

Attachment , aggression and affiliation:
The role of oxytocin in female social behavior.

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The peptide hormones oxytocin and vasopressin have been implicated in a range of mammalian social behaviors including maternal care, pair bonding and affiliation. Oxytocin is of special relevance to female behavior because its effects are strongly modulated by estrogen. This article reviews animal and human research and is organised in terms of two research perspectives. The specific attachment model identifies oxytocin as orchestrating special bonds with offspring and mates, including the use of aggression in the protection of these relationships. The trait affiliation model considers oxytocin in relation to the trait of general social motivation that varies between and within species. Implications for understanding and researching the role of oxytocin in women's attachment, affiliation and aggression are discussed.

1. Background

The peptide hormones oxytocin (OT) and arginine vasopressin (AVP) have been implicated in the regulation of mammalian social behavior. OT and AVP are highly conserved across species in terms of structure and function. Both are composed of nine amino acids (sharing seven in common) and have peripheral and central effects. AVP modulates a number of behaviors exhibited only by males (Goodson & Bass, 2001) while OT is more closely involved in female behavior.

Peripherally, OT regulates uterine contractions during labour and milk ejection during lactation. It is synthesised in magnocellular neurons of the paraventricular (PVN) and supraoptic (SON) nuclei of the hypothalamus which project to the posterior pituitary where OT is released into peripheral circulation. Peripheral effects are typically measured by plasma radioimmunoassay. Centrally, OT acts as a neuromodulator. It is synthesised in the parvocellular neurons of the hypothalamic PVN which projects to limbic sites (hippocampus, amygdala, striatum, hypothalamus, nucleus accumbens) and to mid- and hind-brain nuclei. Central OT is typically measured in cerebrospinal fluid. Central OT release and neuronal activity can be elicited by sexual and reproductive stimuli (copulation, genital and breast stimulation, birth, olfactory stimuli, suckling) and non-sexual stimuli including grooming, light massage and exposure to offspring. Stimulus-induced and peripherally- or intra-cranially injected OT facilitates milk ejection, uterine contractions, parturition, lordosis, copulation, ejaculation, maternal behaviors, partner and offspring preference and social contact (Gimpl & Fahrenholz, 2001).

Oxytocin is of special relevance to females because OT and OT receptors are regulated by estrogen (Lim & Young, 2006). Estrogen receptor β is expressed in hypothalamic neurons that synthesise OT and estrogen receptor α is needed for the synthesis of OT receptors in the amygdala (Patisaul, Scordalakes, Young & Rissman, 2003). Gonadal steroids play a 'permissive' role in modulating central and peripheral OT synthesis and OT receptor proliferation, density and affinity. Indeed, McCarthy, McDonald, Brooks and Goldman (1996, p.1209) observe that the OT receptor is "one of the most strongly estrogen-regulated systems in the brain...estrogen-induced increase in oxytocin receptor binding is integral to its behavior-modifying effects".

I begin this article by reviewing our current knowledge of the behavioral effects of OT based on non-human animal and human studies. This review is organised in terms of two research perspectives implicit in the literature. The *specific attachment* approach examines OT's role in orchestrating bonds with loved ones, including the situation-specific use of aggression to protect those relationships. The *trait affiliation* perspective examines OT as one factor contributing to the enduring trait of affiliation or sociability which varies between and within species. These two models broadly correspond to state versus trait interpretations of OT effects. Following this, I identify some interpretive problems and methodological challenges in OT research. Finally I consider the theoretical and research implications for understanding the role of OT women's affiliation and aggression

