress, or eating disorder psychopathology and balloon explosions in the oxytocin or placebo condition among the BN/BED participant group.

We subsequently conducted a sensitivity analysis to investigate the potential moderating effect of menstrual phase (follicular phase, luteal phase, or hormonal contraception) on the effect of oxytocin on performance in the BART with 3x2 mixed-design ANOVAs for the adjusted average pump count and the total number of balloon explosions. There was neither a significant main effect nor a significant interaction with oxytocin for either dependent variable. The full results of the ANOVA testing the influence of menstrual phase on adjusted average pump count are reported in **Supplementary Table 1**, and the results of the ANOVA testing the influence of menstrual phase on the total number of balloon explosions are reported in **Supplementary Table 2**.

Discussion

The current study aimed to test differences in risk-taking performance on the BART among women with and without clinical levels of recurrent binge eating, which includes women with both BN and BED, as compared to healthy comparison women. Additionally, we investigated the effect of a divided dose of 64IU intranasal oxytocin on risk-taking behaviours in the BART among women with BN and BED, as well as women without prior history of an eating disorder. We hypothesised that women with BN and BED would demonstrate greater risk-taking behaviour on the BART in the placebo condition. This hypothesis was not supported, as there were no significant differences in performance on the BART between the BN/BED and HC participant groups in the placebo condition. We also hypothesised that prior administration of intranasal oxytocin, versus placebo administration, would be associated with

reduced risk-taking behaviour on the BART. Our second hypothesis was also not supported as there was no overall effect of oxytocin on the adjusted average pump count or total balloon explosion count in the BART. Our final hypothesis was that the effect of oxytocin on reducing risk-taking behaviour on the BART would be stronger in women with BN and BED, compared to women without history of an eating disorder. Our final hypothesis was partially supported, as oxytocin was associated with lower risk-taking tendencies among the BN/BED, versus healthy comparison, participant group for the total balloon explosions count. However, there was no such significant moderating effect for the adjusted average pump count variable.

Despite the fact that the moderation effect between participant group and drug condition did not reach significance for the adjusted average pump count variable, it is interesting to note that the direction of effect was in the same direction as for the balloon count variable. That is, participants in the HC group exhibited numerically greater risk-taking tendency compared to the BN/BED participant group in the placebo condition, and this difference was enhanced further in the oxytocin condition. That is, the healthy control group displayed numerically higher risk-taking in the oxytocin versus placebo condition for both variables, and the BN/BED participant group displayed numerically lower risk-taking in the oxytocin versus placebo condition for both variables. The lack of significant differences observed in the adjusted average pump count variable is likely a result of the greater variability in performance on this measure. It would therefore be interesting to investigate further in future studies with larger sample sizes in order to ensure adequate power. This replication is especially important given that we did not statistically control for the two analyses conducted. On the whole, however, given that the same pattern of effect was observed for both BART variables, these findings therefore suggest that the effect of oxytocin on risk-taking tendencies in the BART is moderated by baseline individual differences.

The differential effect of oxytocin on risk-taking performance in the BART may relate to differences in oxytocin functioning among women with BN compared to healthy comparison women. For example, Kim, Kim, Kim, Shin and Treasure [43] have found that the G allele of the rs53576 oxytocin receptor gene polymorphism is associated with greater risk for BN. Similarly, Micali, Crous-Bou, Treasure and Lawson [44] found that the GG variant of the same gene is associated with greater binging and purging behaviour in women. Micali and colleagues [44] also found evidence of a gene X environment interaction, such that the AG/GA variant of the rs2254298 oxytocin receptor gene polymorphism is associated with greater binging and purging behaviour specifically in the context of poor maternal care. This pattern of findings suggests that differences in oxytocinergic functioning play a functional role in recurrent binge-purge behaviour. Additionally, one can speculate that the administration of exogenous oxytocin may differentially affect risk-taking tendencies via different patterns of central receptor binding in each participant group. It is possible that these differences may be related to neural circuits including the nucleus accumbens and ventral tegmental area, both of which contain a high density of oxytocin receptors and hold great significance in underpinning appetite behaviour and the processing of reward receipt; however, this hypothesis requires further evidence for corroboration [45].

