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Maternal Major Depression and Synchrony of Facial Affect During Mother-Child Interactions

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Maternal history of Major Depressive Disorder (MDD) dramatically increases children's risk for developing depression, highlighting the critical need for further research on the specific processes involved in the intergenerational transmission of depression. Although previous research suggests that maternal depression may adversely affect the quality of mother–child interactions, less is known about the role of maternal MDD in the moment-to-moment changes in affect that occur during these interactions. The goal of this project, therefore, was to examine synchrony of facial displays of affect during a positive (Vacation Planning) and a negative (Issues Discussion) mother–child interaction, and how this synchrony may be impacted by maternal history of MDD. In doing so, we examined both concurrent and lagged synchrony of facial affect. We recruited 341 mother–child dyads (child average age = 9.30 years; 50.1% girls; 71.6% Caucasian) with and without a maternal history of MDD. Facial electromyography (EMG), continuously recorded during those tasks, was used to index mother and child facial affect. We found that a maternal history of MDD was associated with reduced concurrent synchrony and lagged synchrony (mother facial affect predicting changes in child facial affect) of positive affect during Vacation Planning. Reduced concurrent mother–child synchrony of positive affect during the discussion was also associated with an increase in child self-reported sad affect from before to after the discussion. These findings provide promising initial evidence for how the dynamic exchange of positive affect during mother–child interactions may be disrupted in families with maternal MDD history.

General Scientific Summary
The findings of this study suggest that maternal history of depression is associated with a potentially maladaptive pattern of dynamic exchange of emotions during mother–child interactions, specifically a diminished exchange of positive affect during pleasant discussions.

Keywords: emotional expressions, mother–child interaction, maternal depression, facial electromyogram (EMG), synchrony

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An extensive body of research provides strong evidence for the far-reaching deleterious effects of maternal depression on child development (Goodman et al., 2011; Weissman et al., 2016). In particular, children of mothers with a history of Major Depressive Disorder (MDD) are more likely to have difficulties in interpersonal, cognitive, emotional, and behavioral functioning, and experience more negative and less positive affect and behavior (Goodman et al., 2011; Liyanarachchi et al., 2013; Murray & Cooper, 1997; Raposa, Hammen, Brennan, & Najman, 2014). Notably, these children are also at a much higher risk of developing depression, as well as other forms of psychopathology, themselves (Goodman et al., 2011).

One factor that may increase risk for the intergenerational transmission of depression is a pattern of dysfunctional dyadic interactions between mothers with a history of MDD and their children (Katz, Hammen, & Brennan, 2013). Indeed, the neuroendocrinological foundations of the mother–child relationship, which are laid as early as the prenatal period (Feldman, Weller, Zagoory-Sharon, & Levine, 2007; Fleming, Ruble, Krieger, & Wong, 1997; Levine, Zagoory-Sharon, Feldman, & Weller, 2007), are a critical factor in fostering children's cognitive and emotional development (Girard, Doyle, & Tremblay, 2017; Stafford, Kuh, Gale, Mishra, & Richards, 2016; Tucker-Drob & Harden, 2012; van de Weijer-Bergsma, Wijnroks, van Haastert, Boom, & Jongmans, 2016). The quality of mother–child dyadic interactions contributes to children's level of adjustment in relationships with peers, symptoms of internalizing and externalizing disorders, and self-injurious behaviors (Carson & Parke, 1996; Crowell et al., 2008; Feldman, Vengrober, & Ebstein, 2014; Hollenstein, Granic, Stoolmiller, & Snyder, 2004; Olino et al., 2008; Weaver, Shaw, Crossan, Dishion, & Wilson, 2015).

Notably, maternal MDD could disrupt the dyads' mutual capacity for regulation during interactions (Cohn & Tronick, 1989). Indeed, mother–child interactions among dyads with a maternal history of MDD have been characterized by a number of specific maladaptive patterns of verbal and nonverbal communication (for a meta-analytic review, see Lovejoy, Graczyk, O'Hare, & Neuman, 2000). For example, mothers with a current MDD diagnosis have been found to display more negative and less positive verbal behavior (Gordon et al., 1989), more negative affect (Radke-Yarrow, Nottelmann, Belmont, & Welsh, 1993), and have a more negative affective style, indexed by criticism, induction of guilt, and intrusiveness (Hamilton, Jones, & Hammen, 1993) while interacting with their children. Notably, there is evidence that mothers with current MDD, compared to never depressed mothers, evidence longer bouts of negative affect and those negative affect intervals are more likely to be reciprocated by their daughters (Radke-Yarrow et al., 1993). Together, these findings strongly suggest that maternal MDD may influence various aspects of mother–child interactions, including the mutual expression of affect.

