The Effects of Posterior Pituitary Vasopressin on Human Social Behavior

Authors: Wu Xiaoyan

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Abstract

Arginine Vasopressin (AVP), one of the neuroendocrine hormones and commonly referred to as vasopressin, has been found to play a crucial modulatory role in complex human social behaviors. First, in the domain of familial relationships, vasopressin can facilitate male sexual behavior and paternal behavior. Second, regarding social evaluation, vasopressin can elicit hostility among males and affiliative behavior among females. Finally, in social decision-making, vasopressin can enhance self-interested social decision-making in males while promoting interpersonal relationship harmonization in females. Current issues in this research field include: disproportionate male-to-female participant ratios, with existing studies predominantly focusing on males; the need for further investigation into clinical treatments for mental disorders; and insufficient control over other variables. Future research should continue to explore the regulatory effects of vasopressin on various aspects of human functioning, including emotion regulation and learning.

Full Text

The Effects of Vasopressin on Human Social Behavior

Xiaoyan Wu[12], Chunliang Feng[2], Jiahua Xu , Zhenhong He , Yi Luo , Yuejia Luo[123]

[1]Center for Brain Disorders and Cognitive Science, Shenzhen University, Shenzhen 518060, China
[2]Shenzhen Key Laboratory of Affective and Social Cognitive Science, Shenzhen 518060, China
[3]Center for Emotion and Brain, Shenzhen Institute of Neuroscience, Shenzhen 518060, China
State Key Laboratory of Cognitive Neuroscience and Learning, Beijing Normal University, Beijing 100875, China

Division of Neuroscience and Experimental Psychology, School of Biological Sciences, University of Manchester, Manchester, United Kingdom
Virginia Tech Carilion Research Institute, Virginia Tech, Roanoke, USA

Abstract

Arginine vasopressin (AVP), a neuroendocrine hormone commonly referred to as vasopressin, plays a crucial role in regulating complex human social behaviors. First, regarding family relationships, vasopressin promotes sexual behavior and paternal behavior in men. Second, in social evaluation, vasopressin can elicit hostility among men and affiliative behavior among women. Finally, in social decision-making, vasopressin enhances self-interested social decisions in men while promoting interpersonal reconciliation in women. Current limitations in this field include: (1) a gender imbalance with male-dominated samples, (2) the need for further investigation into clinical applications for psychological disorders, and (3) insufficient control of other variables. Future research should continue to explore vasopressin' s modulatory effects on emotion regulation, learning, and other aspects of human functioning.

Keywords: arginine vasopressin; human social behavior; gender differences

Vasopressin is a neuroendocrine hormone composed of nine amino acids, also known as arginine vasopressin (hereafter referred to as vasopressin). Its structure is highly similar to oxytocin, differing only at the third and eighth amino acid positions (Aspe-Sanchez, Moreno, Rivera, Rossi, & Ewer, 2015). Vasopressin is synthesized in neurons of the paraventricular and supraoptic nuclei of the hypothalamus, transported via the supraopticohypophyseal and paraventriculohypophyseal tracts to the posterior pituitary, and released into the bloodstream to act on the peripheral nervous system, with some projections reaching the central nervous system to influence individual behavior (Caldwell, 2017). Early animal studies demonstrated that vasopressin importantly regulates social behaviors, including mating, parental care, gregariousness, and aggression (Caldwell, 2017; Goodson & Thompson, 2010; Kelly & Goodson, 2014). Over the past decade, advances in research methodology—particularly intranasal administration (Born et al., 2002)—have enabled increasing numbers of researchers to investigate vasopressin's modulatory effects on human social behavior. Through intranasal delivery, vasopressin can bypass the blood-brain barrier and directly affect the central nervous system, thereby influencing behavior (Rutherford et al., 2017; Waller et al., 2015; Yang, Ma, Yang, Zhu, & Wang, 2018). Early animal research found that individuals with low vasopressin levels exhibit social cognitive deficits such as amnesia and inability to learn avoidance behaviors (Lim, Bielsky, & Young, 2005), suggesting that manipulating vasopressin levels could serve as a therapeutic intervention for these disorders. Similar findings have emerged in human studies. For instance, first-episode schizophrenia patients show lower vasopressin concentrations in cerebrospinal fluid compared to healthy populations (Geng et al., 2017), and chronic vasopressin administration can improve memory (Geng et al., 2017) and emotional stimulus processing in schizophrenia patients (Vadas et al., 2017). Therefore, further exploration of

vasopressin' s impact on social functioning may advance clinical treatment of psychological disorders such as anxiety, autism, and depression.

Since information perception and processing—particularly memory—represent the processes through which individuals encode and store environmental information, thereby determining behavioral activity (Ferguson & Bargh, 2004), understanding vasopressin' s effects on social behavior necessitates first examining its role in cognitive processing. Synthesizing current research, we will review vasopressin' s influence on human social behavior across two domains: family relationships and social interaction.

