HORMONAL CONTAGION:

PHYSIOLOGICAL COVARIATION

BETWEEN FRIENDS

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Abstract: Friendships constitute important relationships, and often function to reduce stress, but have been understudied. While engaging in co-ruminations, close female friends are adrenocortically attuned. In mother-child dyads, infants coordinate their stress response with their caregivers without experiencing the stressor themselves. The current study used a modified version of the Trier Social Stress Test to examine whether i) female friends (101 dyads) are physiologically attuned (i.e., cortisol and progesterone); ii) attunement differs as a function of social acceptance or rejection external to the dyad; and, iii) friends can 'catch' a stress response only through non-verbal cues. Friends showed both cortisol and progesterone attunement at the beginning of the study. Friends showed cortisol attunement across time and conditions. Friends' progesterone levels were significantly, but negatively associated across time and conditions. Friends did not, however, show a stress contagion as a result of one friend experiencing stress. These findings suggest that cortisol and progesterone play different roles in the attunement of stress and subsequent affiliation.

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CHAPTER I

INTRODUCTION

Navigating social challenges, such as those involved in opportunities for social gain or loss, reliably activates the hypothalamic-pituitary-adrenal (HPA) axis, spurring the release of its primary glucocorticoid product, cortisol (Nesse & Young, 2000; Sapolsky, Romero, & Munck, 2000). Close relationships can function to up-or down-regulate HPA activity, thereby influencing biobehavioral responses to social challenges (Del Giudice, Ellis, & Shirtcliff, 2011). For girls and women, same-sex close friends are essential sources of social support, particularly for coping with psychosocial stressors (Rose & Rudolph, 2006; Taylor et al., 2000). In these relationships, intimacy is typically established through dyadic self-disclosure followed by empathy and validation of emotions, particularly negative emotions (Benenson, & Christakos, 2003; Byrd-Craven, Geary, Rose, & Ponzi, 2008; Rose, 2002). This creates an avenue whereby women are more vulnerable to relationship distress, even if the distress is not their own (Rose, Glick, Smith, Schwartz-Mette, & Borowski, 2017). There is also evidence of bi-directional stress system coordination between friends during the process of seeking social support for psychosocial challenges (Rankin, Swearingen-Stanborough, Granger, & Byrd-Craven,

2018). Thus, female friendships can be characterized by somewhat of a paradox in that they can function to buffer stress but can also serve as sources of negative emotion contagion and shared distress.

The verbal exchange of information may not be necessary for all relationships to evoke physiological attunement, sometimes known as interpersonal concordance or co-regulation. Waters, West, and Mendes (2014) demonstrated that when mothers experienced a stressful positive evaluation task, a stressful negative evaluation task, or a non-stress control task, infants' physiological responses reflected their mother's reactivity to the stress manipulation. These findings are remarkable given that the infants and mothers were separated for the stressor task, thus the infants did not have any direct knowledge of their mother's experiences. The infants were likely relying on non-verbal behavioral cues to assess their mother's emotional and physiological distress.

Mother-infant pairs in which the mother experienced negative evaluation (i.e., social rejection) showed the most robust physiological coordination (Waters et al., 2014), suggesting that loss of social support may be particularly important to monitor for these dyads. They also found that infants of mothers who experienced evaluation, positive or negative, showed more stranger avoidance compared with infants whose mothers were in the control condition. Taken together, these results provide evidence that one function of physiological coordination in close relationships is to help to inform the individual about the nature of the psychosocial environment (Waters et al., 2014; Waters, West, Karnilowicz, & Mendes, 2017).

Given this, I sought to determine the mechanism(s) by which physiological coordination occurs within close female friendships. In other words, are friends as attuned to

each other's physiological states as infants are with their mothers? Is a verbal exchange of information a necessity for establishing physiological coordination? Building off of Taylor and colleagues' seminal tend-and-befriend model of female friendships (Taylor et al., 2000), I examined the role of hormones that help regulate affiliation, such as progesterone, in the process of coordinating HPA responses.

CHAPTER II

REVIEW OF LITERATURE

Friendship Dynamics and Stress Physiology

Human social life is ripe with opportunities for social gains (e.g., acceptance) or loss (e.g., rejection), suggesting there is an advantage for a flexible and adaptable stress response system to meet these challenges (Del Giudice et al., 2011; Dickerson, & Kemeny, 2004; Flinn, 2006). According to Taylor's Tend-and-Befriend model, same-sex friendships in girls and women are predicted to function, at least in part, to cope with psychosocial stressors (Taylor et al., 2000; Taylor, 2006). Self-disclosing personal information and emotions in the context of a close friendship are associated with resistance to the negative effects of stress (Uchino, Uno, & Holt-Lunstad, 1999), and this behavior is much more common in female same-sex friendships than in males (Gore & Colten, 1991; Rose & Rudolph, 2006).

According to the Tend-and-Befriend model, affiliative tendencies (e.g., self-disclosure, maintaining physical proximity) under stress are predicted to be mediated by oxytocin and dopaminergic systems. Positive social contact resulting from affiliative efforts is associated with reduced HPA axis and autonomic nervous system activity. This stress-reduction suggests social support buffers the stress response, possibly by providing

solutions and/or an ally in tackling psychosocial challenges. Negative social contacts, on the other hand, are associated with exacerbation of the stress response, similar to unpredictable parent-child relationships. This exacerbation of the stress response suggests social support is paramount in regulating the stress response, at least in women. Further, the tendency to engage in tending-and-befriending behaviors under duress (Nickels, Kubicki, & Maestripieri, 2017; Turton & Campbell, 2005) may explain why girls and women appear to be more resilient to stress (Taylor, 2006).

Progesterone

One hormone that interacts with cortisol is progesterone. Progesterone is a steroid and sex hormone involved in the menstrual cycle and pregnancy. Like cortisol, progesterone, and allopregnanolone, a neuroactive metabolite of progesterone, are released during stress (Fortuyn, et al., 2004; Herrera, Nielsen, & Mather, 2016), though it is unclear if progesterone and allopregnanolone have a suppressing effect on the HPA axis (Childs, Van Dam, & Wit, 2010; Stephens, Mahon, McCaul, & Wand, 2016; Gaffey & Wirth, 2014).

Social rejection, but not acceptance, produces a reliable cortisol response, especially for females (Blackhart, Eckel, & Tice, 2007; Clauss & Byrd-Craven, 2019; Stroud, Papandonatos, D'Angelo, Brush, & Lloyd-Richardson, 2017; Stroud, et al., 2002). Wirth and Schultheiss (2006) used film segments as manipulations and found that the fear of rejection (i.e., film clip to arouse avoidance-based affiliation motivation; *A.I.*), was associated with progesterone and cortisol increase. Contrary to previous work (Schultheiss, Wirth, & Stanton, 2004), progesterone did not increase following the approach affiliation condition (i.e., film clip to arouse hope of closeness; *The Bridges of*

Madison County), but one's baseline affiliation motivation predicted an increase in progesterone in the approach affiliation condition (Wirth & Schultheiss, 2006).