2. Specific attachment

2.1 Maternal care and defence: Animal studies.

The role of OT in maternal behavior has been extensively researched and thoroughly reviewed elsewhere (Broad, Curley & Keverne, 2006; Insel, 2000; Kendrick, 2000). Although females in many mammalian species avoid and even attack newborns, these hostile nulliparous females quickly become nurturant after giving birth. In late pregnancy, in response to rising estrogen levels, OT receptors are upregulated in the uterus and the brain. Vagino-cervical stimulation during parturition triggers activation of OT neurons in the hypothalamus stimulating release of OT in many brain areas including the preoptic area, ventral tagmental area and olfactory bulb. These central pathways are critical for coordinated maternal behavior including nest building, retrieving pups to the nest, licking them and crouching to afford pups body heat and access to the nipple. In 1979, Pedersen and Prange first demonstrated that intracerebroventricular infusion of OT can induce maternal responses in estrogen-primed virgin rats. Reciprocally, the onset of maternal behavior can be inhibited by OT antagonists, lesions of OT cells and antibodies to OT (Insel, 2000). Recent studies of OT knockout mice in semi-naturalistic environments have revealed significant deficits in mothering (Ragnauth, Devidze, Moy, Finley, Goodwillie, Kow et al., 2005; Takayanagi, Yoshida, Bielsky, Ross, Kawamata, Onaka et al., 2005). However OT has been implicated specifically in the onset, not the maintenance, of maternal care. Once established, lesions of the PVN (the source of OT) do not interfere with it (Kendrick, 2000). Maternal care-giving in higher mammals such as primates may be emancipated from neuroendocrine effects. In rhesus monkeys OT measured immediately before and after parturition shows

no correlation with maternal behaviors such as grooming or contact (Cooke, Higley, Shannon, Lindell, Higley, Suomi et al., 1997).

Maternal aggression against infanticidal conspecifics represents the 'other side of the coin' of mother-infant bonding. While OT inhibits aggression directed towards the pups, it simultaneously enhances attacks on intruders (Debiec, 2005; Pedersen, 2004). Maternal aggression is typically studied experimentally in rodents by introducing a strange conspecific of either sex into the mother's home cage in the presence of her pups. Maternal aggression is associated with low levels of fear (Gammie, Negrón, Newman & Rhodes, 2004; Hard & Hansen, 1985; but see Lonstein & Gammie, 2002). Following parturition there is down-regulation of corticotropin releasing factor which controls activity in the hypothalamic pituitary axis (Lonstein 2005; Neumann, 2002, 2003). Intracerebroventricular infusion of CRF significantly inhibits maternal aggression while leaving other maternal behaviors unaffected (Gammie, et al., 2004).

Administering OT to rodents and humans reduces amygdala activation, increases parasympathetic functioning, inhibits CRF neurons, decreases corticosteroid release, and results in lower levels of fearful behavior (Dreifuss, Dubois-Dauphin, Widmer & Raggenbass, 1992; McCarthy et al., 1996; Uvnäs-Moberg, 1997; Windle, Kershaw, Shanks, Wood, Lightman & Ingram, 2004; but see Douglas, Brunton, Bosch, Russell & Neumann, 2003). The process by which OT attenuates fear in the rat has recently been clarified (Huber, Veinante & Stoop, 2005). The central amygdala controls autonomic fear responses through connections to PAG, reticular formation and hypothalamus. Within the central amygdala, there are two distinct populations

of neurons; one is excited by OT receptors and a second is inhibited by OT but excited by AVP receptors. AVP activity excites neurons in the medial part of the central amygdala that stimulate fear arousal and responses. OT activates neurons in the lateral and capsular portion of the central amygdala which inhibit the fear-inducing effects of AVP through GABA projections.

However evidence for a direct relationship between OT release and maternal aggression remains equivocal (Kendrick 2000; Lonstein & Gammie 2002). Table 1 presents a summary of animal findings on OT and female aggression, the majority of which examine maternal aggression. A number of studies are supportive of the roles of OT and fear attenuation in explaining maternal aggression. OT levels rise in the PVN in both the mother and a female intruder in the maternal defence test (Bosch, Kromer, Brunton & Neumann, 2004) and this rise is correlated with aggressive behavior, especially for dams bred for high anxiety (Bosch, Meddle, Beiderbeck, Douglas & Neumann, 2005). Infusion of OT into the central amygdala increases maternal aggression (Ferris, Foote, Meltser, Plenby, Smith & Insel, 1992) while lesions of the PVN decrease it (Consiglio & Lucion, 1996). However other studies have found a null or even negative relationship between aggression and OT, which may be the result of differences in the specific site and method of lesion, and the extent of damage (Giovenardi, Padoin, Cadore & Lucion, 1998)