1.1 Auditory Processing and Attention

Early auditory attention experiments revealed that vasopressin affects auditory attentional processes. Using the oddball auditory paradigm, Pietrowsky (1994, 1996) found that intranasal vasopressin increased N2 (Dodt et al., 1994) and P3 amplitudes in response to novel stimuli compared to intranasal placebo (saline). In another attention vigilance task requiring participants to silently count tones presented to the right ear, vasopressin increased vertex potential amplitudes relative to placebo (Fehm-Wolfsdorf, Bachholz, Born, Voigt, & Fehm, 1988). In a dichotic listening paradigm, intranasal vasopressin enhanced N2 amplitudes in response to deviating stimuli (Born, Bothor, Pietrowsky, & Fehm-Wolfsdorf, 1987). These findings collectively indicate that vasopressin increases attentional resource allocation to novel stimuli. Additionally, a study examining emotional word processing required participants to judge whether words (with negative, positive, or neutral valence) exceeded six letters in length. Results showed that vasopressin increased P3 amplitudes in response to emotional compared to neutral words (Naumann, Bartussek, Kaiser, & Fehm-Wolfsdorf, 1991). Together, these studies demonstrate that vasopressin modulates both general cognitive processing and emotional information processing. To further understand vasopressin' s real-world impact, researchers have begun employing ecologically valid stimuli (e.g., emotional faces) and designing various social interaction paradigms.

1.2 Face Recognition and Memory

Research using faces as experimental materials has revealed vasopressin' s influence on visual stimulus processing. In one face recognition task, male participants were first presented with a series of face images, after which new faces were introduced and participants judged whether they "recognized" them (i.e., had seen them previously). Results showed that compared to neutral faces, vasopressin-treated individuals were more likely to judge emotionally intense old faces (e.g., angry, happy) as familiar, suggesting that vasopressin enhances memory for and familiarity with emotional facial information. Another study employed an implicit social cognition judgment task in which participants viewed negative emotional faces (e.g., angry, fearful). Researchers found that compared to familiar faces (presented before the task), unfamiliar faces significantly

activated the left temporoparietal junction; this difference disappeared after vasopressin administration, indicating that vasopressin reduced the differential neural response between familiar and unfamiliar faces (Zink et al., 2011). The left temporoparietal junction is closely associated with theory of mind (Tsoi, Dungan, Waytz, & Young, 2016), and its activation in this study was interpreted as reflecting mental state attribution toward strangers. Vasopressin appears to reduce this motivational process of inferring others' intentions when viewing unfamiliar faces, making neural responses to strangers more similar to those toward familiar individuals. These findings collectively suggest that vasopressin facilitates emotional face processing and memory.

1.3 Social Feedback Processing

Social feedback refers to responses individuals receive from others after performing certain behaviors during social interactions, with outcomes fully or partially contingent on one' s own actions (Zanesco, Tipura, Posada, Clément, & Pegna, 2018). Negative social feedback—receiving negative responses after an action (Achterberg, van Duijvenvoorde, Bakermanskranenburg, & Crone, 2016)—such as receiving an electric shock after performing an action, is closely related to various psychiatric disorders including depression, autism, and anxiety. Such negative feedback can induce negative emotions, stress states, and panic (Weidenfeld, Itzik, & Ovadia, 2015). To examine whether vasopressin can alleviate negative reactions induced by negative social feedback, Gozzi et al. (2017) developed a task including both positive and negative feedback. In the experiment, negative feedback stimuli were presented when participants' reaction times fell below a certain threshold, and positive feedback when they exceeded it. Results showed that negative feedback activated multiple brain regions compared to positive feedback, including the temporoparietal junction (associated with theory of mind), anterior insula and supplementary motor cortex (associated with pain processing), and right fusiform gyrus (associated with visual emotion recognition). However, after vasopressin administration, these regions showed no significant difference in activation between negative and positive feedback, suggesting that vasopressin attenuates neural responses to negative social feedback (Gozzi, Dashow, Thurm, Swedo, & Zink, 2017). This study highlights vasopressin' s potential as a clinical treatment for social anxiety and other psychological disorders.

In summary, research indicates that during face processing, vasopressin enhances memory and recognition of emotional faces and increases familiarity with unfamiliar emotional faces. During social feedback processing, vasopressin reduces neural responses to negative social feedback in brain regions involved in theory of mind and pain processing, suggesting that vasopressin decreases sensitivity/arousal to negative feedback information. These findings demonstrate vasopressin' s important modulatory role in social information processing, which may further influence performance during social interactions. Consequently, scientists have increasingly focused on which human social behaviors vasopressin

affects and how these effects manifest in everyday life.

2.1 Family Relationships

Investigations of vasopressin's impact on social behavior have begun with family relationships, as they represent fundamental social bonds and families constitute the basic units of society (Bott & Spillius, 2014). Research has revealed close associations between vasopressin and both pair bonding/pair relationships and father-child relationships.

2.1.1 Pair Bonding and Sexual Relationships Early animal models demonstrated that vasopressin promotes sexual behavior in males. For example, vasopressin injection increased male prairie voles' approach behavior toward opposite-sex individuals (Winslow, Hastings, Carter, Harbaugh, & Insel, 1993). Similar findings emerged in coppery titi monkeys (*Callicebus cupreus*), where intranasal vasopressin increased males' willingness to approach their female partners (Jarcho, Mendoza, Mason, Yang, & Bales, 2011). Human studies have also linked vasopressin to male pair bonding. A genetic study found that RS3 repeat polymorphism in the arginine vasopressin 1a receptor (AVPR1a) promoter region was significantly associated with pair bonding (measured by the Partner Bonding Scale), with this correlation significant only in male participants (Walum et al., 2008). Using blood measurements, Taylor et al. (2010) found that vasopressin levels in men were positively correlated with relationship anxiety in romantic relationships. Guastella et al. (2011) observed that intranasal vasopressin enhanced processing and recognition of sex-related words in men. Compared to placebo, male participants who received intranasal vasopressin identified their partners' angry expressions more rapidly, suggesting that vasopressin may facilitate men' s responses to partners' negative emotions (Marshall, 2013). A recent study found that men rated unfamiliar female faces as more attractive after vasopressin administration compared to unfamiliar male faces (Price et al., 2017). These findings collectively indicate a close association between vasopressin and male pair bonding/sexual relationships. Functional magnetic resonance imaging studies have shown that when men view female faces, brain regions involved in reward processing—such as the right nucleus accumbens and bilateral lateral septum—are significantly activated, suggesting that vasopressin modulates the reward system' s response to opposite-sex faces, potentially promoting courtship and sexual behavior (Rilling et al., 2017). Beyond sexual relationships, researchers have also examined vasopressin' s role in parent-child relationships and offspring care.