There are mixed findings regarding whether progesterone is associated with social rejection (Gaffey & Wirth, 2014; Maner, Miller, Schmidt, & Eckel, 2010; Seidel et al., 2013), but there does seem to be agreement that one of progesterone's main roles is in facilitating social affiliative motives (Brown et al., 2009; Schultheiss et al., 2004). Brown and colleagues (2009) had dyads of strangers either participate in a closeness induction task or a neutral task. Individuals engaged in the closeness induction task had higher levels of progesterone compared to those in the neutral task. Progesterone either remained constant or increased for those in the closeness induction task but decreased for those engaged in the neutral task. Although progesterone increases did not predict altruistic motivation during session one, at session two (one week later) progesterone increases from session one led to an increased willingness to sacrifice for the partner regardless of condition. Cortisol was also studied but did not affect the condition nor willingness to sacrifice.

Using a modified version of the Trier Social Stress Test (TSST), Duffy et al. (2017) examined progesterone and cortisol simultaneously. Participants were either socially rejected or accepted; further, participants either had an opportunity to reaffiliate by either conducting the TSST face-to-face or behind a barrier or did not. They found that rejection leads to higher cortisol levels and acceptance led to higher progesterone levels; face-to-face and individual differences moderated these results (i.e., higher rejection sensitivity and social anxiety is associated with increases in progesterone in the face-to-face condition but decreases in progesterone in the blocked condition; Duffy et al., 2017).

Maner and colleagues (2010) also found individuals high in social anxiety showed progesterone decreases following social exclusion, whereas those high in rejection sensitivity showed increases in progesterone, suggesting an increase in affiliative motivations.

Attunement

Attunement (i.e., synchrony) is when two (or more) individuals are synchronized either behaviorally (e.g., social gaze; Feldman, 2007) and/or physiologically (e.g., similar heart rates, levels of cortisol, etc.). Attunement is theorized to be the physiological manifestation of a dyad's shared emotional and behavioral experiences (Feldman, 2007). Most of the current literature has focused on parenting and romantic relationships. In general, physiological attunement is typically assessed by correlations between a dyad's scores (e.g., heart rate, skin variance, cortisol, etc.). Mothers and their children are attuned (i.e., interbeat interval series cardiovascular) moment-by-moment when interacting, but not when they were not interacting (Suveg, Shaffer, & Davis, 2016) and are most strongly adrenocortically attuned during challenges (e.g., a cognitive assessment; Ruttle, Serbin, Stack, Schwartzman, & Shirtcliff, 2011).

Attunement extends to other close relationships as well. In early romantic relationships, supportive behaviors such as reassuring, encouraging, and expressing love are associated with stronger adrenocortical attunement (Ha, Yeung, Rogers, Poulsen, Kornienko, & Granger, 2016). Thus, even in a relatively short amount of time (e.g., newly dating couples), attunement appears to play an important role in romantic relationships.

For older adult couples (i.e., between the ages 60 and 70; married at least 35 years), marital interaction is less physiologically arousing, and negative affect is associated with higher levels of physiological arousal compared to middle-aged couples (i.e., between the ages 40 and 50; married at least 15 years; Levenson, Carstensen, & Gottman, 1994). Moreover, marital interaction for men and not women garnered a physiological response (e.g., interbeat intervals, skin conductance; Levenson et al., 1994). For romantic relationships, physiological attunement has been associated with a variety of outcomes such as relationship satisfaction (Levenson & Gottman, 1983; Liu, Rovine, Cousino Klein, & Almeida, 2013), sexual satisfaction (Freihart & Meston, 2019), divorce outcomes (Gottman & Levenson, 2000), and time spent together (Papp, Pendry, Simon, & Adam, 2013; for review see Timmons, Margolin, & Saxbe, 2015).

Taken together these findings show that across relationship types, whether that be familial or romantic, physiological attunement is a key indicator of relationship dynamics. As with the stress response and thus physiological arousal in general, physiological attunement may work as a cue that something challenging and/or important is occurring. For physiological attunement specifically, the cue is something challenging is occurring within our relationships and/or to those individuals important to us. For example, while engaging in a conflict (Cook, 2020; Nelson, Laurent, Bernstein, & Laurent, 2017) or a cognitive assessment (Ruttle, et al., 2011).

Although being physiologically attuned can be an index of positive relationship quality and long-term positive outcomes, it may also come at a cost. Some costs include initiating a stress response when otherwise it would not be necessary and exacerbating a stress response during an already stressful time (e.g., conflict). Given the most salient

stressors and buffers are our relationships, being attuned to our closest allies (e.g., mother, partner, etc.) is critical. Yet, the physiological attunement literature has surprisingly overlooked another key relationship, friendship.

Within friendships, friends are similar to one another on a variety of outcomes including alcohol misuse, autistic traits, anxiety, and depression (Bolis, Lahnakoski, Seidel, Tamm, & Schilbach, 2021; Conway, Rancourt, Adelman, Burk, & Prinstein, 2011; Giletta, et al., 2011, 2012; Prinstein, 2007; Schwartz-Mette & Rose, 2012). These similarities are particularly salient for females (Conway, et al., 2011; Giletta, et al., 2012; Prinstein, 2007). One possible avenue by which friends are catching each other's depression and anxiety, then, may be through co-rumination (i.e., excessive problem discussion; Schwartz-Mette & Rose, 2012; Schwartz-Mette & Smith, 2018).

Although the friendship and peer literatures are rich with regards to similarities, few have focused on physiological attunement. Rankin et al. (2018) established that, when late adolescent close female friends engage in co-rumination, they are adrenocortically attuned. Further, when close friends enter the lab, they are adrenocortically attuned, suggesting that the typical pattern for friends engaging with each other in daily life is to be physiologically attuned (Rankin et al., 2018). Cook (2020) replicated the findings that close friends are physiologically attuned such that close female friends in late adolescence were attuned in their negative and positive affect, cortisol, and salivary alpha-amylase while engaging in a conflict interaction task.

The Current Study

The goal of the current study is to better understand the role of the attunement of the HPA and hypothalamic-pituitary-gonadal (HPG) axes within female friendships in

coping with psychosocial stressors. The focus is on females because they are, on average, more susceptible than males to their friend's emotional states (Magen & Konasewich, 2011) and more likely to engage in friendship behavior (e.g., co-rumination; Rose, 2002) that increase their likelihood of 'catching' internalizing symptoms (e.g., depression and anxiety; Schwartz-Mette & Rose, 2012). Thus far, the majority of research done in adults or older children on the contagious effects of emotions allow individuals to communicate verbally. This study examines contagion and attunement following nonverbal interactions using a non-invasive multi-system approach to assess salivary cortisol and salivary progesterone.

The current study had one friend complete the modified version of the TSST. The purpose of this was to have the dyad become unattuned when the friend in the stressor condition became stressed and the friend in the control condition did not react to the control task. Once the dyad became unattuned, this would be able to establish stress contagion if they became reattuned. Specifically, the current study examined whether i) close friends are physiologically attuned via cortisol and progesterone; ii) attunement differs as a function of social acceptance or rejection external to the dyad; and iii) close friends can 'catch' a stress response to social acceptance and/or rejection through only non-verbal cues.