2.2 Maternal care and defence: Human studies.

The fact that OT in rodents has been implicated only in the post-partum transition from infant aversion to attachment, together with the fact that nulliparous girls and women are not averse to infants, has led some

researchers to suggest that human maternal behavior has been freed from OT control (Kendrick, 2000; Broad et al., 2006). Nonetheless, in humans, OT rises in the cerebrospinal fluid during childbirth and post-partum plasma levels are correlated with positive feelings and reduced anxiety (Takagi, Tanizawa, Otsuki, Haruta & Yamaji, 1985). Viewing images of one's infant activates brain regions associated with reward that are also rich in OT and AVP receptors (Bartels & Zeki, 2004). Lactation is associated with lowered subjective stress and less negative mood states (Mezzacappa & Katkin, 2002) and in breast-feeding women, basal OT levels are negatively correlated with anxiety and guilt (Uvnäs-Moberg, Widström, Nissen & Björvell, 1990). Lactation is also associated with lowered cortisol (Amico, Johnston & Vagnucci, 1994) and attenuated ACTH, cortisol and glucose responses to exercise stress (Altemus, Deuster, Gallivan, Carter & Gold, 1995) and during suckling there is a negative relationship between plasma OT and ACTH levels (Chiodera, Salvarani, Bacchimodena, Spallanzani, Cigarini, Alboni et al., 1991).

Research into the role of OT in lowering mothers' acute response to situational stress has produced with mixed results. In a standard laboratory stress test, prior nursing (as compared to holding the infant) for 15 minutes attenuated the magnitude of total and free cortisol responses in lactating women, but it did not increase their OT levels (Heinrichs, Meinlschmitt, Neumann, Wagner, Kirchbaum, Ehlert et al., 2001). In a similar stress test with bottle-feeding and breast-feeding mothers, only half of the breast-feeding mothers showed an anticipatory increase in OT (although this was more common than among bottle feeders). However those mothers who did show

OT increases also had significantly lower blood pressure during the stress test (Light, Smith, Johns, Brownley, Hofheimer & Amico, 2000).

Parallels have been drawn between maternal aggression in other species and women's protectiveness and aggressive defence of their infants (Hrdy 1999). The extent to which such maternal feelings and behaviors are associated with OT is unknown and clearly there are ethical problems in asking new mothers to imagine (let alone experience) scenarios in which their infant is under threat.

2.3 Mate relations: Animal studies.

The role of OT in partner preference and the formation of pair bonds has exploited comparisons between two related species: The prairie vole which shows a strong partner preference and bi-parental care, and the promiscuous montane vole. OT antagonists block the formation of partner preference in the female prairie vole without interfering with mating. (AVP shows a similar effect in males.) OT receptors are found in the nucleus accumbens and prelimbic cortex of the prairie vole---areas rich in dopamine receptors mediating reward. Administration of OT induces central dopamine release and vica versa. The co-action of OT and dopamine appears to be critical for partner preference: D2 dopamine receptors, stimulated during mating, associate the reward centres with the olfactory signature of the mate registered by OT (Edwards & Self, 2006). In the promiscuous montane vole, the OT and dopamine systems are uncoupled.

To the extent that adult pair-bonding shares common features and mechanisms with mother-infant attachment, the implications for aggression are similar. We would expect attachment to a mate to be associated with

inhibition of aggression directed toward them, together with a willingness to use aggression in protection of the relationship. Evidence supporting diminished cross-sex aggression in the context of OT availability has been reported for monogamous Mongolian gerbils (Razzoli, Cushing, Carter & Valsecchi, 2003) and prairie voles (Witt, Carter & Walton, 1990). OT knockout females are significantly more aggressive than normal females when paired with males (Ragnauth et al., 2005). In monogamous species, these pacific OT effects allow time and opportunity for the formation of a pair bond which is necessary before a female is willing to mate (Getz, Carter & Gavish, 1981; Razzoli et al., 2003; Witt, 1997).

The specific attachment model also suggests a readiness in paired females to offensively attack same-sex rivals. Female prairie voles become increasingly aggressive to other females after cohabitation with a male (Bowler, Cushing & Carter, 2002). This effect is significantly enhanced by intraperitoneal OT injections within 24 hours of birth (Bales and Carter, 2003).

2.4 Mate relations: Human studies

The association of OT with pair bonding in voles excited exploration of a similar relationship in humans. Viewing pictures of one's partner activates dopaminergic pathways associated with reward that are also rich in OT and AVP receptors (Bartels & Zeki, 2004; Fisher, Aron & Brown, 2006). Women's OT rises during massage, genital stimulation, orgasm and copulation (Pedersen 2004; Insel, 2000). However studies which directly measure OT in the context of romantic relationships have produced mixed results.