2.1.2 Parent-Child Relationships Studies of fathers with infants under 2.5 years old revealed that urinary vasopressin levels were negatively correlated with infant age, suggesting that vasopressin is involved in facilitating the transition to fatherhood during early infancy (Gray, Parkin, & Samms-Vaughan, 2007). Researchers also found that when fathers watched videos of their children, brain regions associated with social cognition and relationship formation (inferior frontal

gyrus and insula) were activated, and this activation was negatively correlated with peripheral vasopressin levels (measured via blood samples) (Atzil, Hendler, Zagoory-Sharon, Winetraub, & Feldman, 2012). Using intranasal administration, investigators found that expectant fathers showed increased attention to infant-related stimuli, indicating that vasopressin can promote paternal behavior (Cohen-Bendahan, Beijers, van Doornen, & De, 2015). However, another study failed to find behavioral or neural changes in response to infant stimuli after vasopressin administration (Li, Chen, Mascaro, Haroon, & Rilling, 2017). This discrepancy may relate to participant characteristics, as that study used fathers of 1-2-year-old infants who had frequent daily contact with their children and whose caregiving experiences and hormonal levels had already changed (Kim et al., 2014), suggesting that duration of paternal care may be a confounding variable. A recent study administered intranasal vasopressin to unmarried men and had them view emotional infant faces. Results showed that ambiguous emotional infant faces elicited larger LPP amplitudes than clearly emotional faces, suggesting that vasopressin increases attentional allocation to infants with uncertain emotional states, possibly related to protective motivations (Wu, Xu, Luo, & Feng, 2018). Interestingly, individuals who experienced high-quality paternal care during childhood showed higher empathy ratings when viewing videos of painful and pleasurable events after vasopressin administration, indicating greater sensitivity to others' emotional states (Tabak et al., 2015). These findings suggest that vasopressin' s modulatory role in parent-child relationships may be transgenerational: on one hand, vasopressin promotes paternal behavior; on the other, it affects social development in individuals who received quality paternal care during childhood.

Research demonstrates that vasopressin is closely associated with both male sexual and father-child relationships, with vasopressin administration enhancing sexual and paternal behavior in men. These findings align with early animal research. However, human life is more complex and diverse than animal models, leading researchers to increasingly focus on vasopressin' s modulatory role in social interpersonal interactions.

2.2 Social Interaction

2.2.1 Emotional Response and Social Evaluation Studies examining emotional response and social evaluation require participants to rate social characteristics of pictured individuals, such as approachability and attractiveness, thereby simulating real-world nonverbal interactions. Research has revealed vasopressin' s important modulatory role in interpersonal interactions. Thompson (2004, 2006) found that vasopressin modulates emotional responses and social evaluation: intranasal vasopressin induced hostility in men viewing unfamiliar male faces, manifested as unfriendly facial responses (increased corrugator activity) and lower approachability ratings. Similarly, in an emotional face recognition task, intranasal vasopressin reduced accuracy in recognizing emotions from unfamiliar male faces but did not affect recognition of female

faces, suggesting that vasopressin impairs empathy in men responding to other males and triggers tense interpersonal interactions (Uzefovsky, Shalev, Israel, Knafo, & Ebstein, 2012). Using functional magnetic resonance imaging, Zink et al. (2010) found that this negative emotion/hostility induction was mediated by vasopressin' s modulation of functional connectivity and activation between the medial prefrontal cortex and amygdala—specifically, vasopressin reduced medial prefrontal inhibition of the amygdala, resulting in greater amygdala activation and increased negative emotion (Tian, Feng, Feng, Gu, & Luo, 2015).

While most research has focused on male participants, a few studies have included female participants to examine gender effects. Women showed different responses than men at the same dosage and under identical task conditions. For example, Thompson et al. (2006) recorded facial electromyography and behavioral responses, finding that intranasal vasopressin induced hostile/unfriendly responses in men viewing other males (as described above), whereas in women viewing other females, vasopressin elicited friendly facial responses (increased zygomaticus activity) and higher approachability ratings, indicating that vasopressin promotes prosocial behavior among women toward same-sex individuals.

These findings demonstrate vasopressin' s important modulatory role in human social interaction. In emotional response and social evaluation, limited evidence suggests gender-specific effects: vasopressin is associated with hostility perception among men and affiliative interactions among women. These results align with early animal research showing that vasopressin increases aggressive behavior among male rodents (e.g., fighting, biting, chasing) (Caldwell & Albers, 2004), while producing opposite effects in females, reducing defensive aggression (Gutzler, Karom, Erwin, & Albers, 2010) and maternal aggression (Nephew, Byrnes, & Bridges, 2010). Genetic studies provide converging support: Zai et al. (2012) found that the AVPR1b rs35369693 allele was positively associated with childhood aggression, with this correlation stronger in boys (Luppino, Moul, Hawes, Brennan, & Dadds, 2014).