Less is known, however, about the potential impact of maternal depression on the moment-to-moment exchange, or synchrony, of both positive and negative affective expressions during mother–child interactions. Mother–child synchrony is described as the dynamic interpersonal reciprocation of behavioral cues and physiological processes during social contact. Synchrony involves coordination and reciprocal adaptation of verbal and nonverbal processes between caregivers and children and involves both partners' responsivity as well as capacity to respond to each other (Leclère et al., 2014). As such, it is an essential formative experience that plays a critical role in child development and the quality of the mother–child relationship (Feldman, 2012; Leclère et al., 2014). Dyadic synchrony has been researched in multiple systems including gaze, body movements, arousal indicators, affect, heart rate variability, adrenocortical activity, and neural processes (Feldman, 2012). Greater mother–infant synchrony of communicative behaviors (e.g., gaze) was found to predict greater self-regulation, secure attachment, and fewer behavioral problems in childhood (Feldman, 2007). Additionally, greater physiological (respiratory sinus arrhythmia; RSA) mother–child synchrony has been associated with increased resilience among children exposed to high-risk contexts, including maternal MDD and exposure to trauma (Gray, Lipschutz, & Scheeringa, 2018; Woody, Feurer, Sosoo, Hastings, & Gibb, 2016). In addition, greater dyadic synchrony in other physiological and behavioral processes, including stress-related biochemical activity and expressed affect, has been associated with maladaptive familial contexts, including a maternal history of MDD. For instance, dyads with a history of maternal depression evidenced greater concordance in cortisol fluctuations during the day (Merwin, Smith, Kushner, Lemay, & Dougherty, 2017). Intriguingly, mother–child diurnal cortisol concordance was even stronger among children with higher overall cortisol production, suggesting that children who experience higher stress levels may be more susceptible to the impact of maternal stress physiology (Pratt et al., 2017; Tarullo, St. John, & Meyer, 2017). In a separate observational study focused on expressed affect, researchers found that, although dyads with and without a history of maternal MDD did not differ in the overall level of expressed negativity during a conflict task, there was a moment-to-moment negative escalation between depressed mothers and their children (McMakin et al., 2011). Together, these data suggest the effects of maternal MDD on mother–child synchrony persist beyond the current episode of depression and can be observed among dyads with a history of maternal MDD regardless of their current depression status. Moreover, the findings imply that depressed mothers and their offspring are characterized by greater moment-to-moment synchrony in cortisol levels and reciprocal transactional exacerbation of negative affective behaviors during conflict and failure to capitalize on positive affect. To date, however, no study of which we are aware has examined the potential effects of maternal MDD on the synchrony of expressed affect during mother–child interactions utilizing a physiological tool to capture dynamic changes in facial affect.

To address this gap in the literature, the present study examined whether maternal history of MDD moderated the concurrent, as well as lagged, synchrony of mother and child facial affect during positive and negative mother–child interaction tasks using facial EMG. Due to its high temporal resolution and sensitivity to subtle facial musculature changes, facial EMG represents a valuable tool to objectively measure dynamic changes in facial affect (Tassinary, Cacioppo, & Vanman, 2007). Importantly, previous research has documented that facial EMG activity differentiates the valence and intensity of the affective response well beyond visual coding (Cacioppo, Petty, Losch, & Kim, 1986). Additionally, facial EMG has been successfully used in previous research in school-age children between the ages of 6–12 years old (Armstrong, Hutchinson, Laing, & Jinks, 2007; Deschamps, Munsters, Kenemans, Schutter, & Matthys, 2014; Oberman, Winkielman, & Ramachandran, 2009) as well as toddlers (Geangu, Quadrelli, Conte, Croci, & Turati, 2016), with participants evidencing increases in the activity of muscles typically associated with positive emotional expressions (e.g., zygomaticus major) in response to positively valenced emotional stimuli (e.g., smiling faces) and a corresponding reduction in this activity in response to negatively valenced stimuli. Conversely, activity in the corrugator muscle increases in response to negatively valanced stimuli (de Wied, van Boxtel, Zaalberg, Goudena, & Matthys, 2006). In addition to studies in adults, a number of studies have use EMG to successfully index facial affect in children as young as 7 months of age using zygomaticus major activity to index positive affect and corrugator activity to assess negative emotional expressions (e.g., Deschamps et al., 2014; de Wied et al., 2006; Geangu et al., 2016; Kaiser, Crespo-Llado, Turati, & Geangu, 2017). Thus, unlike the majority of previous studies in this area that used behavioral coding systems to examine interpersonal exchange of emotional expressions, we used facial electromyography (EMG) to index facial expressions of emotion. Specifically, we focused on EMG activity of the corrugator supercilii muscle, which is typically involved in bringing the eyebrows together during frowning, to index the expression of negative affect. In addition, we used EMG activity of zygomaticus major muscle, which is involved in raising the corners on the lips during smiling, to index the expression of positive affect (cf. Cacioppo et al., 1986; Dimberg, 1990). Notably, previous research suggests that activity in the corrugator supercilii muscle region is potentiated in response to unpleasant stimuli and reduced by pleasant stimuli, whereas activity in the zygomaticus major region is potentiated in response to pleasant stimuli and inhibited in response to unpleasant stimuli. (Cacioppo et al., 1986; Lang, Greenwald, Bradley, & Hamm, 1993). These effects have been demonstrated using a wide variety of stimuli, including images, sounds, voices, faces, bodily expressions (Larsen, Norris, & Cacioppo, 2003; Magnée, Stekelenburg, Kemner, & de Gelder, 2007) and have been consistently observed in clinical and nonclinical populations across different ages including children (Deschamps et al., 2014; Heller, Greischar, Honor, Anderle, & Davidson, 2011; Neta, Norris, & Whalen, 2009).

The EMG signal was continuously recorded while mothers and children were engaged in both positively valenced (Vacation Planning) and negatively valenced (Issues) discussions. Based on previous findings with behaviorally coded levels of affect that showed greater reciprocity of negative affect during interactions between daughters and their currently depressed mothers (Radke-Yarrow et al., 1993) and depressed mothers and their offspring (McMakin et al., 2011), we hypothesized that mother–child dyads with a maternal history of MDD would demonstrate higher synchrony for negative emotional expressions than would dyads with no history of maternal MDD. Additionally, based on previous research suggesting that currently depressed mothers exhibit less positive behavior during mother–child interactions (Gordon et al., 1989), we hypothesized that mother–child dyads with a history of MDD would evidence lower synchrony for positive emotional expressions than dyads with no history of maternal MDD. Given the limited research on the effects of the interaction's content on mother–child synchrony, we did not make any hypotheses about whether these effects would be stronger in positively versus negatively valenced discussions. In addition, although we were primarily focused on concurrent synchrony of facial affect during the discussions, we also examined lagged synchrony in which we examined the impact of mothers' facial affect on changes in children's facial affect as well as the impact of children's facial affect on changes in mothers' facial affect. Finally, to further examine the affective consequences of mother–child synchrony, we examined the association between EMG synchrony during each discussion and changes in self-reported sad affect from before to after each discussion.