One line of research has focused on relationship quality with results that ran contrary to expectations. Basal plasma OT levels were negatively

correlated with being in a current dating, cohabiting or marital relationship and positively correlated with interpersonal distress (Turner, Altemus, Enos, Cooper & McGuinness, 1999). This was replicated in a further study which found basal OT to be negatively correlated with marriage quality, physically affectionate contact, degree of partner's understanding and appreciation and women's ability to open up to them (Taylor, Gonzago, Klein, Hu, Greendale & Seeman, 2006).

A second approach has examined whether recalling experiences of romance (and its loss) produces changes in OT levels. Results have been inconsistent. In one study, there was considerable variability between subjects with 44 per cent showing the anticipated OT increase to positive emotion and 56 per cent the expected decrease to negative emotion (Turner et al., 1999). In neither case was the overall OT effect significant. Those who showed an OT rise in response to positive memories were more frequently in a current relationship, and self-reported less over-intrusiveness and over-nurturance. However in a follow-up study, OT actually decreased over time in response to positive emotion while negative mood had no effect on OT (Turner, Altemus, Yip, Kupferman, Fletcher, Bostrom et al., 2002). When re-living and describing a love episode, OT reactivity was unrelated to self report of love intensity (Gonzago, Turner, Keltner, Campos & Altemus, 2006).

A third approach has examined the short-term effects of tactile contact from a partner. Blood was taken from men and women before, during and after a 10 minute period of warm contact with their partner that ended with a hug (Grewen, Girdler, Amico & Light, 2005). Individuals with more supportive partners showed higher levels of OT throughout. In a further study of partner

contact in relation to a stressful public speaking task (Light, Grewen & Amico, 2005), women were grouped into low, medium and high OT levels according to their baseline readings. High OT women reported more frequent hugs and massages from partners, although they did not report a better emotional relationship with them. Although high OT women had lower blood pressure and heart rate at baseline, the groups did not differ in their physiological response on the three subsequent measures (speech preparation, delivery and recovery).

In summary, the contradictory human results and their competing interpretations need to be addressed. Does elevated OT act as an impetus to seek affectionate contact (Taylor et al., 2006) or is it a response to such contact (Uvnas-Moberg, 1998)?

3. Trait affiliation model

Oxytocin has been implicated in the motivation to affiliate more generally. Affiliation is conceived of as an enduring trait, similar to sociability, subject to variation between species and individuals in contrast to 'attachment' which characterises a specific dyadic relationship.

3.1 Trait affiliation: Animal studies.

It has been suggested that OT promotes sociability by reducing anxiety in response to novel conspecifics (Carter, 1998). The naturally affiliative bonnet monkey shows higher OT levels in cerebrospinal fluid than the less sociable pigtail macaque (Rosenblum, Smith, Altemus, Scharf, Owens, Nemeroff et al., 2002). Intracranial or subcutaneous injection of OT increases social contact time in rats (Witt, Winslow & Insel, 1992), female gerbils (Razzoli et al. 2003) and squirrel monkeys (Winslow & Insel, 1991).

Individual differences in affiliation may reflect early nurturing experiences and their effects on the OT system (Cushing & Kramer, 2005). In rats, repeated mother-infant separations and decreased maternal licking and grooming are associated with reduced OT binding in the amygdala (Francis, Champagne & Meaney, 2000; Winslow, Noble, Lyon, Sterk & Insel, 2003). Rhesus monkeys deprived of maternal care display disturbed and asocial behavior including avoidance of physical contact, stereotypic and self-directed behaviors, gaze avoidance and attachment to inanimate objects. These monkeys also have decreased cerebrospinal OT measured between 18 and 36 months. Levels of cerebrospinal OT (but not plasma OT) are positively correlated with affiliative behavior (Winslow, 2005).

Mirroring increased sociability, we would expect decreased aggression in non-threat situations. In hamsters, OT injected into the hypothalamus has been found to decrease female aggression toward a non-aggressive female intruder in a dose dependent manner (Harmon, Huhman, Moore & Albers, 2002). In rats, experimentally induced over-expression of OT receptors in the amygdala was associated with lowered anxiety but an increased number of attacks by virgin females against a virgin female intruder (Bosch, Waldherr, Nair, Hermanth, Young & Neumann, 2006).