2.2.2 Social Decision-Making Social decision-making refers to decision behaviors individuals make in social contexts based on goals, beliefs, and others' intentions (Yoder & Decety, 2018). Initial findings linking vasopressin to social decision-making were reported by Knafo et al. (2008), who found that AVPR1a gene polymorphism was associated with monetary allocation decisions. In their study, participants' AVPR1a RS3 promoter region repeat polymorphisms were classified as long or short alleles. In a subsequent Dictator Game—in which two participants assume "allocator" and "receiver" roles to divide a sum of money, with receivers only able to accept the allocator' s proposal—individuals with long RS3 alleles tended to allocate more money to others and reported higher levels of prosociality. While this study demonstrated associations between vasopressin receptor genes and social behavior, correlational limitations necessitate additional approaches to further understand vasopressin' s social functions.

Recent studies using intranasal vasopressin administration have provided addi-

tional insights. One of the most commonly used paradigms for studying cooperation is the Prisoner' s Dilemma game, which simulates real-world cooperation and betrayal behaviors. In this task, two participants decide whether to cooperate with each other; mutual cooperation yields monetary rewards for both, while unilateral cooperation results in substantial loss for the cooperator and maximum gain for the defector. Using this paradigm, James (2014) and Feng (2015) found that compared to saline, vasopressin increased mutually beneficial cooperation in men, with enhanced activation in the striatum, basal forebrain, insula, amygdala, and hippocampus. Conversely, women receiving vasopressin were more likely to continue cooperating even after being betrayed (Feng, Hackett, et al., 2015; Feng et al., 2014), suggesting that vasopressin promotes "reconciliation" behaviors in women. During these tasks, activation in the striatum, basal forebrain, insula, amygdala, and hippocampus decreased in women (Feng, Hackett, et al., 2015; Feng et al., 2014). Since these regions are important for reward processing, social relationship formation, arousal, and detection of salient stimuli, these results suggest that vasopressin enhances neural arousal to cooperative rewards in men but not women, thereby promoting continued engagement.

The Taylor Aggression Paradigm is commonly used to study social competition. In this task, two participants compete in a reaction time task, with the loser receiving punishment (e.g., electric shock, noise) from the opponent. When men lost competitions and received punishment, intranasal vasopressin significantly increased activation in the right superior temporal sulcus, suggesting that during competitive activities, vasopressin enhances activation in brain regions associated with mentalizing and appraisal processes, thereby increasing engagement in the current competitive activity (Brunnlieb, Muente, Kraemer, Tempelmann, & Heldmann, 2013).

Risk-taking decisions involve probabilistic positive or negative outcomes following a decision. Recent research has also found that vasopressin affects risk-taking behavior in social contexts. One risk-taking paradigm presents participants with a series of risky activities (e.g., skydiving, jumping) and asks them to choose whether to participate. Choosing not to participate yields no feedback, while participation may result in success or failure. Patel et al. (2015) found that intranasal vasopressin reduced participation in risky activities, interpreted as a defensive self-protective behavior, suggesting that vasopressin promotes environmental adaptation and survival. Brunnlieb et al. (2016) investigated vasopressin' s effects on risky cooperation using a Stag Hunt paradigm, in which mutual cooperation yields maximum rewards (unlike the intermediate rewards in Prisoner' s Dilemma). Consistent with Prisoner' s Dilemma findings, vasopressin increased mutually beneficial cooperation. During these tasks, vasopressin reduced dorsolateral prefrontal cortex activation and enhanced its inhibition of the amygdala. Since the dorsolateral prefrontal cortex is traditionally implicated in risk assessment and cognitive control (Decety, Jackson, Sommerville, Chaminade, & Meltzoff, 2004), these findings suggest that vasopressin reduces risk assessment processes and, through cognitive control, decreases amygdala responses to novel

stimuli (Brunnlieb et al., 2016). The seemingly contradictory conclusions—that vasopressin both decreases and increases risk-taking—likely reflect differences in feedback valence across studies. In Patel et al.' s (2015) study, risk-taking involved personal safety, whereas Brunnlieb et al.' s (2016) study involved monetary gains. Both findings indicate that vasopressin promotes adaptive behavior to maximize safe and comfortable environmental conditions.

In summary, regarding social decision-making, intranasal vasopressin promotes greater engagement in economically motivated (self-interest-related) cooperative activities in men, corresponding to increased neural arousal in regions such as the striatum, basal forebrain, insula, amygdala, and hippocampus. In women, vasopressin promotes behaviors that seek harmonious interpersonal relationships, with corresponding decreases in activation in these same regions. In risk-taking contexts, vasopressin enables individuals to make advantageous decisions based on current circumstances: when decisions involve personal safety, vasopressin promotes risk avoidance; when decisions involve economic gain, vasopressin promotes risk-taking.

3. Summary and Outlook

In conclusion, during social cognition, vasopressin increases attention to novel stimuli, promotes memory for emotional faces, and influences processing of negative social feedback. In social interaction studies, vasopressin effects show gender specificity: in men, vasopressin promotes paternal and sexual behavior, elicits inter-male hostility, and facilitates self-interest-related decisions; in women, vasopressin enhances affiliative behavior and promotes interpersonal reconciliation.

Early animal research established that vasopressin promotes monogamous pair bonding and biparental care, regulating males' preference for mates and offspring (Bamshad, Novak, & Vries, 1993; De Vries, Wang, & Ferris, 1994; Wang, Liu, Young, & Insel, 2000; Wynne-Edwards & Timonin, 2007) and aggression toward other males (Donaldson & Young, 2008). Compelling evidence includes increased pup care frequency in male hamsters following intracerebroventricular vasopressin injection (De Vries et al., 1994) and vasopressin-induced mate approach and same-sex aggression in male prairie voles (Winslow et al., 1993).