Method

Participants

Participants were 341 mother–child dyads recruited from the community. Because siblings were allowed in the study, this included 302 mothers and 341 children. Mothers were required to either have a history of at least one episode of MDD in their lifetime ($n = 136$), or have no lifetime history of MDD ($n = 166$). Children participated with their biological mother, with whom they had lived full-time their entire lives. Children were excluded if they had a learning disability or developmental disorder based on mother report. The average age of mothers was 36.86 years ($SD = 5.77$). In terms of race/ethnicity, the majority were Caucasian (82.1%) and the rest were African American (14.2%), Asian/Pacific Islander (1.3%), biracial (1.7%), or from other racial/ethnic groups (0.7%). The average age of children was 9.30 years ($SD = 1.47$) and 51.0% were boys. In terms of children's race/ethnicity, the majority were Caucasian (71.6%), and the rest were African American (14.1%), biracial (13.2%), Asian/Pacific Islander (0.3%), or from other racial/ethnic groups (0.9%). The median annual family income was between $35,001 and $40,000 (range: less than $5,000 per year to more than $115,000 per year).

Measures

Depressive diagnoses and symptoms. The Structured Clinical Interview for DSM–IV–TR Axis I Disorders (SCID-I; First, Spitzer, Gibbon, & Williams, 2002) and the Schedule for Affective Disorders and Schizophrenia for School-Age Children–Present and Lifetime Version (K-SADS-PL; Kaufman et al., 1997) were used to assess mothers' and children's histories of DSM–IV Axis I diagnoses. The SCID-I and K-SADS-PL were administered by two separate trained interviewers. As noted above, 136 (45.0%) mothers met criteria for lifetime MDD, 14 (4.6%) of whom met criteria for current MDD. In addition, 53 women met criteria for one or more current anxiety disorder diagnoses (social phobia: $n = 27$; agoraphobia: $n = 11$; generalized anxiety disorder: $n = 10$; panic disorder: $n = 10$, obsessive–compulsive disorder: $n = 7$; and posttraumatic stress disorder: $n = 5$). A total of nine (2.6%) children had a lifetime history of major depressive disorder, six of whom had a mother with a history of MDD in their lifetime. One child (0.3%) was diagnosed with current MDD and 19 (5.6%) met criteria for one or more current anxiety disorder diagnoses (social phobia: $n = 11$; generalized anxiety disorder: $n = 6$; separation anxiety disorder: $n = 4$; agoraphobia: $n = 2$; obsessive–compulsive disorder: $n = 2$; panic disorder: $n = 1$; and posttraumatic stress disorder: $n = 1$). To assess interrater reliability, a subset of 20 SCID-I and 20 K-SADS-PL interviews from this project were coded by a second rater, and kappa coefficients for MDD diagnoses in mothers and children were excellent (κs = .89 and 1.00, respectively).

Mothers' and children's current depressive symptoms were assessed using the Beck Depression Inventory-II (BDI-II; Beck, Steer, & Brown, 1996) and Children's Depression Inventory (CDI; Kovacs, 1985), respectively. Both scales exhibit good validity and reliability in community samples (Beck et al., 1996; Smucker, Craighead, Craighead, & Green, 1986). In the current study sample, the BDI-II and CDI exhibited good internal consistency (αs = .87 and .80, respectively).

Discussion paradigm. Prior to the Discussion Paradigm, mothers and children both completed an Issue Checklist, which presents a series of potential topics of disagreement (fighting with siblings, helping with housework, etc.) and asks mothers and children to independently identify whether they have had recent (within the last month) interactions regarding any of these topics and, if so, how negative those interactions were. Following this, participants began the Discussion Paradigm (Robin & Foster, 2003) by engaging in a 4-minute Vacation Planning task, during which they planned a vacation for just the two of them together. All dyads in the study took all 4 min for this conversation. Then, the dyads engaged in a 6-minute Issues Discussion task, during which they were instructed to talk about one of the issues from the Issue Checklist (the one rated as the most negative by the mother and child), describe the recent disagreement, and try to resolve it. If the family completed their discussion in less than 6 min, they were instructed to move on to the next issue from the Issue Checklist.

Participants rated their current mood three times during the discussion paradigm using a Visual Analogue Scale (VAS; Folstein & Luria, 1973): before and after the Vacation Planning task and after the Issues Discussion task. Specifically, mothers and children independently rated how they were feeling from *Very Happy* to *Very Sad* on a scale measuring 100 mm. To calculate VAS sadness scores, participants' ratings were measured from left to right on the 100-mm scale, with higher numbers indicating higher levels of state sadness.

EMG signal recording and processing. During each phase of the Discussion Paradigm, facial EMG was recorded simultaneously from the mother and child using Biopac M150 wireless recording systems (BIOPAC Systems Inc., Goleta, CA). The EMG signal was recorded using miniature (4 mm) surface bipolar Ag/AgCl electrodes following standard procedures and placement (Cacioppo et al., 1986). Electrodes filled with electrode gel were attached over the corrugator supercilii and zygomaticus major muscles via adhesive rings (Cacioppo et al., 1986). Before the electrodes were attached, the skin was cleaned using 70% isopropyl alcohol swabs. MindWare EMG 3.0.12 (Mindware Technologies Ltd., Gahanna, OH) was used to transform and analyze the EMG signals. The EMG signal was sampled at 1,000 Hz and band-pass filtered within the frequency range of 20–500 Hz. Additionally, a 60-Hz notch filter was applied to remove the power line noise component, after which the EMG signal was then rectified and integrated. The data were then binned into 1-s epochs. Average EMG activity for each muscle during Vacation Planning and Issues Discussion for mothers and children is described in Table 1.