3.2 Trait affiliation: Human studies.

The effects of OT on human affiliation have been ascribed to both attenuation of anxiety and activation of reward systems. The majority of studies have addressed the first of these possibilities with seemingly contradictory results. However these apparent contradictions may reflect a

feedback system in which stress induces OT release (a positive association) which in turn reduces stress levels (a negative association).

Trait measures of anxiety fail to show a consistent relationship with basal plasma OT. In post-partum women, significant negative correlations were found between OT and four of 15 personality scales; somatic and psychic anxiety, muscular tension and guilt (Uvnäs-Moberg et al., 1990). However, in non-pregnant women, no significant correlation was found with any personality factor (Uvnäs-Moberg, Arn, Jonsson, Ek & Nilsson, 1993) and in a study of patients with gastrointestinal disorders, a significant positive relationship was found with two (of 19) traits; indirect aggression and guilt (Uvnäs-Moberg, Arn, Theorell and Jonsson, 1991). However the relationship between OT and anxiety may be modulated (and statistically masked) by affiliation. Strong interpersonal relationships are positively correlated with OT and negatively correlated with anxiety. When these opposing relationships are partialled out, the correlation between OT and anxiety is significant and positive (Tops, van Peer, Korf, Wijers & Tucker, 2007).

Other studies have examined acute OT response to stress. In response to an uncontrollable auditory stressor, plasma OT rose but only among women high in emotionality (Sanders, Freilicher & Lightman, 1990). In a double-blind within-subjects study, subjects were administered cortisol (normally released by the HPA in response to stress) or a placebo. OT levels rose in response to cortisol but again only for emotionally demonstrative participants (Tops, van Peer & Korf, 2007). No relationship between OT and stress reduction was found in older women: During a laboratory stressor task, OT levels were unrelated to cortisol levels (Taylor et al., 2006).

The effect of OT on stress reduction has also been examined. Intranasally administered OT was associated with a decline in salivary free cortisol in men with this decline being significantly less marked among those who had experienced early parental separation (Meinlschmidt, & Helm, 2007). This suggests, consistent with animal studies, that OT's anxiolytic effects can be attenuated by disturbed early attachments.

While the relationship between plasma OT and stress remains uncertain, an innovative experimental study using fear-inducing stimuli in concert with brain imaging has produced promising results (Kirsch, Esslinger, Chen, Mier, Lis, Siddhanti et al., 2005). Fifteen healthy males received either OT or a placebo in a double-blind, cross-over design. They were exposed to fear-inducing images and control stimuli while fMRI was used to track activity in the amygdala and related brain regions. OT administration significantly depressed amygdala activation in the fear-inducing conditions. OT also decreased the functional connectivity between the central nucleus of the amygdala and midbrain regions that control arousal and fearful behavior. A reduction in human autonomic responses to aversive pictures after OT administration has also been reported (Pitman, Orr & Lasko, 1993). Further experimental studies are needed which explicitly address the proposed feedback model (OT is released in response to stressors and in turn exerts an anxiolytic effect) in concert with neuroimaging technology to identify the site of these effects.

A different interpretation of OT effects has been suggested in a recent neurobehavioral model (Depue & Morrone-Strupinsky, 2005). Rather than emphasising anxiety reduction, it is proposed that OT positively enhances

social motivation. Individual differences in affiliation may reflect differences in the motivation to seek social interactions and the capacity to experience reward from them. Affiliative motivation derives from dopaminergic neurons running from the ventral tagmental area to the nucleus accumbens. Oxytocin and OT receptors are found in these same areas where they interact with the dopamine system. Affiliative reward derives from endogeneous opiate release and binding which occurs during many of the same socio-sexual experiences that are associated with OT release. The rewarding effects of opiates occur in the same hypothalamic nuclei as those implicated in OT and OT can increase central opiate release by up to 300 percent (Csiffary, Ruttner, Toth & Palkowits, 1992).