Recent human research has yielded findings consistent with animal models. We propose that vasopressin' s promotion of male sexual and paternal behavior, induction of inter-male hostility, and facilitation of self-interested decisions may relate to species-typical motivations for offspring protection and mate guarding. This interpretation is supported by social decision-making research: when cooperation yields greater survival resources, vasopressin promotes male cooperation; otherwise, it does not (Feng, Hackett, et al., 2015; Feng et al., 2014). Conversely, vasopressin' s promotion of prosocial behavior among women (Chen et al., 2016; Feng, Hackett, et al., 2015; Thompson, George, Walton, Orr, & Benson, 2006) may relate to offspring care, as women typically serve as primary caregivers, and

affiliations with other women facilitate offspring rearing. However, research on vasopressin in women remains limited and requires future investigation.

Some researchers propose that vasopressin' s social effects may be largely mediated by anxiety induction, suggesting that anxiety level represents a confounding variable. In the Trier Social Stress Test—a psychological stress protocol designed by Professor Kirschbaum at the University of Trier in which participants undergo interviews and mental arithmetic before three "experts" to elicit behavioral and physiological stress responses—intransal vasopressin increased salivary cortisol and heart rate (Ebstein et al., 2009). Similarly, Thompson et al. (2006) found that intranasal vasopressin increased anxiety states. Therefore, previous findings might simply reflect different anxiety-reduction strategies across contexts. As Taylor' s (2000) evolutionary theory suggests, different social roles and family statuses have led to sex-specific strategies for coping with anxiety and stress being selectively preserved. The "fight-or-flight" response characterizes male reactions to external threats, such as vasopressin-induced hostility toward other men (Thompson et al., 2006) and increased self-interested social behavior (Brunnlieb et al., 2016; Feng, Hackett, et al., 2015). In contrast, women respond to external threats by forming alliances with other women, which helps avoid danger and provide safe environments for offspring. The gender differences we have summarized in vasopressin' s effects on emotional response, social evaluation, and social decision-making provide some support for this evolutionary framework.

This research field remains in its early stages, with several critical issues requiring resolution:

First, the vast majority of vasopressin studies have used male participants. This stems partly from early animal research showing primary effects on male social behavior (Young, Murphy Young, & Hammock, 2005) and partly from the methodological challenge of controlling for menstrual cycle effects on female hormone levels (Champagne, Diorio, Sharma, & Meaney, 2001). Future research should control for and avoid such confounding variables.

Second, although vasopressin is closely associated with numerous psychiatric disorders—evidenced by links between vasopressin V1b receptor gene (AVPR1B) and childhood mood disorders (Dempster et al., 2007; Malik et al., 2014), panic disorder (Kreek, Zhou, & Levran, 2011), schizophrenia (Golimbet, Alfimova, Abramova, Kaleda, & Gritsenko, 2015), and autism (S. Y. Yang et al., 2017)—its therapeutic applications remain preliminary. Most current research uses healthy participants; future studies should focus more on psychiatric populations to explore whether vasopressin can alleviate symptom burden.

Third, vasopressin' s effects are modulated by additional factors. Hormone dosage produces different effects, with high and low doses yielding distinct outcomes (Zhu et al., 2010), requiring careful consideration in future research. Additionally, personality traits and individual differences matter: Feng et al. (2015) found that vasopressin' s cooperation-promoting effects were moderated by neu-

roticism, and vasopressin' s empathy-enhancing effects were observed only in individuals who received high-quality paternal care during childhood (Tabak et al., 2015). These results indicate that vasopressin' s neuropharmacological mechanisms are influenced by individual differences that should be considered in future research.

Finally, this field remains nascent, and subsequent studies should continue exploring vasopressin' s influence on other aspects of human social behavior, including emotion regulation, learning, and memory. Additionally, to enhance ecological validity, future research should consider using hyperscanning technology to examine vasopressin' s modulatory effects during real-life interactions, thereby advancing our understanding of vasopressin' s social functions.

References

Achterberg, M., van Duijvenvoorde, A. C., Bakermanskranenburg, M. J., & Crone, E. A. (2016). Control your anger! The neural basis of aggression regulation in response to negative social feedback. *Social cognitive and affective neuroscience, 11*(5), 712–720.

Aspe-Sanchez, M., Moreno, M., Rivera, M. I., Rossi, A., & Ewer, J. (2015). Oxytocin and Vasopressin Receptor Gene Polymorphisms: Role in social and psychiatric traits. *Frontiers in neuroscience, 9*, 510.

Atzil, S., Hendler, T., Zagoory-Sharon, O., Winetraub, Y., & Feldman, R. (2012). Synchrony and specificity in the maternal and the paternal brain: relations to oxytocin and vasopressin. *Journal of the American Academy of Child and Adolescent Psychiatry, 51*(8), 798–811.

Bamshad, M., Novak, M. A., & Vries, G. J. (1993). Sex and species differences in the vasopressin innervation of sexually naive and parental prairie voles, microtus ochrogaster and meadow voles, microtus pennsylvanicus. *Journal of neuroendocrinology, 5*(3), 247–255.

Born, Bothor, Pietrowsky, & Fehm-Wolfsdorf. (1987). Influences of vasopressin and oxytocin on human event-related brain potentials in an attention task. *Journal of Psychophysiology, 1*(4), 311–322.

Born, Lange, T., Kern, W., McGregor, G. P., Bickel, U., & Fehm, H. L. (2002). Sniffing neuropeptides: a transnasal approach to the human brain. *Nature neuroscience, 5*(6), 514.