With regards to the lack of statistically significant baseline differences in risk-taking on the BART between HC and BN/BED groups, the current results add to a mixed field of findings on the BART among participants with disinhibited eating. In non-clinical samples of participants with disinhibited eating, defined by higher scores on the Disinhibition scale of the Three Factor Eating Questionnaire [46], greater levels of risk-taking behaviour on the BART have been observed following prior exposure to food images and food consumption [17, 18]. The presentation of food stimuli was replicated in the current study given that participants viewed images and received small sips of chocolate milk during the course of the fMRI task conducted

prior to the BART. However, we failed to observe greater risk-taking behaviour in the BN/BED participant group in the placebo condition.

By contrast to previous research in sub-clinical samples of disinhibited eaters, previous studies recruiting clinical samples of participants with BN or BED found similar findings to those reported in the current study. That is, there was no difference in responding on the BART among obese participants with or without BED [19], nor between participants with BN and healthy comparison participants [20]. On the whole, these findings demonstrate that individuals with BN and BED do not demonstrate greater risk-taking on the BART and, if anything, instead exhibit numerically smaller risk-taking tendency.

With regards to limitations in interpreting the current findings, it should be noted that tasks such as the BART have been previously criticised for their limited utility in measuring the type of impulsive behaviour generally exhibited by individuals with clinical levels of recurrent binge eating. For example, Leitch and colleagues [18] found that women with disinhibited eating tended to display higher levels of "Reflective impulsivity", defined by a failure to compile and evaluate relevant information before making a decision, as compared to tendencies to perform differently on measures of "Impulsive actions" and "Impulsive choices". Additionally, it is also possible that laboratory tasks involving virtual rewards may lack the reward value for participants which would elicit behaviours representative of real-world risk-taking, and more general reward-approach behaviours. Indeed, a similar measure of risk-taking behaviour, the Iowa Gambling Task, has recently been criticised for being poorly correlated with self-reported real-life risk-taking behaviour [47], leading to increased interest in the BART as an alternative measure of decision-making in risk-taking scenarios. Future validation studies would be useful in more firmly establishing the ecological validity of risk-taking tasks among populations with binge eating behaviour.

Limitations of the current study also include small sample size, which limited our power to detect small effects. Additionally, the neural effects of oxytocin are moderated by dose [48] time and method of administration [32], so it is possible that a different pattern of effects would have been observed using different doses or methods of administration. It would also be interesting to further explore differences with and without prior exposure to images of food or calorie-dense drinks and without prior administration of the fMRI scan, which may have affected responding on the BART by exposing participants to an unfamiliar stressor. Given differences in hormonal secretion across the course of circadian cycles [49], which may have interacted with the effect of the exogenously-administered oxytocin, it should also be noted that the current results may not generalise to different times of day (e.g., in the morning or early afternoon). Finally, given the possibility for error inherent in participants self-reporting menstrual phase, future studies can improve accuracy in assessing the interaction between menstrual phase and exogenous oxytocin by testing blood concentrations of follicle stimulating hormone.

Clinical Implications

Previous research has described BN as being characterised by elevated levels of both reward and punishment sensitivity [50]. The fact that BN is commonly comorbid with substance use disorders [51] has contributed to the hypothesis that reward approach behaviours tend to "win out" over fear of punishment across life domains [52, 53]. However, the current findings add to previous work using the BART to suggest that elevated risk-taking behaviour is not always evident in BN/BED. Previous work has suggested that elevated levels of risk-taking behaviour may exist predominantly in subgroup of people with BN comorbid with either borderline personality disorder [51] or attention-deficit/hyperactivity disorder [54]. Future research would therefore be helpful to determine whether there is differential responsiveness to reward, versus

punishment, in women with comorbid BN and borderline personality disorder versus women without a comorbid personality disorder.

Conclusion

To conclude, the current study aimed to replicate previous studies comparing performance on the BART between women with clinical levels of recurrent binge eating to comparison women without history of an eating disorder. We further aimed to investigate the influence of intranasal oxytocin on risk-taking in the BART among women with BN and BED and comparison women without history of an eating disorder. There were no significant baseline differences in performance on the BART between women with and without BN or BED in the placebo condition. We found evidence of a significant interaction for the balloon explosion variable such that a divided dose of 64IU oxytocin enhanced initial numerical differences in risk-taking between the participant groups: increasing risk-taking in the healthy control group and decreasing risk-taking in the BN/BED participant group. Although not reaching significance, the same trend was observed for the adjusted average pump count variable. Future studies with greater power would be useful in further clarifying whether cross-domain heightened risk-taking is restricted to some subgroups of people with BN.