Procedure

Participants were recruited from the community through a variety of means (e.g., TV and online advertisements). Mothers were initially screened over the phone to determine eligibility. Upon arrival at the laboratory, participants were asked to provide informed consent and children were asked to provide assent to participate in the study. Following this, mothers were administered the SCID-I by a research assistant. Next, the mother was administered the KSADS-PL by a separate interviewer, who later administered the KSADS-PL and questionnaires to the child. Interviewers encouraged children to ask questions if they needed clarification about specific items on each questionnaire. Finally, participants completed the Discussion Paradigm. This project was approved by the university's Institutional Review Board.

Analysis Plan

We followed recommendations of Helm, Miller, Kahle, Troxel, and Hastings (2018) for examining concurrent and lagged synchrony. Specifically, we detrended and standardized the EMG data by fitting a linear trend to each series and saving the residuals. Detrended data were then converted to z-scores so that values reflected changes in EMG activity across each task relative to that person's own mean EMG activity within the task.

To examine concurrent synchrony of mother and child facial expressions of emotion during each interaction task, and whether this synchrony would be moderated by mothers' histories of MDD, we used linear mixed models (LMM) with an autoregressive (AR1) covariance structure to account for the nested structure of the data (epochs within person, siblings within family). Specifically, using child EMG activity (corrugator supercilii or zygomaticus major) during each 1-s epoch of an interaction task as the outcome variable, mother EMG activity from the same muscle during each 1-s epoch was entered as a predictor variable. Mother history of MDD, and the mother MDD × mother EMG interaction were also included as predictor variables. Separate analyses were

Table 1
Means and Standard Deviations for Mother and Child EMG

Task	Muscle	Mothers	Children
Vacation planning	Corrugator, mV	12975.73 (11513.39)	18267.35 (28290.73)
	Zygomaticus, mV	32726.15 (36081.00)	52668.89 (65822.93)
Issue discussion	Corrugator, mV	15182.28 (12730.88)	20044.58 (32004.81)
	Zygomaticus, mV	19504.67 (25192.61)	47337.28 (76392.66)

Note. Untransformed data is presented to facilitate comparisons with other studies.

conducted for each muscle group and each interaction task (4 analyses total). The Level 1 model for these analyses was:

$$\text{Child EMG}_{tj} = \pi_{0j} + \pi_{1j}(\text{Mother EMG}_{tj}) + e_{tj},$$

where Child EMG_{tj} represents the EMG level at time t for dyad j, π_{0j} is the Child EMG intercept, π_{1j} is the slope of the relation between mother and child EMG activity (EMG synchrony) at time t for a given dyad, and e_{tj} represents the error term.

The Level 2 model was:

$$\pi_{0j} = \beta_{00} + \beta_{01}(\text{Mother MDD}) + r_{0j}$$
$$\pi_{0j} = \beta_{10} + \beta_{11}(\text{Mother MDD}) + r_{1j}$$

where β_{01} is the cross-level interaction term representing the effect of mother MDD on the child EMG intercept and β_{11} is the cross-level interaction terms representing the effect of mother MDD on the slope of the relation between mother and child EMG activity at time t. Finally, β_{00} and β_{10} represent the intercepts of their respective equations and, and r_{0j} and r_{1j} represent the error terms.

To examine lagged synchrony (i.e., whether mother EMG activity predicted prospective changes in child EMG activity and vice versa), we created lagged EMG variables reflecting EMG activity at Time T-1 (1 second prior) and used these to predict subsequent EMG activity at Time T. As before, we used LMM to account for the nested structure of the data. Focusing first on the impact of mother EMG activity on changes in children's EMG activity, we examined whether mother EMG at T-1 predicted child EMG at Time T, statistically controlling for child EMG at Time T-1. To do this, the Level 1 equation above was altered so that we included mother EMG at Time T-1 rather than mother EMG at Time T and we also included child EMG at Time T-1 as an additional covariate. The Level 2 model remained the same. Separate analyses were conducted for each muscle group and each interaction task (4 analyses total). Analogous analyses were conducted to examine the impact of child EMG activity on changes in mother EMG activity.

Finally, we examined the impact of EMG synchrony during the Vacation Planning and Issues Discussion tasks on changes in self-reported sad affect during each task. To do this, we first calculated the average moment-to-moment correlation in mother and child EMG activity for each task reflecting within dyad synchrony for corrugator and for zygomaticus major activity during each task. The coefficients were created separately for each task (4 total). Then, using linear regression analyses with postdiscussion self-reported sad affect as the criterion variable, we entered prediscussion self-reported affect, within-task EMG synchrony, mother MDD, and the mother MDD × EMG synchrony interaction as predictors. This allowed examine whether EMG synchrony within each discussion predicted residual change in sadness from before to after the discussion and whether this was moderated by maternal history of MDD. Again, separate analyses were conducted for each muscle group and task.

Results

An initial examination of the data revealed that the BDI-II and CDI were not normally distributed. These were log-transformed prior to further analysis to satisfy assumptions of normality. In addition, there were some missing questionnaire data; however, none of the variables was missing more that 8%. Given the presence of missing data, we examined whether the data were missing at random, thereby justifying the use of data imputation methods for estimating missing values (Schafer & Graham, 2002). Little's missing completely at random (MCAR) test, for which the null hypothesis is that the data are MCAR (Little & Rubin, 2002) was nonsignificant, $\chi^2 = 57.41$ (51), $p = .25$, supporting the imputation of missing values with the estimation-maximization algorithm (Moon, 1996; Schafer & Graham, 2002). The demographic and clinical characteristics for the participants are presented in Table 2. To facilitate comparisons with other studies, values presented in the table are based on the untransformed data.