Bott, E., & Spillius, E. B. (2014). *Family and social network: Roles, norms and external relationships in ordinary urban families*. Routledge.

Brunnlieb, Muente, T. F., Kraemer, U., Tempelmann, C., & Heldmann, M. (2013). Vasopressin modulates neural responses during human reactive aggression. *Social neuroscience, 8*(2), 164–177.

Brunnlieb, Nave, G., Camerer, C. F., Schosser, S., Vogt, B., Münte, T. F., &

Heldmann, M. (2016). Vasopressin increases human risky cooperative behavior. *Proceedings of the National Academy of Sciences, 113*(8), 2051.

Caldwell. (2017). Oxytocin and vasopressin: powerful regulators of social behavior. *The Neuroscientist, 23*(5), 517-528.

Caldwell, & Albers, H. E. (2004). Effect of photoperiod on vasopressin-induced aggression in syrian hamsters. *Hormones and behavior, 46*(4), 444-449.

Champagne, F., Diorio, J., Sharma, S., & Meaney, M. J. (2001). Naturally occurring variations in maternal behavior in the rat are associated with differences in estrogen-inducible central oxytocin receptors. *Proceedings of the National Academy of Sciences, 98*(22), 12736-12741.

Chartrand, T. L., & Bargh, J. A. (1999). The chameleon effect: the perception-behavior link and social interaction. *Journal of personality and social psychology, 76*(6), 893.

Chen, X., Hackett, P. D., DeMarco, A. C., Feng, C., Stair, S., Haroon, E., ··· Rilling, J. K. (2016). Effects of oxytocin and vasopressin on the neural response to unreciprocated cooperation within brain regions involved in stress and anxiety in men and women. *Brain imaging and behavior, 10*(2), 581-593.

Cohen-Bendahan, C. C., Beijers, R., van Doornen, L. J., & De, W. C. (2015). Explicit and implicit caregiving interests in expectant fathers: Do endogenous and exogenous oxytocin and vasopressin matter? *Infant Behavior and Development, 41*, 26-37.

De Vries, G., Wang, Z., & Ferris, C. (1994). The role of septal vasopressin innervation in paternal behavior in prairie voles (*Microtus ochrogaster*). *Proceedings of the National Academy of Sciences, 91*, 400-404.

Decety, J., Jackson, P. L., Sommerville, J. A., Chaminade, T., & Meltzoff, A. N. (2004). The neural bases of cooperation and competition: an fMRI investigation. *Neuroimage, 23*(2), 744-751.

Dempster, E. L., Burcescu, I., Wigg, K., Kiss, E., Baji, I., Gadoros, J., ···Kovacs, M. (2007). Evidence of an association between the vasopressin V1b receptor gene (AVPR1B) and childhood-onset mood disorders. *Archives of general psychiatry, 64*(10), 1189-1195.

Dodt, C., Pietrowsky, R., Sewing, A., Zabel, A., Fehm, H. L., & Born, J. (1994). Effects of vasopressin on event-related potential indicators of cognitive stimulus processing in young and old humans. *Journal of gerontology, 49*(4), M183-M188.

Donaldson, Z. R., & Young, L. J. (2008). Oxytocin, vasopressin, and the neurogenetics of sociality. *Science, 322*(5903), 900-904.

Ebstein, R. P., Israel, S., Lerer, E., Uzefovsky, F., Shalev, I., Gritsenko, I., ··· Yirmiya, N. (2009). Arginine vasopressin and oxytocin modulate human social behavior. *Annals of the New York Academy of Sciences, 1167*(1), 87-102.

Fehm-Wolfsdorf, G., Bachholz, G., Born, J., Voigt, K., & Fehm, H. L. (1988). Vasopressin but not oxytocin enhances cortical arousal: an integrative hypothesis on behavioral effects of neurohypophyseal hormones. *Psychopharmacology, 94*(4), 496–500.

Feng, C., Demarco, A. C., Haroon, E., & Rilling, J. K. (2015). Neuroticism modulates the effects of intranasal vasopressin treatment on the neural response to positive and negative social interactions. *Neuropsychologia, 73*, 108–115.

Feng, C., Hackett, P. D., DeMarco, A. C., Chen, X., Stair, S., Haroon, E., ··· Rilling, J. K. (2015). Oxytocin and vasopressin effects on the neural response to social cooperation are modulated by sex in humans. *Brain imaging and behavior, 9*(4), 754–764.

Feng, C., Li, W., Tian, T., Luo, Y., Gu, R., Zhou, C., & Luo, Y.-j. (2014). Arousal modulates valence effects on both early and late stages of affective picture processing in a passive viewing task. *Social neuroscience, 9*(4), 364–377.

Ferguson, M. J., & Bargh, J. A. (2004). How social perception can automatically influence behavior. *Trends in cognitive sciences, 8*(1), 33–39.

Geng, C.-H., Wang, C., Yang, J., Wang, H., Ma, R.-Q., Liu, X., & Wang, C.-H. (2017). Arginine vasopressin improves the memory deficits in Han Chinese patients with first-episode schizophrenia. *Peptides, 97*, 8–15.

Golimbet, V., Alfimova, M., Abramova, L., Kaleda, V., & Gritsenko, I. (2015). Arginine vasopressin 1a receptor RS3 promoter microsatellites in schizophrenia: a study of the effect of the "risk" allele on clinical symptoms and facial affect recognition. *Psychiatry research, 225*(3), 739–742.