Close friends are predicted to detect these changes and coordinate their physiology accordingly (e.g., attune to them). Specifically, I predict that friends will have greater adrenocortical attunement in the rejection condition and greater progesterone attunement in the acceptance condition. Moreover, Friend 2's cortisol levels are expected to increase when their friend receives social rejection, and Friend 2's progesterone levels are

expected to increase when their friend receives acceptance, suggesting close friends can "catch" hormonal responses to social feedback occurring outside the dyad.

CHAPTER III

METHODOLOGY

Participants

Based on power estimations for dyadic studies (Kenny, Kashy, & Cook, 2006), 30 dyads were needed per condition. There were three between-subjects conditions. I recruited 101 dyads in total. Eight dyads were excluded due to missing data (e.g., not enough saliva) and one dyad was excluded because they had a friendship with the research assistant who was the judge. This left 32 dyads in the positive evaluation condition, 30 dyads in the negative evaluation condition, and 30 dyads in the neutral (control) condition.

Participants were 184 undergraduate women (92 friendship dyads; M_{age} = 18.94, SD = 1.97 years, range 18 to 37; 69.4% White, non-Hispanic, 8.2% Native American or Native Alaskan, 8.2% Multiracial, 5.5% Hispanic, 4.4% Black, and 3.3% Asian). All dyads included adult (18+) females indicating that they were "best" or "close" friends. Participants were recruited from the psychology subject pool at Oklahoma State University and received partial course credit for their time. The close friend who signed up received course credit, but if both wanted course credit, they both received it. All participants completed informed consent before beginning the study, and the study was

reviewed and approved by the Institutional Review Board at Oklahoma State University (See Appendix A).

Procedure

Session 1

To habituate participants to the lab, both participants completed a survey (e.g., friendship satisfaction) on a computer in the lab. The computers were set up so that the participants are sitting across from one another, facing each other with the backs of their computer screens touching so that they could not see each other's computer screen.

Session 2

Session two took place two days later at the same scheduled time (for example, if participants sign up for Monday at 2:00 p.m., the second session was Wednesday at 2:00 p.m.) with the same research assistant from Session 1. Data collection occurred between 10 a.m. and 5 p.m. to avoid the sharp rise and fall in cortisol levels in the morning due to the diurnal rhythm of HPA activity. During Session 2 both participants (i) completed a health screener; (ii) completed a talking discussion task (i.e., "Please talk to your friend about your favorite TV show or movie."). Participants were not monitored and were free to discuss. This task aimed to give them time to interact together (10 minutes). They then provided saliva samples (Time 1). Friend 1 then participated in a modified version of the TSST (i.e., acceptance, rejection, or neutral) in a separate room, while Friend 2 participated in a non-stressor task (10 minutes). Participants then provided a second saliva sample (Time 2). Participants were then reunited in the same room, instructed not to talk, and asked to complete a computer-based questionnaire in the original room (20

minutes). They provided a third saliva sample (Time 3) and were debriefed. Saliva samples were stored at -80 degrees C until the day of assay. See Figure 1.

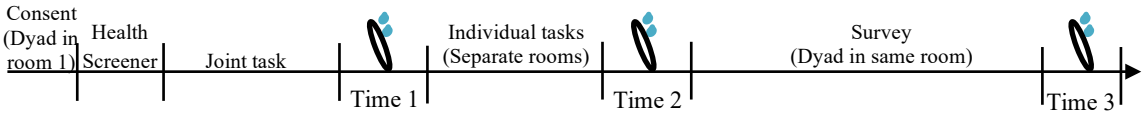

Figure 1. Procedure

Friend 1 – Stressor Task. Friend 1 was always in the stressor condition, and they were randomly assigned by dyad. In the stressor task, Friend 1 completed a modified TSST (Duffy et al., 2017; Kirschbaum, Pirke, & Hellhammer, 1993; Waters, West, & Mendes, 2014). Friend 1 was instructed to give a 5-minute speech about their strengths and weaknesses imagining there is a $500 scholarship and describing why they deserve the scholarship and how they would use the funds.

The speech was followed by a 5-minute question and answer session. Friend 1 was randomly assigned to one of three conditions: social acceptance, social rejection, or no evaluation (neutral). The social evaluation was provided by a trained female evaluator (research assistant). In the social acceptance condition, the evaluator was more positive by smiling, leaning forward, nodding, and gave positive feedback. In the social rejection condition, the evaluator was more negative by frowning, leaning back, crossing their arms, and gave negative feedback. In the neutral condition, the evaluator stayed in the room to keep the participants on time and collect saliva and gave no behavioral or verbal feedback. In all three conditions, the participants were led to believe the interaction was being videotaped. They were thoroughly debriefed after completing the study. See Appendix B for details.

Separate Task: Friend 2 – Non-stressor Task. In the non-stressor group, Friend 2 was asked to design an amusement park. They were given a list of suggested structures and rides to include (e.g., roller coaster, food court) and graphing paper to design the amusement park and label areas appropriately. See Appendix C for details.

Measures

Participants completed a background questionnaire and questionnaires about their friendship (e.g., friendship satisfaction) during session 1. Participants completed questionnaires about themselves (e.g., health screener) during Session 2. Only the measures that are related to the goals of this study are described here.

Background questionnaire.

A background questionnaire was used to collect common demographic information (e.g., age, ethnicity).

Menstrual cycle status.

A menstrual cycle status questionnaire was used to collect information on cycle regularity, the current day of their cycle, and if they were on any hormonal-based contraceptives. Participants responded by entering the number of days for the following question: 1 "How many days has it been since the first day of your last menstrual period?". For the question on cycle regularity, participants responded to the question, "How regular are your cycles" by selecting "1 = Same length each cycle", "2 = Very regular (within one or two days)", "3 = Somewhat regular (within 3 or 4 days)", "4 = Somewhat irregular (varying as much as a week in length)", and "5 = Quite irregular (varying by more than a week in length)". For the question on hormonal based contraceptives, participants responded to the question, "Please select the statement that

best describes you" by selecting "1 = I take some form of birth control", "2 = I use some form of birth control which is hormone-based (e.g., Norplant), "3 = I take hormones for any other reason (e.g., therapeutic for medical purposes)", "4 = I am pregnant or not currently menstruating for any reason", and "5 = None of the above".

Salivary Analyses

Participants were instructed to avoid potential confounding influences on HPA responses by restricting intake of food, caffeine, and nicotine at least 1 hour prior to saliva collection. Saliva samples were collected 5 min prior to the task (pre-task), immediately after (post-task), and 20 min after the task (follow-up) and later assayed for cortisol and progesterone. Following Granger et al. (2012) whole saliva samples were collected by having participants providing passive drool. Because all saliva samples from each pair were taken simultaneously (between 10:00 a.m. and 5:00 p.m.), the sampling time of day was not statistically controlled. All samples were assayed in duplicate using a commercially available immunoassay without modification to the manufacturer's recommended protocol (Salimetrics, Carlsbad, CA) using Enzyme-Linked Immunosorbent Assay (ELISA) kits provided by Salimetrics.