Concurrent Synchrony of Facial Affect

We then used LMM to examine concurrent synchrony of EMG activity during the Vacation Planning and Issues Discussion and to determine whether this was moderated by maternal history of MDD. The results are summarized in Table 3. Focusing first on zygomaticus major activity, we found significant concurrent synchrony during the Vacation Planning, $t(81,835) = 17.56$, $p < .001$, $r_{effect\ size} = .06$, and the Issues Discussion, $t(122,387) = 10.11$, $p < .001$, $r_{effect\ size} = .03$. This synchrony was moderated by

Table 2
Descriptive Statistics for Mothers and Children

Variable	No mother MDD	History of mother MDD	$r_{effect\ size}$
Mother Age (*M, SD*)	37.71 (5.84)	35.83 (5.52)	−.16**
Mother ethnicity (% Caucasian)	82.5	81.6	−.00
Child age (*M, SD*)	9.48 (1.48)	9.09 (1.42)	−.13*
Child ethnicity (% Caucasian)	71.0	72.3	.01
Child sex (% female)	56.5	42.6	−.14*
Child MDD (% with lifetime diagnosis)	1.6	3.9	.07
BDI-II (*M, SD*)	5.77 (7.01)	9.93 (8.96)	.25**
CDI (*M, SD*)	5.47 (5.50)	6.20 (5.01)	.10
Annual family income (median)	40,001–45,000	25,001–30,000	−.26**

Note. CDI = Children's Depression Inventory, BDI-II = Beck Depression Inventory-II, MDD = Major Depressive Disorder. Untransformed values are presented to facilitate comparisons with other studies; however, the group differences are maintained when using transformed variables.
* $p < .05$. ** $p < .01$.

Table 3
Results of the Concurrent Synchrony Analyses

Predictor	Zygomaticus				Corrugator			
	Vacation		Conflict		Vacation		Conflict	
	t	$r_{effect\ size}$	t	$r_{effect\ size}$	t	$r_{effect\ size}$	t	$r_{effect\ size}$
Mother EMG	17.56**	.06	10.11**	.03	4.26**	.01	8.25**	.02
Mother MDD	−.13	.00	−.05	.00	−.01	.00	.97	.00
Mother MDD × Mother EMG	2.91*	.01	−.67	.01	1.67	.01	−1.15	.00

* $p < .01$. ** $p < .001$.

mother MDD history for the Vacation Planning, $t(81{,}815) = 2.91$, $p = .004$, $r_{effect\ size} = .01$, but not the Issues, $t(12{,}2335) = -0.67$, $p = .50$, $r_{effect\ size} = .002$, discussion. To examine the form of the significant mother MDD × mother zygomaticus major activity interaction, we examined the main effect of mother zygomaticus activity on child zygomaticus activity separately in dyads with and without a maternal history of MDD. The association between mother and child zygomaticus major activity was stronger among dyads with no history of maternal MDD, $t(44{,}633) = 23.01$, $p < .001$, $r_{effect\ size} = .11$, than among dyads with a history of maternal MDD, $t(37{,}170) = 17.45$, $p < .001$, $r_{effect\ size} = .09$. Therefore, although all mother–child dyads exhibited positive concurrent synchrony in facial displays of positive affect during the Vacation Planning discussion, this synchrony was stronger among dyads with no maternal history of MDD than among dyads with a maternal history of MDD.

To examine the robustness of these findings, we conducted additional analyses to determine whether each of the significant relations reported above would be maintained when we (a) excluded dyads in which the mother or child met criteria for current MDD and when we statistically controlled for the influence of mothers' and children's (b) current depressive symptoms, (c) VAS sadness ratings, and d) demographic factors (family income and mother and child age, sex, and ethnicity). In all cases, the significant effects were maintained (all ps $< .01$).

Focusing next on synchrony of corrugator activity, we found a significant, positive relation between mother and corrugator activity during the Vacation Planning, $t(81{,}818) = 4.26$, $p < .001$, $r_{effect\ size} = .01$, and Issues Discussion, $t(12{,}2736) = 8.25$, $p < .001$, $r_{effect\ size} = .02$. In contrast, the main effect of maternal MDD history was nonsignificant during the Vacation Planning, $t(10{,}361) = -0.01$, $p = .99$ $r_{effect\ size} < .001$, or Issues, $t(13{,}061) = -0.04$, $p = .97$, $r_{effect\ size} < .001$, discussion. Similarly, the mother MDD × mother corrugator activity interaction was nonsignificant during the Vacation Planning, $t(81{,}805) = 1.67$, $p = .09$, $r_{effect\ size} = .006$, and Issues, $t(12{,}2704) = -1.50$, $p = .14$, $r_{effect\ size} = .004$, discussion. Therefore, mothers and children exhibited positive synchrony in facial displays of negative affect during both the Vacation Planning and the Issues Discussion, with no significant difference in synchrony between dyads with and without a maternal history of MDD.

As before, we conducted additional analyses to determine whether each of the significant relations reported above would be maintained when we (a) excluded dyads in which the mother or child met criteria for current MDD and when we statistically controlled for the influence of mothers' and children's (b) current depressive symptoms, (c) VAS sadness ratings, and (d) demographic factors (family income and mother and child age, sex, and ethnicity). In all cases, the significant effects were maintained (all ps $< .01$).