Are the prosocial effects of OT due to enhanced social motivation and reward or to decreased anxiety and fear? A recent study (Kosfeld, Heinrichs, Zak, Fischbacher & Fehr, 2005) addresses this question by examining the role of OT in fostering trust in a game with real monetary stakes. 'Investors' had the option of giving money to a trustee. If they did so, the transferred amount was tripled. The trustee could then return to the investor their full share, some part of it or none. (In a control 'risk' condition, participants believed that a random mechanism decided the amount of back transfer.) The key trust variable---the amount invested---was increased by the intranasal administration of OT. In explaining this effect, the authors were able to rule out explanations in terms of a non-specific increase in prosocial inclination (OT had no effect on trustees' monetary return to the investor), optimism (OT and placebo investors did not differ in their expectation of receiving a back transfer), mood (there was no significant difference in mood and calmness

before and after OT administration), risk aversion (there were no differences between OT and placebo groups in the risk condition) and betrayal aversion (betrayal was not possible in the risk condition yet participants made lower transfers). The results are compatible with two effects of OT. It promotes interpersonal trust by inhibiting defensive behaviors and by linking this inhibition with the activation of dopaminergic reward circuits.

4. Issues in research interpretation and implementation.

The bulk of OT research to date has been performed on rodents. Even within these taxa, there is inconsistency in the findings. In addition, there is considerable variation in receptor distribution across mammalian species. Extrapolation to humans presents the additional problem of the extent to which 'hard-wired' responses, such as maternal behavior, pair bonding and aggression, have been superseded by the learning and cultural transmission afforded by increased cortical size.

Within species, it is also important to consider the sex-specificity of neuropeptide impact. Although OT is generally more influential in female behavior, OT has been shown to affect some male behaviors including partner preferences, sexual behavior and social recognition (Cushing & Kramer, 2005). Both sexes have receptors for both neuropeptides (Goodson & Bass, 2001) and no sex differences in AVP or OT innervation of the human brain have been detected (Fliers, Guldenaar, Wal & Swaab, 1986; Witt, 1997). To complicate matters further, the structural similarity of AVP and OT means that they are capable of binding to each others' receptors. The effects of the same peptide can also vary dramatically in males and females. For example, in men intranasally administered AVP stimulates agonistic facial expressions

and decreased perception of friendliness in response to images of same-sex strangers. In women administration of the same peptide, results in affiliative facial expressions and increased perception of friendliness (Thompson, George, Walton, Orr & Benson, 2006).

Differences in the source of OT need to be taken into account in interpreting results. Because peripheral OT can be assayed from blood samples while central OT requires more invasive measurement of cerebrospinal fluid, most human studies tell us about peripheral reactions. The extent to which peripheral and central release are coordinated is doubtful (Gimpl & Fahrenholz, 2001). In some species a small quantity of peripherally administered OT crosses the blood–brain barrier or it may influence behavior via afferent feedback to the CNS. Studies of plasma OT also vary in their use of basal versus reactive measures. In nursing women, the effects of basal OT may be different from pulsatile OT (Uvnäs-Moberg et al., 1990).

The fact that OT acts as part of a larger biological system means that its effects can frequently appear as statistical interaction terms or be masked by other variables. The effects of OT are embedded within the steroid and stress hormone systems and interact with classical neurotransmitter systems (Depue & Morrone-Strupinsky, 2005; Jorgensen, Kjaer, Knigge, Moller & Warberg, 2003). OT levels are also responsive to early experience (Cushing & Kramer, 2005). In short, there are complex, iterative and multi-directional relationships which we are only beginning to unravel and such work, for obvious reasons, is chiefly being undertaken on non-human mammals.

Human studies require innovative methodologies. Recent studies have manipulated neuropeptides as an independent variable using intranasal

administration in blind, crossover designs. Administered in this way, OT crosses the blood brain barrier; its effects are manifest within 10 minutes and last for approximately 80 minutes (Born, Lange, Kern, McGregor, Bickel & Fehm, 2002). In addition to examining central OT effects on behavioral and physiological responses, the specific sites of OT activity can be further investigated using functional fMRI techniques. A less intrusive method in human research is to exploit variations in estrogen levels which facilitate OT effects----menstrual cycle variations are a natural candidate or comparisons of post-menopausal women using or not using hormone replacement therapy.