At the time of analyses, samples were thawed at room temperature for 1.5 hrs and centrifuged at 3000 rpms for 15 minutes. From there, I followed Salimetrics protocols for assaying cortisol and progesterone. Standards, samples, and controls were pipetted within 20 minutes for each 96 well plate, and then assay diluent with a conjugate enzyme solution was pipetted using a multichannel pipette. Plates were incubated at room temperature and then washed using a wash buffer, followed by applying a TMB substrate solution, and finally adding a stop solution prior to analyses. Samples were analyzed with

a Bio-Tek ELX- 808 using a GEN 5 microplate reader. All controls for both cortisol and progesterone were in range, and their intra- and inter-assay coefficients were 4.13% and 10.93% for cortisol, and 3.71% and 11.80% for progesterone, respectively.

CHAPTER IV

FINDINGS

Descriptive Statistics

Across conditions and participants, there were a total of 21 outliers which were recoded to three standard deviations above the mean (Byrd-Craven et al., 2012; see table 1 for outliers).

Table 1.
The number of outliers across time points and conditions.

	Cortisol			Progesterone		
Friend	Time 1	Time 2	Time 3	Time 1	Time 2	Time 3
Friend 1	2	2	2	1	4	2
Friend 2	1	1	1	2	2	1

Table 2 provides the raw overall means and standard deviations for cortisol and progesterone for Friend 1 and Friend 2 across the three time points. Shaprio-Wilk's test of normality showed that all raw cortisol and progesterone data violated the assumptions of normality ($p < .05$); therefore, I log-transformed the cortisol and progesterone raw data for further analyses.

Table 2.
Descriptive statistics for cortisol and progesterone for close friends across time points and conditions.

	Cortisol			Progesterone		
Friend	Time 1	Time 2	Time 3	Time 1	Time 2	Time 3
Neutral						
Friend 1	.19 (.09)	.19 (.12)	.18 (.13)	93.76 (74.83)	118.72 (97.63)	115.21 (92.87)
Friend 2	.18 (.12)	.17 (.07)	.17 (.07)	100.13 (71.11)	107.01 (72.35)	115.72 (72.31)
Social Acceptance						
Friend 1	.18 (.14)	.17 (.11)	.17 (.17)	89.80 (67.10)	90.04 (67.06)	93.25 (59.91)
Friend 2	.21 (.17)	.20 (.15)	.18 (.10)	81.80 (52.40)	94.14 (68.52)	105.19 (75.25)
Social Rejection						
Friend 1	.21 (.14)	.18 (.11)	.20 (.13)	112.52 (80.26)	91.27 (71.96)	118.37 (101.08)
Friend 2	.19 (.12)	.15 (.09)	.12 (.07)	93.13 (60.05)	92.75 (65.01)	102.98 (61.95)

Note: Raw data for salivary cortisol (µg/dL) and salivary progesterone (pg/mL). For cortisol and progesterone, a significant change is 10%.

For Friend 1, the average amount of days that had passed since the onset of menstrual bleeding were, $M = 12.60$, $SD = 9.04$, and Friend 2, $M = 14.67$, $SD = 11.58$. For Friend 1, 48 did not indicate that they were on any hormonal based contraceptives, 29 were on some form of birth control, 9 were on a hormonal based contraceptive, 3 were on some other form of hormonal medication, 1 reported currently pregnant or not menstruating for some other reason, and 3 did not answer. For Friend 2, 28 were on some form of hormonal medication, 25 were on some form of birth control, 17 were on some form of hormonal based medication, 15 reported currently pregnant or not menstruating for some other reason, 8 did not indicate taking any birth control, and 1 did not answer.

Hypothesis Testing

All analyses used the log-transformed cortisol and progesterone data. To investigate cortisol and progesterone attunement between Friend 1 and Friend 2 at the time of arrival, our first prediction, I calculated the intra-class correlation (ICC). The ICC represents the shared variance and represents the similarity within dyad members, therefore, quantifying the degree to which individuals with a fixed degree of relatedness (like siblings or friends) resemble each other on a trait (Griffin & Gonzalez, 2003). Behavior genetics has been using it for years because it accounts for the interdependent nature of the relationship. In Pearson correlations, each variable is centered and scaled by its own mean and standard deviation whereas ICCs are centered and scaled using a pooled mean and standard deviation. At time one for all conditions not controlling for birth control, the intraclass correlations for cortisol was .28 and .40 for progesterone, suggesting that at the time of arrival friends' cortisol and progesterone were physiologically attuned with each other supporting hypothesis one (see Figures 2 and 3).