Lagged Synchrony Predicting Changes in Child Facial Affect

As can be seen in Table 4, higher levels of mother zygomaticus activity at Time T-1 predicted increases in child zygomaticus from Time T-1 to Time T during both the Vacation Planning and the Issues Discussion (all ps $< .001$). Higher levels of mother corrugator activity at Time T-1 predicted increases in child corrugator activity from Time T-1 to Time T during the Vacation Planning ($p < .001$) but not during the Issues Discussion, $t(45{,}399) = 1.82$, $p = .07$, $r_{effect\ size} = .01$. Finally, there was a significant mother MDD × mother zygomaticus T-1 interaction predicting changes in children's zygomaticus activity during the Vacation Planning, $t(24{,}017) = 2.39$, $p = .02$, $r_{effect\ size} = .01$. Paralleling what we

Table 4
Results of the Lagged Synchrony Analyses Predicting Child EMG

Predictor	Zygomaticus				Corrugator			
	Vacation		Conflict		Vacation		Conflict	
	t	$r_{effect\ size}$	t	$r_{effect\ size}$	t	$r_{effect\ size}$	t	$r_{effect\ size}$
Child EMG_{T-1}	253.96*	.85	365.18*	.87	206.92*	.76	301.94*	.82
Mother EMG_{T-1}	10.28*	.06	14.61*	.07	3.33*	.02	1.82	.01
Mother MDD	−.01	.00	−.04	.00	.01	.00	.07	.00
Mother MDD × Mother EMG_{T-1}	2.39*	.01	−.39	.00	−.56	.00	−1.33	.01

* $p < .001$.

found in the concurrent synchrony analyses, we found that mother corrugator activity at Time T-1 more strongly predicted change in child zygomaticus activity from Time T-1 to Time T among dyads with no history of maternal MDD, $t(13{,}526) = 14.29$ $p = .001$, $r_{effect\ size} = .12$, than among dyads with a history of maternal MDD, $t(12{,}127) = 10.27$, $p = .001$, $r_{effect\ size} = .09$.

As before, to examine the robustness of these findings, we conducted additional analyses to determine whether each of the significant relations reported above would be maintained when we (a) excluded dyads in which the mother or child met criteria for current MDD and when we statistically controlled for the influence of mothers' and children's (b) current depressive symptoms, (c) VAS sadness ratings, and (d) demographic factors (family income and mother and child age, sex, and ethnicity). In all cases, the significant effects were maintained (all $ps < .01$).

Lagged Synchrony Predicting Changes in Mother Facial Affect

As can be seen in Table 5, there were significant main effects of child zygomaticus activity at T-1 predicting changes in mother zygomaticus activity from Time T-1 to Time T during the Vacation Planning and Issue Discussion (all $ps < .001$). Similarly, there were significant main effects of child corrugator activity at Time T-1 predicting changes in mother corrugator activity from Time T-1 to Time T during both the Vacation and Conflict Discussions (all $ps < .001$). However, maternal history of MDD did not moderate any of these relations (lowest $p = .19$). Therefore, higher levels of children's facial displays of both positive and negative affect predicted increases in mother's displays of positive and negative affect 1 s later in both discussions to a similar degree in dyads with and without a maternal history of MDD.[1]

Concurrent Mother–Child EMG Synchrony and Changes in Self-Reported Affect

Prior to examining the impact of EMG synchrony on self-reported sad affect, we first examined overall levels of sad affect in mothers and children across the three phases of the Interaction Task (pretask, post-Vacation discussion, post-Issues discussion) in mothers and children using a repeated measures ANOVA. There was a significant effect of task on the VAS sadness ratings for mothers, $F(2, 680) = 96.98$, $p < .001$, $\eta^2_{partial} = .22$, and children, $F(2, 680) = 11.84$, $p < .001$, $\eta^2_{partial} = .03$. As can be seen in Figure 1, post hoc tests revealed that mothers' reports of sadness were highest following the Issues discussion, followed by the pretask rating, and were lowest following Vacation Planning (all $ps < .001$). Similarly, children's reports of sadness were highest following the Issues discussion, followed by the pretask rating, and were lowest following Vacation Planning (all $ps \leq .05$). We conducted similar analyses using maternal MDD as a between-subjects factor and there was no significant main effect of mother MDD, $F(2, 339) = 0.09$, $p = .76$, $\eta^2_{partial} < .001$; $F(2, 339) = 1.32$, $p = .25$, $\eta^2_{partial} = .004$, or mother MDD $\times$ task interaction, $F(2, 678) = 2.38$, $p = .09$, $\eta^2_{partial} = .01$; $F(2, 678) = 0.93$, $p = .40$, $\eta^2_{partial} = .003$, for either mothers' VAS ratings, or children's VAS ratings, respectively.

We then examined the impact of mother–child EMG synchrony during each discussion on changes in sadness ratings from before to after the discussion and whether this relation is moderated by maternal MDD history. Specifically, as described above, we used linear regression analyses with posttask VAS sadness scores entered as the outcome variable and pretask VAS sadness scores entered as a covariate, which allowed us to determine whether EMG synchrony scores predicted residual change in VAS sadness. Separate analyses were conducted to examine change in mother-rated and child-rated sadness. Pretask VAS sadness significantly predicted posttask VAS sadness in all analyses (all $ps < .001$). In the next step, we entered the EMG synchrony scores reflecting mother–child EMG synchrony during that task. As noted above, to obtain those scores, we calculated the average of moment-to-moment correlation in mother–child EMG activity separately for each task and muscle group (4 total). We found that greater synchrony in zygomaticus major activity during the Vacation Planning discussion was associated with a decrease in children's ratings of sadness from before to after the Vacation Planning discussion, $t(340) = -2.49$, $p = .01$, $r_{effect\ size} = .13$. Similarly, greater mother–child synchrony in zygomaticus major activity during the Issues Discussion was significantly associated with a decrease in mothers', $t(340) = -2.85$, $p = .005$, $r_{effect\ size} = .15$, and children's, $t(340) = -2.49$, $p = .01$, $r_{effect\ size} = .13$, ratings of sadness from before to after the Issues Discussion. In addition, greater synchrony in corrugator activity during the Vacation Planning was significantly associated with an increase in children's ratings of sadness from before to after the Vacation Planning, $t(340) = 2.62$, $p = .009$, $r_{effect\ size} = .14$. None of the other main effects of synchrony on mother or child posttask VAS sadness were significant (lowest $p = .24$). Finally, maternal history of MDD moderated the relation between dyadic synchrony in zygomaticus activity during the Vacation Planning and mothers' self-reported sadness, $t(340) = -2.03$, $p = .04$, $r_{effect\ size} = .11$, such that greater synchrony was associated with reduction in sadness among mothers with a history of MDD, $t(154) = -2.29$, $p = .02$, $r_{effect\ size} = .18$, but not among mothers with no history of depression, $t(185) = 0.48$, $p = .62$, $r_{effect\ size} = .03$. None of the other mother MDD $\times$ EMG synchrony interactions was significant (lowest $p = .20$). All of these relations remained significant when we statistically controlled for the influence of mothers' and children's (a) current depressive symptoms, (b) VAS sadness ratings, and (c) demographic factors (family income and mother and child age, sex, and ethnicity (all $ps < .03$). However, when we excluded dyads in which the mother or child met criteria for current MDD, the association between greater dyadic synchrony in zygomaticus major during the Issues Discussion and decrease in child ratings of sadness became marginally significant $t(340) = -1.77$, $p = .08$, $r_{effect\ size} = .10$.