Goodson, J. L., & Thompson, R. R. (2010). Nonapeptide mechanisms of social cognition, behavior and species-specific social systems. *Current Opinion in Neurobiology, 20*(6), 784–794.

Gozzi, M., Dashow, E. M., Thurm, A., Swedo, S. E., & Zink, C. F. (2017). Effects of oxytocin and vasopressin preferential brain responses negative social feedback. *Neuropsychopharmacology, 42*(7), 1409.

Gray, P. B., Parkin, J., & Samms-Vaughan, M. (2007). Hormonal correlates of human paternal interactions: A hospital-based investigation in urban Jamaica. *Hormones and Behavior, 52*(4), 499–507.

Guastella, A. J., Kenyon, A. R., Unkelbach, C., Alvares, G. A., & Hickie, I. B. (2011). Arginine Vasopressin selectively enhances recognition of sexual cues in male humans. *Psychoneuroendocrinology, 36*(2), 294–297.

Gutzler, S. J., Karom, M., Erwin, W., & Albers, H. (2010). Arginine-vasopressin and the regulation of aggression in female Syrian hamsters (*Mesocricetus auratus*). *European Journal of Neuroscience, 31*(9), 1655–1663.

Jarcho, M., Mendoza, S., Mason, W., Yang, X., & Bales, K. (2011). Intranasal vasopressin affects pair bonding and peripheral gene expression in male *Callicebus cupreus*. *Genes, Brain and Behavior, 10*(3), 375–383.

Kelly, A. M., & Goodson, J. L. (2014). Hypothalamic oxytocin and vasopressin neurons exert sex-specific effects on pair bonding, gregariousness, and aggression in finches. *Proceedings of the National Academy of Sciences, 111*(16), 6069–6074.

Kim, P., Rigo, P., Mayes, L. C., Feldman, R., Leckman, J. F., & Swain, J. E. (2014). Neural plasticity in fathers of human infants. *Social neuroscience, 9*(5), 522–535.

Knafo, A., Israel, S., Darvasi, A., Bachner-Melman, R., Uzefovsky, F., Cohen, L., ···Raz, Y. (2008). Individual differences in allocation of funds in the dictator game associated with length of the arginine vasopressin 1a receptor RS3 promoter region and correlation between RS3 length and hippocampal mRNA. *Genes, Brain and Behavior, 7*(3), 266–275.

Kreek, M. J., Zhou, Y., & Levran, O. (2011). Functions of arginine vasopressin and its receptors: importance of human molecular genetics studies in bidirectional translational research. *Biological psychiatry, 70*(6), 502.

Li, Chen, Mascaro, Haroon, & Rilling. (2017). Intranasal oxytocin, but not vasopressin, augments neural responses to toddlers in human fathers. *Hormones and behavior, 93*, 193–202.

Lim, M. M., Bielsky, I. F., & Young, L. J. (2005). Neuropeptides and the social brain: potential rodent models of autism. *International Journal of Developmental Neuroscience, 23*(2-3), 235–243.

Luppino, D., Moul, C., Hawes, D. J., Brennan, J., & Dadds, M. R. (2014). Association between a polymorphism of the vasopressin 1B receptor gene and aggression in children. *Psychiatric genetics, 24*(5), 185–190.

Malik, A. I., Zai, C. C., Berall, L., Abu, Z., Din, F., Nowrouzi, B., ···Beitchman, J. H. (2014). The role of genetic variants in genes regulating the oxytocin–vasopressin neurohumoral system in childhood-onset aggression. *Psychiatric genetics, 24*(5), 201–210.

Marshall. (2013). Posttraumatic stress disorder and partner-specific social cognition: a pilot study of sex differences in the impact of arginine vasopressin. *Biological psychology, 93*(2), 296–303.

Naumann, E., Bartussek, D., Kaiser, W., & Fehm-Wolfsdorf, G. (1991). Vasopressin and cognitive processes: two event-related potential studies. *Peptides, 12*(6), 1379–1384.

Nephew, B. C., Byrnes, E. M., & Bridges, R. S. (2010). Vasopressin mediates enhanced offspring protection in multiparous rats. *Neuropharmacology, 58*(1), 102–106.

Patel, N., Grillon, C., Pavletic, N., Rosen, D., Pine, D. S., & Ernst, M. (2015). Oxytocin and vasopressin modulate risk-taking. *Physiology & behavior, 139*, 254–260.

Pietrowsky, R., Strüben, C., Mölle, M., Fehm, H. L., & Born, J. (1996). Brain potential changes after intranasal vs. intravenous administration of vasopressin: evidence for a direct nose-brain pathway for peptide effects in humans. *Biological psychiatry, 39*(5), 332–340.

Price, D., Burris, D., Cloutier, A., Thompson, C. B., Rilling, J. K., & Thompson, R. R. (2017). Dose-dependent and lasting influences of intranasal vasopressin on face processing in men. *Frontiers in Endocrinology, 8*, 220.

Rilling, J. K., Li, T., Chen, X., Gautam, P., Haroon, E., & Thompson, R. R. (2017). Arginine vasopressin effects on subjective judgments and neural responses to same and other-sex faces in men and women. *Frontiers in Endocrinology, 8*, 200.

Rutherford, H. J., Guo, X. M., Graber, K. M., Hayes, N. J., Pelphrey, K. A., & Mayes, L. C. (2017). Intranasal oxytocin and the neural correlates of infant face processing in non-parent women. *Biological psychology, 129*, 45–48.

Tabak, B. A., Meyer, M. L., Castle, E., Dutcher, J. M., Irwin, M. R., Han, J. H., ···Eisenberger, N. I. (2015). Vasopressin, but not oxytocin, increases empathic concern among individuals who received higher levels of paternal warmth: A randomized controlled trial. *Psychoneuroendocrinology, 51*, 253–261.