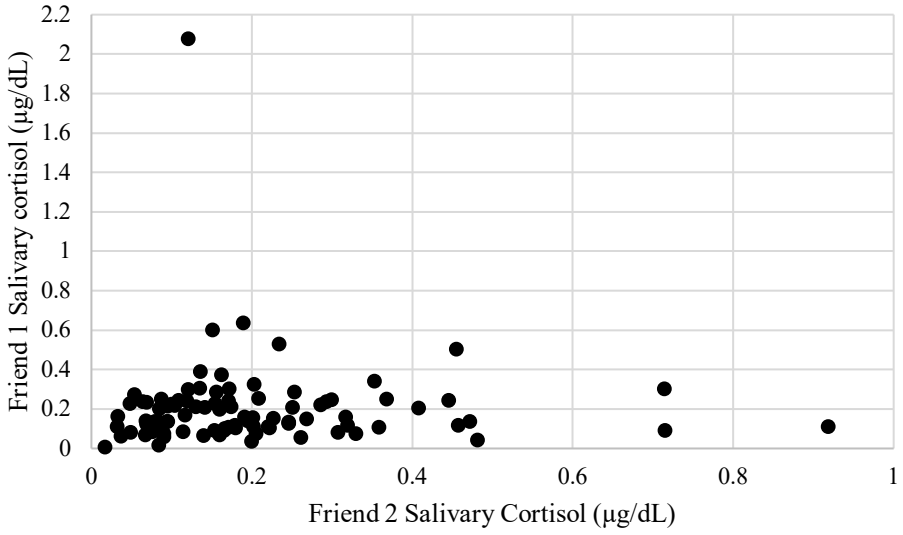

Figure 2. Raw data for time 1 cortisol

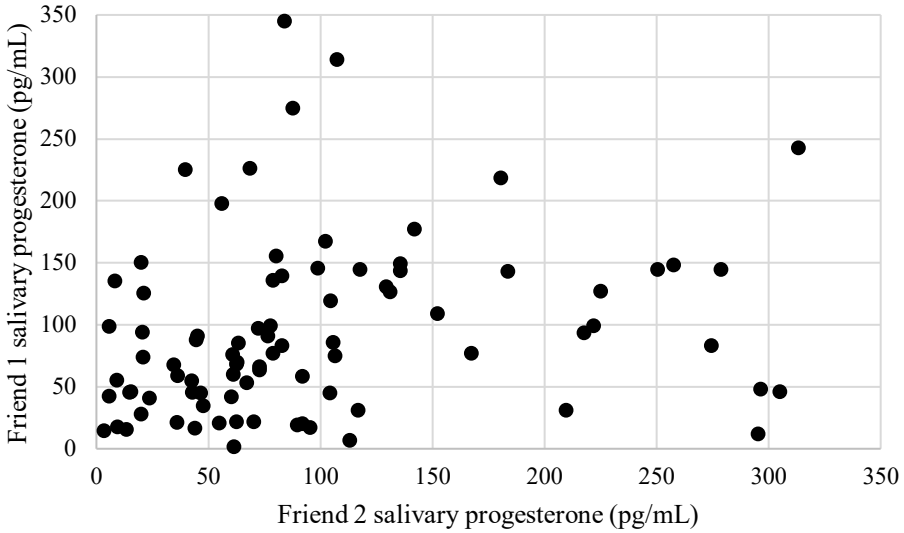

Figure 3. Raw data for time 1 progesterone

I controlled for menstrual cycle status by including the number of days that have passed since the onset of menstrual bleeding and if they were taking any hormonal-based contraceptives for both Friend 1 and Friend 2. All hormonal contraceptives or medications (oral, implant, and patch) were included in the same category.

Because the friends' cortisol and progesterone scores are correlated, the proposed analyses did not account for the inter-dependent nature of the data being nested within the dyad, therefore was not interpretable. The Actor-Partner Interdependence Model (APIM: Cook & Kenny, 2005) was used to test dyadic cortisol and progesterone synchrony across experimental conditions and time. The APIM simultaneously estimates the effect of a person's own variable (actor effect) and the effect of the same variable but from the partner (partner effect) on an outcome variable. The partner effect is the effect of a person's partner's X variable on the person's Y variable (e.g., Friend 1's time 2 cortisol on Friend 2's time 3 cortisol). In this model, Friend 1 (i.e., the friend in the stressor

condition) was the actor and Friend 2 (i.e., the friend in the control condition) was the partner. For our research question and hypotheses, I report the partner effects only to determine if cortisol and progesterone for Friend 1 predicted cortisol and progesterone for Friend 2.

To test our second prediction, whether physiological attunement differed as a function of social rejection or acceptance, I ran an APIM model to predict cortisol levels of Friend 2 at time 3 from Friend 1 at time 2 across conditions controlling for menstrual cycle and birth control. This is because Friend 1 is experiencing the stressor at Time 2. Friend 2 (i.e., the friend in the control condition) should activate a response when they are reunited at Time 3. Cortisol for Friend 1 at time 2 did not predict cortisol for Friend 2 at time 3 across conditions, b = -.003, SE = .01, t(235.20) = -.12, p = .90. Overall, cortisol for Friend 1 positively predicted cortisol for Friend 2 across conditions and time, b = .11, SE = .04, t(320.97) = 2.60, p = .01 (see Fig. 4).

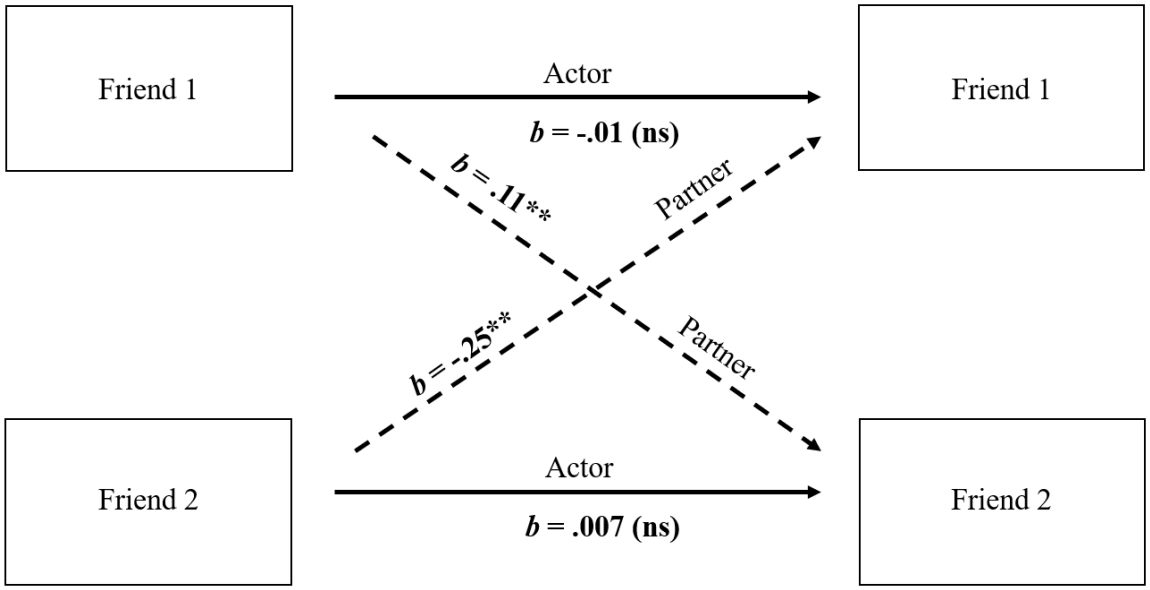

Figure 4. Actor-Partner Interdependence Model for cortisol with distinguishable dyads model. *p < .05, **p < .01, ***p < .001

Thus, friends were largely coordinated across conditions and time for cortisol. Cortisol levels between friends showed a substantial amount of attunement across the task, but attunement is not influenced by social acceptance or rejection.

I ran a similar model for progesterone, and progesterone for Friend 1 at time 2 did not predict progesterone for Friend 2 at time 3, $b = .007$, $SE = .01$, $t(251.70) = .54$, $p = .58$. Overall, progesterone for Friend 1 negatively predicted progesterone for Friend 2 across conditions and time, $b = -.08$, $SE = .03$, $t(352,24) = -2.31$, $p = .02$ (see Fig. 5).

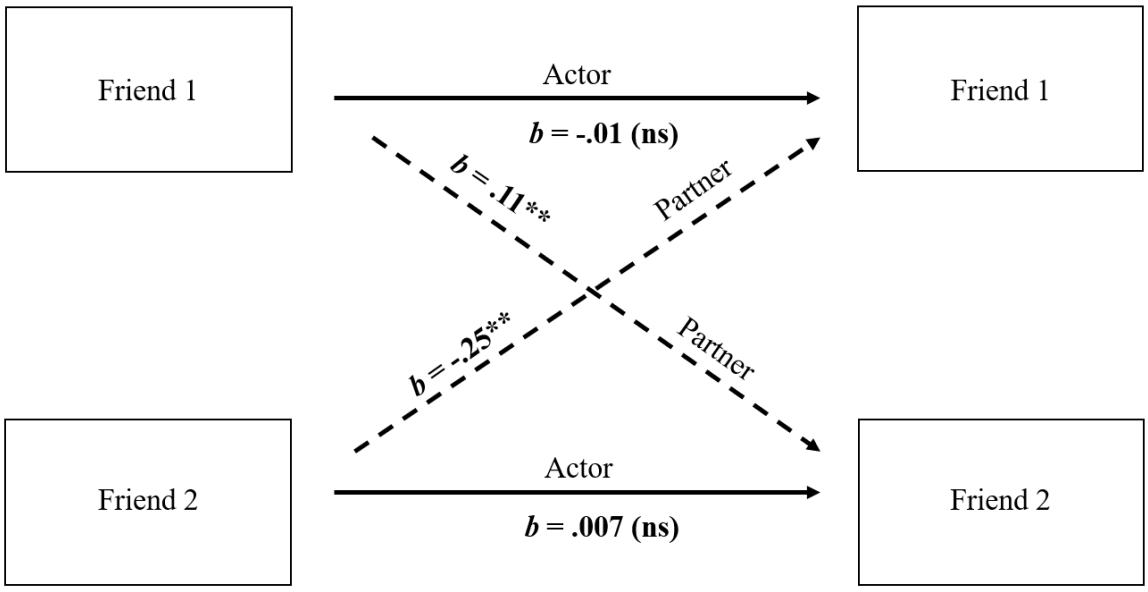

Figure 5. Actor-Partner Interdependence Model for progesterone with distinguishable dyads model. *$p < .05$, **$p < .01$, ***$p < .001$