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Table 1

Descriptive demographic data

	Healthy Control (*n* = 27)			BN/BED (*n* = 25)		
	Mean(SD)	Median(IQR)	Skew	Mean(SD)	Median(IQR)	Skew
Age	24.04(3.65)	24.00(6.00)	0.78	25.46(6.39)	23.50(10.00)	0.95
BMI	22.26(1.98)	22.04(1.76)	1.33	24.17(5.34)	23.09(3.87)	2.32
RQF Education Level	5.43(1.70)	6(4)	-0.70	4.63(1.79)	4.5(3)	0.08

Note. BN = bulimia nervosa; BED = binge eating disorder; IQR = interquartile range; BMI = body mass index; RQF = Regulated Qualifications Framework.

Table 2

Descriptive statistics for the Depression, Anxiety, and Stress Scales (21-item version)

	Healthy Control (*n* = 25)			BN/BED (*n* = 25)				
	Mean(SD)	*Median(IQR)*	*Skew*	*Mean(SD)*	*Median(IQR)*	*Skew*	*d*	*t*
Depression Scale	1.92(3.08)	0.00(2.00)	2.01	21.42(11.32)	24.00(15.00)	-0.45	2.37	-8.31
Anxiety Scale	1.04(1.54)	0.00(2.00)	1.12	12.16(9.18)	10.00(12.00)	1.06	1.69	-5.97
Stress Scale	2.88(3.17)	2.00(6.00)	0.50	20.56(11.20)	20.00(18.00)	0.09	2.19	-7.59

Note. BN = bulimia nervosa; BED = binge eating disorder; EDE-Q = Eating Disorder Examination – Questionnaire Version.

Table 3

Descriptive statistics for the Subscales of the Eating Disorder Examination – Questionnaire Version

	Healthy Control (*n* = 26)			BN/BED (*n* = 25)				
	Mean(SD)	*Median(IQR)*	*Skew*	*Mean(SD)*	*Median(IQR)*	*Skew*	*U*	*p*
EDE-Q Restraint	0.55(0.73)	0.40(0.70)	1.74	3.35(1.68)	4.00(2.10)	-0.97	577.50	< .001
EDE-Q Eating Concern	0.25(0.49)	0.00(0.20)	2.59	3.85(1.23)	4.20(1.90)	-0.13	649.00	< .001
EDE-Q Weight Concern	0.82(1.31)	0.40(0.85)	2.54	4.66(1.11)	4.80(1.50)	-1.34	623.00	< .001
EDE-Q Shape Concern	1.20(1.39)	0.63(1.44)	1.81	5.08(1.07)	5.63(1.63)	-1.21	627.50	< .001

Note. BN = bulimia nervosa; BED = binge eating disorder; EDE-Q = Eating Disorder Examination – Questionnaire Version.

Table 4

Descriptive statistics for performance on the Balloon Analogue Risk Task, separated by eating disorder status

	Healthy Control (*n* = 27)				BN/BED (*n* = 25)			
	Placebo		Oxytocin		Placebo		Oxytocin	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Adjusted Average Pump Count	37.62	10.656	38.43	12.033	33.95	13.061	31.95	10.926
Total Explosions	8.70	3.760	9.19	3.950	7.28	3.422	6.58	3.387

Note. BN = bulimia nervosa; BED = binge eating disorder.

Table 5

Pearson correlations between the total balloon explosions among the BN/BED participant group and the DASS and EDE-Q scales

	1	2	3	4	5	6	7	8
1. Total Explosions(PL)	-							
2. Total Explosions (OT)	.76***							
3. DASS Stress Scale	-.01	-.06						
4. DASS Depression Scale	-.02	-.22	.69***					
5. DASS Anxiety Scale	.22	.27	.67***	.35				
6. Restraint	.05	.27	.10	-.12	.16			
7. Eating Concern	.14	.31	.16	-.18	.27	.48*		
8. Shape Concern	-.04	.17	.08	-.03	.17	.51*	.71***	
9. Weight Concern	.05	.18	.31	-.03	.33	.41*	.78***	.81***

Note. BN = bulimia nervosa; BED = binge eating disorder; DASS = Depression, Anxiety, and Stress Scales; EDE-Q = Eating Disorder Examination – Questionnaire version; OT = oxytocin condition; PL = placebo condition.

* $p < .05$.

*** $p < .001$.

Figure Legends

Supplementary Figure 1. The influence of oxytocin on the adjusted average pump count variable. ED = eating disorder participant group; HC = healthy control participant group. Error bars represent confidence intervals.

Supplementary Figure 2. The influence of oxytocin on total balloon explosions. ED = eating disorder participant group; HC = healthy control participant group. Error bars represent confidence intervals.