Discussion

The primary goal of this study was to examine the potential impact of maternal history of MDD on the concurrent and lagged

[1] Although not a primary focus of this study, we also examined the potential role of children's depressive symptom levels on synchrony of facial affect and describe the analyses and results in detail in the footnote. We thank an anonymous reviewer for suggesting these analyses, which were conducted following the same approach as for the primary concurrent and lagged synchrony analyses, but with children's CDI score (main effect and all interactions) entered in the models.

Table 5
Results of the Lagged Synchrony Analyses Predicting Mother EMG

	Zygomaticus				Corrugator			
	Vacation		Conflict		Vacation		Conflict	
Predictor	t	$r_{effect\ size}$	t	$r_{effect\ size}$	t	$r_{effect\ size}$	t	$r_{effect\ size}$
Mother EMG_{T-1}	263.08*	.85	350.86*	.85	219.75*	.78	323.71*	.83
Child EMG_{T-1}	22.27*	.13	19.63*	.09	7.64*	.04	5.50*	.02
Mother MDD	.11	.00	.06	.00	−.02	.00	−.04	.00
Mother MDD × Mother EMG_{T-1}	−.78	.00	−.39	.00	−1.32	.00	−.99	.00

* $p < .001$.

synchrony of mother–child facial affect during positively valenced (Vacation Planning) and negatively valenced (Issues Discussion) interactions utilizing an objective physiological tool (i.e., EMG). Consistent with prior findings (e.g., McMakin et al., 2011; Radke-Yarrow et al., 1993), we hypothesized that mother–child dyads with a history of mother MDD would demonstrate stronger synchrony for expressions of negative affect, whereas families with no maternal history of MDD would evidence greater synchrony for expressions of positive affect. Our results partially supported these hypotheses. Specifically, we found that mother–child dyads with a history of maternal MDD evidenced less concurrent synchrony of positive emotional expressions, as well as less lagged synchrony of mother positive affect predicting changes in children's positive affect, during the Vacation Planning task. Notably, these results were maintained when we statistically controlled for the influence of mothers' and children's current depressive symptoms, age, sex, ethnicity, and family income, or excluded mothers and children with the current MDD diagnosis, suggesting that they were at least partially independent of mothers' and children's current mood and demographic characteristics. These findings of less concurrent and lagged synchrony of positive affect among mother–child dyads with a history of maternal MDD compared to families with no history of maternal MDD is consistent with previous research showing that currently depressed mothers displayed less positive behavior while interacting with their children (Gordon et al., 1989). Shared positive affect during mother–child interactions has been associated with greater prosociality and empathy in children, facilitating better future relationships with peers (Lunkenheimer, Olson, Hollenstein, Sameroff, & Winter, 2011). Moreover, previous research suggests that children's expression of positive affect

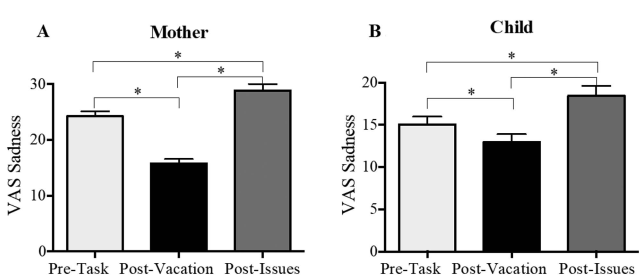

Figure 1. Mother (A) and child (B) VAS sadness ratings prior to the Discussion Paradigm and following the Vacation Planning and Issued Discussions. Sadness ratings for all three tasks were significantly different for both mothers and children.

are sustained by maternal reciprocation of positive emotion, touch, or play (Bai, Repetti, & Sperling, 2016). The current findings suggest that maternal history of MDD may adversely influence the normative mother–child exchange of positive affect, an effect that is least partially independent of current depression in the mother or child, and which is consistent with previous research on the impact of maternal MDD history on physiological synchrony (Woody et al., 2016).

Contrary to our hypotheses, however, maternal history of MDD did not moderate the concurrent or lagged synchrony of negative expressions. Specifically, we hypothesized greater negative affect exchange among dyads with a maternal history of MDD based on previous results showing more frequent bouts of negative affect among depressed mothers, which are reciprocated by their children, (Radke-Yarrow et al., 1993), moment-to-moment negative escalation between the depressed mother and their child (McMakin et al., 2011), as well as the broader literature on negative reciprocity in adult dyads (Cordova, Jacobson, Gottman, Rushe, & Cox, 1993; Heyman, 2001; Levenson & Gottman, 1983). Indeed, researchers hypothesize that the reciprocity of negative emotional expressions may lead to escalation of conflict and intensity of negative affect during the interaction (Salazar, 2015). The current study suggests that differences in the moment-to-moment exchange of positive, but not negative emotion differentiate mother–child dyads with and without a history of maternal MDD.