Thus, friends were inversely coordinated across conditions and time for progesterone. Progesterone levels between friends became discordant across the task, and attunement is not influenced by social acceptance or rejection.

To test whether close friends can 'catch' a stress response through non-verbal cues, across conditions controlling for menstrual cycle and birth control I ran an APIM

model at time 3 for cortisol between Friend 1 and Friend 2, and another APIM model for progesterone between Friend 1 and Friend 2. The results did not support our prediction. At time 3, cortisol for Friend 1 did not predict with cortisol to Friend 2, b = .007, SE = .02, t(74.34) = .29, p = .76. Similarly, at time 3, progesterone for Friend 1 did not predict with progesterone to Friend 2, b = -.002, SE = .01, t(74.84) = -.17, p = .86. Therefore, there is no evidence that close friends can catch a stress response through non-verbal cues.

CHAPTER V

DISCUSSION

I experimentally tested whether close friends are physiologically attuned, whether attunement is affected by social acceptance or rejection, and if a stress response can be communicated non-verbally after being exposed to a stressful condition. I found evidence that close friends are physiologically attuned, but attunement is not influenced by social acceptance or rejection, nor can friends 'catch' a physiological response without talking to one another. Cortisol levels between friends showed a substantial amount of attunement across the task, however progesterone levels became discordant, possibly in response to separation and the inability to affiliate afterward. This adds to the complex findings regarding the functional role of cortisol and progesterone in attunement in close relationships. Taken together, this set of findings provide new insight on the interplay of cortisol and progesterone in regulating responses to rejection and directing affiliation to buffer those effects.

For girls and women, same-sex close friends are essential sources of social support, particularly for coping with psychosocial stressors (Rose & Rudolph, 2006; Taylor et al., 2000). There is evidence of stress system attunement between friends during the process social support for psychosocial challenges (Rankin et al., 2018). Given the

importance of close friendships in buffering stress, particularly for females, I was interested if a verbal exchange of information is necessary for establishing hormonal contagion in close female friends. Waters and colleagues (2014, 2017) have demonstrated when mothers experience a stressor, infants' can 'catch' their mother's reactivity to the stress manipulation. While it appears that verbal interaction may have been necessary for friends' to transfer stress responses post-stressor, friends did remain attuned across all three-time points.

I sought to determine the mechanism by which a stress response might be transferred between friends. By examining whether the cortisol and progesterone activity of the friend who experienced the stressor predicted the friend's cortisol and progesterone who did not undergo the stressor, as Waters and colleagues (2014) did, I did not find any evidence that close friends are physiologically attuned after a friend has experienced a stressor per se, but rather during the entire task, even while separated. This suggests that unlike infants and their mothers, the verbal transmission of information may be necessary for stress contagion to occur in friendships.

The current study had one friend complete the modified version of the TSST. The purpose of this was to have the dyad become unattuned when the friend in the stressor condition. Once the dyad became unattuned, this would be able to establish stress contagion if they became reattuned. Participants did not show a reaction to the TSST, therefore I could not directly answer if stress contagion is occurring. the friend in the stressor condition was not predicting the friend in the control condition which may provide evidence even if the friend in the stressor condition did show a reaction contagion would not have occurred.

The TSST not eliciting a reaction may be due to their friends acting as a buffer to the stressor. There are several factors underlying friendships specifically, such as speaking to your friend about a stressful event, knowing your friend is close by, and/or knowing you will be able to talk to them shortly afterward, that may be driving this buffering effect. In other words, it may have been the presence of a friend that resulted in a buffered stress response to the TSST. Additionally, I conducted a modified version on the TSST therefore it may be the modification to the TSST that may have led to participants not mounting a stress response.

Emerging literature has found evidence for physiological attunement within friendships (Cook, 2020; Rankin et al., 2018), but the focus has been on the stress response system. The current study extended the examination of attunement to progesterone in friendships. While this study found evidence of stress system attunement, I did show that friends seem to be tracking each other's progesterone response, albeit in an inverse pattern. This is consistent with somewhat social affiliative motives that are associated with progesterone (Brown et al., 2009; Duffy et al., 2017; Schultheiss et al., 2004), and the inverse pattern may reflect a time and information lag because they could not exchange information other than non-verbal cues.

I did not find an impact of experimental condition (rejection, acceptance, or control) on progesterone attunement between the friends, which implies that their discordance may have been a response to the separation and lack of information exchange. Taken together with previous findings, the results suggest that progesterone may function to facilitate the kind of information exchange that would eventually lead to stress system attunement and the transfer of emotional responses seen in previous work

on female friendship dyads (Byrd-Craven et al., 2008; Byrd-Craven, Granger, & Auer, 2011; Rankin et al., 2018).

This is one of the first studies of its kind to examine the physiological underpinnings of female friendships, and these results should be regarded as tentative until limitations are addressed. First, participants did not mount a stress response to the TSST. Second, I did not have a condition that allowed for friendship dyads to interact post-stressor, and thus cannot say with certainty that verbal interaction would have resulted in adrenocortical attunement, though previous findings suggest that to be the case (Cook, 2020; Rankin et al., 2018). Third, the sample consisted of college students who are in a unique developmental stage (late adolescence/emerging adulthood) and whose social life may not be representative of the overall population. For example, this population may have more time to spend with their friends and may have more shared challenges and stressors compared with their peers already in the workforce. Further investigations are needed to understand important trade-offs that occur within female friendships such as how the nature of interactions between friends serves to buffer the stress response and/or facilitate the transfer of distress and negative affect.

In sum, while I replicated previous findings (Rankin et al., 2018) that close female friends are adrenocortically attuned when they enter the lab and extended this by finding close friends also showed progesterone attunement at the onset of the study. I did not find any evidence that close friends can 'catch' each other's stress response without verbal transmission, but did find that their HPA responses remained attuned across the task. That is, the process is likely bi-directional in nature, requiring more information transmission than subtle non-verbal cues will allow, at least in friendships. The study's

focus on multiple biomarkers representing the HPA and HPG axes helps to uncover the role of these systems in facilitating support-seeking under duress and extends Taylor and colleagues' tend-and-befriend model to incorporate progesterone.