5. Implications for research on women's affiliation and aggression

Oxytocin is explicitly incorporated in the 'tend and befriend' biosocial model of women's affiliation and aggression proposed by Taylor, Klein, Lewis, Gruenewald, Gurung & Uppdegraff (2000). They argue that mammalian females' evolutionarily role in nursing and defending offspring meant that a fight-or-flight response in the face of threat might risk injury to or fatal abandonment of their offspring. While testosterone primes aggressive behavior in men, females largely lack androgens and so 'are unlikely to show a physical 'fight' response to threat' (Taylor et al., 2000, p. 413). Under threat, estrogen-potentiated OT serves to "calm the female who is physiologically aroused by a stressor and also to promote affiliative behavior, including maternal behavior toward offspring" (Taylor et al., 2000, 416). Under threat, females do not attack or flee but seek the proximity of other females for protection against predators and conspecific males. Persuasive empirical evidence supports their assertion that, under stress, women seek affiliation with others to a greater degree than men. .

Indeed OT effects might be usefully examined in connection with women's trait affiliation more generally. Women value interpersonal connectedness and interdependence while men prioritise autonomy and independence (Cross & Madson, 1997). These differences are confirmed by psychometric inventories of female-typical traits including empathy, supportiveness and interdependence (Bem, 1974; Spence, 1985). Women rate themselves as more trusting, nurturant and extraverted than men (Feingold, 1994) and these findings have been replicated cross-culturally (Costa, Terracciano & McCrea, 2003). Women's friendships show greater trust in terms of emotional self-disclosure while men tend to avoid sharing vulnerable feelings that might compromise their autonomy (Cross & Madson, 1997).

As a corollary of their affiliation, women as a sex display less physical and verbal aggression than men (Archer, 2000, 2004). The 'tend-and-befriend' model directly addresses this robust finding. The difficulty is that it does not explain why females should ever employ direct aggression. Although Taylor et al. parenthetically acknowledge the existence of maternal aggression, they conclude that direct female attacks are rare and "confined to situations requiring defence" (Taylor et al., 2000, p. 414). They later identify a range of threats to women and their offspring (including predators, rape, assault, homicide and offspring abuse) all of which appear to be 'situations requiring defence'. Yet they maintain that the tend-and-befriend tactic is used in these circumstances, leaving the question of female aggression unanswered.

I have also suggested an evolutionary account of sex differences in aggression which identifies fear as the mediating variable (Campbell 1999, 2002). Women's lower fitness variance, higher parental investment and higher replacement costs mean that each offspring is extremely valuable. The loss of even one offspring represents a considerable fitness handicap. Although intra-sexual aggression potentially brings fitness rewards for primate females as it does for males (e.g. shorter inter-birth intervals, more surviving offspring), the associated costs are higher. The costs derive from the lower likelihood of offspring survival following the death of a mother compared to a father. A higher level of fear in females is proposed as the psychological mediator of females' less frequent and less lethal use of aggression. Meta-analyses have confirmed that the magnitude of the human sex difference in aggression is significantly correlated with the sex difference in fear and estimated danger of attacking (Bettencourt & Miller 1996; Eagly & Steffen, 1986). This model proposes not only that female aggression should be less frequent and less dangerous than among men, but also that it will be confined to situations where the heavy costs are outweighed by prospective benefits. Maternal aggression is just such a situation (Campbell, 1999). In an infanticidal attack, the costs of non-aggression exceed the costs of aggression and females should and do counterattack. As predicted by the fear-mediation explanation, animal studies strongly suggest that OT maternal aggression is dependent on fear reduction.

There are no studies of the effects of OT on women's mate-directed aggression. However women's aggression is more likely to be expressed against a male partner than against other targets (Archer, 2000). Since only a

minority of these attacks are motivated by self- or child-defence (Archer, 2000; Kruttschnitt & Carbone-Lopez, 2006), how can this be reconciled with the specific attachment proposal that OT enhances sociosexual bonds? One possibility is that OT exerts its bonding effect, at least in part, by reducing women's threat perception and accompanying fear (Broad et al., 2006). In evolutionary terms, copulation constitutes a greater threat to females' safety and survival than to males' (Chapman, Liddle, Kalb, Wolfner & Partidge, 1995; Lew. Morrow & Rice, 2006; Rice, 1996). In humans, there are immediate and long-term dangers posed by men's eagerness for sex: Injury due to men's greater size and strength, rape, jealousy-precipitated partner violence, infertility from sexually transmitted diseases and post-copulatory mate desertion. This may explain women's preference for a longer association prior to sexual intercourse (Buss & Schmitt, 1993). The diminution of fear and increase in trust necessary for a woman's agreement to a sexual relationship may also diminish her fear of employing aggression. Low fear of counter-aggression has been found in women who assault their partners (Archer, 2000; Fiebert & Gonzalez, 1997). Research could usefully examine OT in the context of women's intimate relationships, specifically in terms of its fear-reducing effects and possible facilitation of aggression.