Taylor, S. E., Saphirebernstein, S., & Seeman, T. E. (2010). Are plasma oxytocin in women and plasma vasopressin in men bio markers of distressed pairbond relationships? *Psychological Science, 21*(1), 3–7.

Thompson, R., Gupta, S., Miller, K., Mills, S., & Orr, S. (2004). The effects of vasopressin on human facial responses related to social communication. *Psychoneuroendocrinology, 29*(1), 35–48.

Thompson, R. R., George, K., Walton, J. C., Orr, S. P., & Benson, J. (2006). Sex-specific influences of vasopressin on human social communication. *Proceedings of the National Academy of Sciences, 103*(20), 7889–7894.

Tian, T., Feng, X., Feng, C., Gu, R., & Luo, Y.-J. (2015). When rapid adaptation paradigm is not too rapid: evidence of face-sensitive N170 adaptation effects. *Biological psychology, 109*, 53–60.

Tsoi, L., Dungan, J., Waytz, A., & Young, L. (2016). Distinct neural patterns of social cognition for cooperation versus competition. *Neuroimage, 137*, 86–96.

Uzefovsky, F., Shalev, I., Israel, S., Knafo, A., & Ebstein, R. P. (2012). Vasopressin selectively impairs emotion recognition in men. *Psychoneuroendocrinology, 37*(4), 576–580.

Vadas, L., Bloch, B., Levin, R., Shalev, I., Israel, S., Uzefovsky, F., ···Kremer, I. (2017). Sex-specific effect of intranasal vasopressin, but not oxytocin,

on emotional recognition and perception in schizophrenia patients. *European Psychiatry, 41*, S387-S388.

Waller, C., Wittfoth, M., Fritzsche, K., Timm, L., Wittfoth-Schardt, D., Rottler, E., ···Gündel, H. (2015). Attachment representation modulates oxytocin effects on the processing of own-child faces in fathers. *Psychoneuroendocrinology, 62*, 27-35.

Walum, H., Westberg, L., Henningsson, S., Neiderhiser, J. M., Reiss, D., Igl, W., ···Eriksson, E. (2008). Genetic variation in the vasopressin receptor 1a gene (AVPR1A) associates with pair-bonding behavior in humans. *Proceedings of the National Academy of Sciences, 105*(37), 14153-14156.

Wang, Z., Liu, Y., Young, L., & Insel, T. (2000). Hypothalamic vasopressin gene expression increases in both males and females postpartum in a biparental rodent. *Journal of neuroendocrinology, 12*(2), 111-120.

Weidenfeld, J., Itzik, A., & Ovadia, H. (2015). Electrical stimulation of the amygdala modifies the negative feedback effect of glucocorticoids on the adrenocortical responses to stress. *Neuroimmunomodulation, 22*(6), 394-399.

Winslow, J. T., Hastings, N., Carter, C. S., Harbaugh, C. R., & Insel, T. R. (1993). A role for central vasopressin in pair bonding in monogamous prairie voles. *Nature, 365*(6446), 545-548.

Wu, X., Xu, P., Luo, Y., & Feng, C. (2018). Differential effects of intranasal vasopressin on the processing of adult and infant cues: an ERP study. *Frontiers in Human Neuroscience, 12*, 329.

Wynne-Edwards, K. E., & Timonin, M. E. (2007). Paternal care in rodents: weakening support for hormonal regulation of the transition to behavioral fatherhood in rodent animal models of biparental care. *Hormones and behavior, 52*(1), 114-121.

Yang, F.-J., Ma, L., Yang, J., Zhu, Z.-L., & Wang, C.-H. (2018). Intranasal Vasopressin Relieves Orthopedic Pain After Surgery. *Pain Management Nursing, S1524-9042*(17), 30298-30299.

Yang, S. Y., Kim, S. A., Hur, G. M., Park, M., Park, J.-E., & Yoo, H. J. (2017). Replicative genetic association study between functional polymorphisms in AVPR1A and social behavior scales of autism spectrum disorder in the Korean population. *Molecular Autism, 8*(1), 44.

Yoder, K. J., & Decety, J. (2018). The neuroscience of morality and social decision-making. *Psychology, Crime & Law, 24*(3), 279-295.

Young, L. J., Murphy Young, A. Z., & Hammock, E. A. (2005). Anatomy and neurochemistry of the pair bond. *Journal of Comparative Neurology, 493*(1), 51-57.

Zai, C. C., Muir, K. E., Nowrouzi, B., Shaikh, S. A., Choi, E., Berall, L., ··· Kennedy, J. L. (2012). Possible genetic association between vasopressin receptor

1B and child aggression. *Psychiatry research, 200*(2-3), 784-788.

Zanesco, J., Tipura, E., Posada, A., Clément, F., & Pegna, A. J. (2018). Seeing is believing: Early perceptual brain processes are modified by social feedback. *Social Neuroscience, 1-11.

Zhu, X.-r., Zhang, H.-j., Wu, T.-t., Luo, W.-b., & Luo, Y.-j. (2010). Emotional conflict occurs at an early stage: Evidence from the emotional face-word Stroop task. *Neuroscience Letters, 478*(1), 1-4.

Zink, Kempf, L., Hakimi, S., Rainey, C., Stein, J., & Meyer-Lindenberg, A. (2011). Vasopressin modulates social recognition-related activity in the left temporoparietal junction in humans. *Translational psychiatry, 1*(4), e3.

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