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APPENDICES

APPENDIX A

See next page for the Institutional Review Board approval page.

Oklahoma State University Institutional Review Board

Date:	02/21/2019
Application Number:	AS-19-17
Proposal Title:	Cortisol and Friendship Quality
Principal Investigator:	Ashley Rankin
Co-Investigator(s):	
Faculty Adviser:	Jennifer Craven, Ph.D.
Project Coordinator:	
Research Assistant(s):	
Processed as:	Expedited
Expedited Category:	

Status Recommended by Reviewer(s): Approved
Approval Date: 02/21/2019

The IRB application referenced above has been approved. It is the judgment of the reviewers that the rights and welfare of individuals who may be asked to participate in this study will be respected, and that the research will be conducted in a manner consistent with the IRB requirements as outlined in section 45 CFR 46.

This study meets criteria in the Revised Common Rule, as well as, one or more of the circumstances for which continuing review is not required. As Principal Investigator of this research, you will be required to submit a status report to the IRB triennially.

The final versions of any recruitment, consent, and assent documents bearing the IRB approval stamp are available for download from IRBManager. These are the versions that must be used during the study.

As Principal Investigator, it is your responsibility to do the following:

1. Conduct this study exactly as it has been approved. Any modifications to the research protocol must be approved by the IRB. Protocol modifications requiring approval may include changes to the title, PI, adviser, other research personnel, funding status or sponsor, subject population composition or size, recruitment, inclusion/exclusion criteria, research site, research procedures and consent/assent process or forms.
2. Submit a status report to the IRB when requested
3. Promptly report to the IRB any harm experienced by a participant that is both unanticipated and related per IRB policy.
4. Maintain accurate and complete study records for evaluation by the OSU IRB and, if applicable, inspection by regulatory agencies and/or the study sponsor.
5. Notify the IRB office when your research project is complete or when you are no longer affiliated with Oklahoma State University.

If you have questions about the IRB procedures or need any assistance from the Board, please contact the IRB Office at 405-744-3377 or irb@okstate.edu.

Sincerely,
Oklahoma State University IRB

APPENDICES

APPENDIX B

Positive Feedback

Hello, name of the participant. Please take a seat. My name is the name of RA. During the next part of the study, you will be giving a five-minute speech with follow-up questions about your strengths and weaknesses. Imagine there is a $500 scholarship funded through the psychology department at Oklahoma State University that is up for grabs. This interaction will be videotaped. (RA turns on the camera). Please give a five-minute speech about why you deserve this $500 scholarship and how you would use the funds.

After 5 minutes:

Thank you. As part of the task, I have been instructed to provide feedback concerning the quality of your speech completed today. Before I divulge my evaluation of your speech, I would like to ask you a few additional questions if you don't mind.

What would you describe as your greatest strength?

-Participant replies (45 seconds)

What motivates you as an individual?

-Participant replies (45 seconds)

Why do you are the best candidate for this imaginary scholarship?

-Participant replies (45 seconds)

Though you only had several minutes to speak, you did an exceptional job on elaborating on why you deserve the scholarship. What stands out most to me concerning your speech is your ability to structure your argument in a way that catches hold of the listener. With as little time as you have, I am seeing how quickly you can present and argue your key points. You had no problem with this. Your reasoning to why you deserve the scholarship actually seems to be more well-thought-out and relevant. Your speech did a great job grabbing my attention, which is one of the main issues I look at with this brief speaking period. In a speech like this, where you don't possibly have the time to detail all of the reasons why you deserve the scholarship, you should focus on drawing an emotional response from the listener. With your speech, that is exactly the connection I felt. You seem to be thinking in the right direction, and I would even say your speech is inspiring. Thank you for your time; I will now collect another sample of saliva.

Negative feedback

Hello. Please take a seat. My name is the name of RA. During the next part of the study, you will be giving a five-minute speech with follow-up questions about your strengths and weaknesses. Imagine there is a $500 scholarship funded through the psychology department at Oklahoma State University that is up for grabs. This interaction will be videotaped. (RA turns on the camera). Please give a five-minute speech about why you deserve this $500 scholarship and how you would use the funds. After 5 minutes:

As part of the task, I have been instructed to provide feedback concerning the quality of your speech completed today. Before I divulge my evaluation of your speech, I would like to ask you a few additional questions.

What would you describe as your greatest strengths (list 3)?

-Participant replies (45 seconds)

What motivates you as an individual?

-Participant replies (45 seconds)

Why do you are the best candidate for this imaginary scholarship?

-Participant replies (45 seconds)

Though you only had several minutes to speak, other participants with the same prompt were able to elaborate more on why they deserved the scholarship. What stands out most to me concerning your speech is a failure to structure your argument in a way that catches hold of the listener. With as little time as you have, I am seeing how quickly you can present and argue your key points. It was almost as if you were hesitant to back up your argument. Your reasoning to why you deserve the scholarship has actually been stated in other participants' speech and didn't seem to grab my attention as much as I would like for a strong candidate. In a speech like this, where you don't possibly have the time to detail all of the reasons why you deserve the scholarship, you should focus on drawing an emotional response from the listener. With your speech I didn't have that connection. Although you seem to be thinking in the right direction, your speech is somewhat uninspiring. I feel that your speech overall was weaker than the majority of the other participants. Thank you for your time I will now collect another sample of saliva.

Neutral feedback

Hello. Please take a seat. During the next part of the study, you will be giving a five minute speech with follow-up questions. The task is explained on the notecard. This interaction will be videotaped. (RA turns on the camera). I will be in the room to make sure you stay on task. You may begin.

Judge hands the participant a notecard which reads:

"There is an imaginary $500 scholarship funded through the psychology department at Oklahoma State University that is up for grabs. You will be giving the speech to the camera and you will be recorded. Please give a five-minute speech about why you deserve this $500 scholarship and how you would use the funds.

After your speech please read aloud the following questions and respond:

What would you describe as your greatest strengths (list 3)?

-Participant replies (100 seconds)

What motivates you as an individual (list 3 motivations)?

-Participant replies (100 seconds)

Why do you are the best candidate for this scholarship (list at least 3 reasons why)?

-Participant replies (100 seconds) "

Thank you for your time; I will now collect another sample of saliva.

APPENDICES

APPENDIX C

Plan a Theme Park

Instructions:

You are to plan a theme park with rides and attractions that would appeal to people of all ages. Please use the graphing paper provided to design your theme park. The number beside each item indicates the **maximum** number of blocks it can take up on the graphing paper. **Choose 10 items** from the list below to include in your park. Please label rides and attractions appropriately.