In summary, the tend-and-befriend OT proposal is best suited to explaining the more pacific nature of women compared to men as conceptualised in studies of trait affiliation. It fares less well in explaining women's use of aggression and specifically its disproportionate use against male partners. Here the role of OT in fear reduction may prove a useful avenue of research.

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Table 1: Summary of rodent studies of oxytocin and female aggression.

Authors	Effect of OT on aggression	Species	Form of aggression	Manipulation or correlate of interest	Results
Consiglio & Lucion (1996)	↑	Rats	Maternal aggression (Male intruder)	PVN lesion	Lower frequency and duration of attack
Ferris et al. (1992)	↑	Hamsters	Maternal aggression (Male intruder)	Infusion of OT into CeA.	Increased aggression
Bosch et al. (2005)	↑	Rats	Maternal aggression. (Virgin female intruder)	OT levels measured.	Correlation between offensive behavior and local OT release in PVN and CeA
Bosch et al. (2004)	↑	Rats	Maternal aggression. (Virgin female intruder)	OT levels measured before and after intruder.	PVN OT rises in both mother and intruder No change for either in OT in the CeA or the medio-lateral septum
Neumann et al (2001)	↔	Rats	Maternal aggression. (Virgin or lactating female intruders)	Tested with or without OTA injected into lactating resident.	Rise in ACTH and corticosterone attenuated in lactating residents and intruders. OT rises in virgin intruders only. OTA has no effect on maternal aggression.
Factor et al., 1992	↔	Rats	Maternal aggression.	Midbrain lesions used to disrupt pathway between suckling and OT release.	No effect on maternal aggression

Giovenardi et al. (1998)	↓	Rats	Maternal aggression. (Male intruder)	OT reduced via PVN lesion by ibotenic acid and antisense administration.	Day 5 (normally high aggression levels), increased maternal aggression. Day 18 (normally low aggression levels), no effect.
Lubin et al. (2003)	↓	Rats	Maternal aggression. (Male intruder)	OTA (500ng or 1000ng) or buffer infused into CeA 4 hrs before testing.	1000ng OTA dams attack intruder more often than buffer controls.
Razzoli et al. (2003)	↓	Mongolian gerbil	Cross-sex aggression. Male and female placed together	Intact estrous females compared to ovariectomized females treated with OT & EB	OT + EB decrease aggression in ovariectomized females to same level as intact females.
Witt, Carter & Walton (1990)	↓	Prairie vole	Cross-sex aggression. Male and female placed together	Ovariectomised females treated with oil or EB followed by (ICV or IP) injections of OT.	OT (ICV) + EB decreases aggression to male
Ragnauth et al. (2005)	↓	Mice	Cross-sex aggression. Resident intruder test (male intruder).	OTKO compared with WT	OTKO more aggressive toward male intruders.
Harmon et al. (2002)	↓	Hamsters	Female intra-sexual aggression. Resident intruder test (non-aggressive female intruder).	OT, OTA or saline injected into medial preoptic anterior hypothalamus.	OT causes shorter duration of aggression on immediate test (but not after 30 mins.) OTA has no immediate effect but increases aggression duration after 30 minutes. Dose dependent effect.

Bosch et al. (2006)	↑	Rats	Female intra-sexual aggression. Resident intruder test (virgin female intruder).	Virgin or pregnant females injected in CeA with OTR gene (carried by viral vector)	20% over-expression of OTR in CeA of virgins but no up-regulation in pregnant rats. Virgins show more aggression to intruder and lower anxiety. Maternal aggression not affected.
Bales & Carter (2003)	↑	Prairie voles	Female intra-sexual aggression. Before and after a 4hr exposure to a male.	Neonatal injection of OT, OTA or control.	OT females more aggressive than OTA and control females in the post test.

ACTH=adrenocorticotrophic hormone; CeA=central amygdala; EB=estradiol benzoate; ICV=intracerebroventricular; IP=ontraperitoneal; OT=oxytocin; OTA=oxytocin antagonist; OTKO=oxytocin gene knock out, OTR=oxytocin receptor, PVN=paraventricular nucleus (of the hypothalamus), WT=wild type