Item	Maximum # of Blocks
Roller Coaster	11 X 11
Water Ride	12 X 12
Ferris Wheel	10 X 10
Bumper Cars	10 X 10
Tilt-A-Whirl	9 X 9
Himalaya	10 X 10
Swinging Boat	8 X 8
Virtual Reality Ride	10 X 10

Carnival Game Booths	9 X 9
Gift Shop	8 X 8
Carousel	8 X 8
Train Ride	12 X 12
Mini Roller Coaster	8 X 8
Concession Stand or Restaurant	10 X 10
Amphitheater (for shows)	12 X 12

APPENDICES

APPENDIX D

Functions of Friendship

Forming and maintaining friendships is thought to be more beneficial for human health than any other intervention besides quitting smoking (Holt-Lunstad, Smith, & Layton, 2010). Friendships are also vital to people's happiness, yet the reason they evolved is poorly understood. There are many theories to explain why friendships have evolved including kin selection, reciprocal altruism, the alliance hypothesis, the banker's paradox/insurance hypothesis, and the social brain hypothesis.

Kin selection, introduced by Hamilton, states that selection will favor an individual to incur costs to the individual if the cost is lower than the benefits to the recipient of altruism, multiplied by the probability of genetic relatedness (i.e., $c < rb$; Hamilton, 1963). Evidence supporting kin selection is that there is a preference to cooperate with kin over non-kin across primate species (Foerster et al., 2015; Silk, 2003), kin requires less maintenance compared to non-kin friends (Roberts and Dunbar, 2011), and kin section is a common strategy among hunter-gathers (Kasper & Muller, 2015). Evidence contradicting kin section is that individuals also form deep engagement

relationships with non-kin that would not theoretically lead to an increase in one's direct or indirect fitness (Tooby & Cosmides, 1996). This evidence is weak given friends can aid in your offspring's survival (alloparental support; Silk, 2003; Hrdy, 2011). Further support is primate alloparents are typically mothers or daughters, but in humans, they can also be non-genetically related close friends. According to kin section, individuals cooperate preferentially with kin.

Reciprocal altruism, introduced by Trivers, states that individuals increase the fitness of another with the temporary reduction of fitness to the self, with the expectation this individual will do the same in the future (Trivers, 1971). Reciprocal altruism is theorized to be more likely to occur in species with long life spans, low dispersal rates, and mutual interdependence (Trivers, 1971). The function of friendships, according to this theory, is friends provide benefits to each other while incurring a personal cost reciprocally over time, thereby eventually incurring equal cost and benefits to one another.

Evidence supporting reciprocal altruism shows that humans follow the conditions necessary for reciprocal altruism; they have long lifetimes, low dispersal rates, and mutual interdependence (e.g., food sharing Kramer, 2018). Furthermore, reciprocal altruism is the most common practice among hunter-gathers (Kasper & Muller, 2015) and is common throughout primates suggesting it is deeply ingrained in our evolutionary past (Silk, 2003). Evidence contradicting reciprocal altruism shows that friends actively hide altruistic acts towards their friends, claim they do not keep track of the balance of cooperation (consciously at least), and are upset and hurt when their friend repays a benefit immediately (e.g., loaning $5 and the next day friend pays them back; Silk, 2003).

Further, people invest in their friends when their friends are unlikely to pay the favor back (i.e., sick or dying; Silk, 2003; Tooby & Cosmides, 1996).

Following the logic of the banker's paradox, that the person who needs the loan the most is the person who is least likely to be able to repay it, Tooby and Cosmides introduced the banker's paradox /insurance hypothesis. This theory asserts that eventually I will need assistance, and like the banker's paradox, the time when I need help is when I am the least valuable partner to be able to reciprocate (Tooby & Cosmides, 1996). Therefore, the function of friendships may be to establish a long-standing history of credit before I need a "loan" or help. For example, friends take care of one another when repayment is slim (e.g., cancer patients). However, Tooby & Cosmides (1996) did not take into consideration the high levels of cost likely to incur from their friend and that this form of friendship is extremely rare among primate species (Silk, 2003).

The alliance hypothesis, introduced by DeScioli and Kurzban, states that eventually conflicts will arise and support groups via friendships result to mitigate potential conflicts, preferably before the conflict arises (DeScioli & Kurzban, 2009). According to this theory, friendships function to create support groups for potential conflicts. Evidence supporting this hypothesis shows that if two individuals are in a conflict (Person A&B) and Person A's friend (Person C) is neutral and does not support Person A in the conflict then that Person C is viewed as being against Person A, and not neutral (Shaw et al., 2018). Furthermore, one should desire social partners who rank their own needs above others. DeScioli, Kurzban, Koch, Liben-Nowell (2011) found evidence that one's rank of self from their friends' point of view predicts how that friend is ranked in their own friendship ranking. Evidence contradicting this hypothesis shows that a cue

for the alliance hypothesis should be membership, yet children perceive secret sharing as a stronger cue for friendship than group membership (Liberman & Shaw, 2017). Since information is critical to survival in humans (e.g., what foods are poisonous, which individuals are members on ingroup vs outgroup, etc.), the more individuals cooperating to collect, analyze, and disseminate this knowledge, the more powerful the group (Hess, 2017). Therefore, if secret sharing is viewed as the transmission of information, then it should be expected that this information would only be transmitted between those in the same group (Hess & Hagen, 2019).

The social brain hypothesis, introduced by Dunbar, claims that in primates' neocortical size co-evolved with social group size to acquire and synthesize social information (Dunbar, 2002; 2010; 2018). The function of friendships, according to this theory, is that friends evolved to cooperate with and help keep track of social networks. The groups are theorized in humans to be by a factor of 3 (e.g., core 3-5, sympathy 9-15, etc.) which Zhou et al. (2009) found evidence for. The theorized maximum number of social partners humans can keep track of is 150, which has not changed even with tools like the internet (Dunbar, 2018). The social brain hypothesis, however, does not take into consideration the flexibility of hunter-gathers networks. Bird et al. (2019) found evidence that foraging parties (averaging at 8 ranging from 1-18 individuals) are flexible and the networks are structured more in a hearth, residence, estate, etc. form.

Although this flexibility in social structures should be accounted for the social brain hypothesis, the findings of Bird et al. (2019) may simply reflect a difference in terminology and allowing for a wider range of people to include. For example, Dunbar and colleagues described the groups as core social grouping 3-5, sympathy group 12-20,

bands 30-50, small-scale traditional societies 150, the megaband 500, the tribe (a linguistic unit) 1000–2000 (Dunbar, 2002; Zhou, Sornette, Hill, & Dunbar, 2005). Bird et al. (2019) described the groups as hearth groups 2-12, foraging groups 2-21, residential groups 8-30 or 41-127, estate groups 25-150, dialect named units 50-300, and language group ~1000. Evidence in support of the social brain hypothesis is that baboons living in larger social groups have bigger brains whereas the size of the enclosure did not affect it (Meguerditchian, et al., 2020).

Further, if the brain has evolved to acquire and synthesize social information specifically (Dunbar, 2018; 2010), then there should be endocrine processes that underlie this. There is a variety of evidence that oxytocin and cortisol are involved in deep engagement relationships (likely the core group; Dunbar, 2018; Feldman & Bakermans-Kranenburg, 2017), testosterone, B-endorphins and dopamine are important in dominance hierarchies (Dunbar, 2018; Zigler & Crockford, 2017), and there are differences in testosterone when interacting with someone similar vs dissimilar (DeSoto, 2010). The impact of progesterone on social behavior is less well understood.

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