To explore the possible implications of greater concordance in the exchange of positive affective expressions between mothers and children and on families, we examined relations between dyadic synchrony during each task and changes in mothers' and children's self-reported mood. We found that higher dyadic synchrony in the activity of the zygomaticus major (smiling) muscle was associated with a decrease in child ratings of sadness during both discussion tasks and mother ratings of sadness during the Issues Discussion. Conversely, we found that greater synchrony in the activity for the corrugator (frowning) muscle during the Vacation Planning was related to an increase in children's reports of sadness following this task. Additionally, there was no moderating effect of maternal history of depression on either mothers' or children's ratings of sadness. These findings suggests that dyadic synchrony in expressions of positive emotion may contribute to a decrease in negative mood during both positively and negatively valenced discussions, whereas concordance in the exchange of negative affective expression may be associated with an opposite effect.

The current project has several strengths, including the focus on moment-to-moment assessment of mother–child concurrent and lagged synchrony of affective expressions and the utilization of objective physiological measures (i.e., facial EMG activity) to index the expression of affect expression in this high-risk population, as recommended by previous research (Leclère et al., 2014). Despite these strengths, the current project has several limitations, which provide important directions for future research. First, because of the cross-sectional design, we are unable to draw any conclusions about the effects of mother–child synchrony in positive and negative expressions on child's risk of developing depression in the future. Future research using longitudinal designs is needed to clarify the temporal sequence between maternal MDD, mother–child synchrony of affective expressions, and children's risk of developing depression over time. Additionally, although the use of facial EMG to discriminate between positive and negative affective expressions is well documented in previous research (e.g., Cacioppo et al., 1986), including research with children (REFs), future research using contemporaneous behavioral coding could provide more nuanced details about the effect of maternal MDD on mother–child interactions. Finally, given that we only assessed participants' self-reported sadness during the Discussion Paradigm, future research assessing other relevant emotions, including anger and frustration, is needed.

In conclusion, the current findings provide promising evidence for the effect of mothers' histories of MDD on mother–child synchrony of affective expressions, such that dyads with a history of maternal MDD evidence weaker concurrent and lagged synchrony of positive emotional expressions. If replicated, these results could contribute to developing interventions aiming to improve mother–child interactions that incorporate data from mother–child synchrony of affective expressions, especially among families that are at a higher risk of child MDD due to a history of maternal MDD.

In the concurrent synchrony analyses, we found significant CDI × mother EMG interactions predicting child EMG activity in the Vacation Planning task for both the corrugator, $t(81{,}832.00) = 2.78$, $p = .006$, $r_{effect\ size} = .01$, and the zygomaticus, $t(81{,}795.99) = -5.07$, $p < .001$, $r_{effect\ size} = .02$. To examine the forms of these interactions, we examined levels of concurrent synchrony among dyads in which the child exhibited higher (+1 *SD*) versus lower (−1 *SD*) levels of depressive symptoms. We found stronger concurrent synchrony of corrugator activity among dyads with higher depressive symptom levels, $t(81{,}773.70) = 7.40$, $p < .001$, $r_{effect\ size} = .03$, than among dyads with lower depressive symptom levels, $t(81{,}834.96) = 4.18$, $p < .001$, $r_{effect\ size} = .01$. In contrast, we found stronger synchrony of zygomaticus activity among dyads with lower depressive symptom levels, $t(81{,}819.82) = 24.24$, $p < .001$, $r_{effect\ size} = .08$, than among dyads with higher depressive symptom levels, $t(81{,}791.61) = 16.75$, $p < .001$, $r_{effect\ size} = .06$. Therefore, dyads in which the child had higher levels of depressive symptoms were characterized by stronger concurrent synchrony of negative facial affect (corrugator) and weaker synchrony of positive facial affect (zygomaticus) during the Vacation Planning task.

We also found significant mother MDD × CDI × mother zygomaticus interactions predicting child zygomaticus activity in the concurrent synchrony analyses, $t(122410.35) = 2.12$, $p = .03$, $r_{effect\ size} = .001$, and the lagged synchrony analyses (mother EMG predicting change in child EMG), $t(43{,}553.76) = 3.70$, $p < .001$, $r_{effect\ size} = .02$, during the Issues Discussion. Focusing first on the concurrent synchrony findings, the CDI × mother zygomaticus interaction was significant among dyads with no maternal history of MDD, $t(66{,}540.79) = -5.14$, $p < .001$, $r_{effect\ size} = -.02$, but not among those with a history of maternal MDD, $t(55{,}743.61) = -1.35$, $p = .18$, $r_{effect\ size} = .01$. Among dyads with no history of maternal MDD, the association between mother zygomaticus activity and children's zygomaticus activity was stronger among dyads in which the child had lower CDI scores (−1 *SD*), $t(66{,}621.40) = 10.71$, $p < .001$, $r_{effect\ size} = .04$, than among dyads in which the child had higher CDI scores (+1 *SD*), $t(66{,}537.98) = 3.52$, $p < .001$, $r_{effect\ size} = .01$.

Focusing next on the lagged synchrony findings, we again found that the CDI × mother zygomaticus interaction was significant among dyads with no maternal history of MDD, $t(23{,}806.22) = -3.64$, $p < .001$, $r_{effect\ size} = -.02$, but not among those with a history of maternal MDD, $t(20{,}017.80) = 1.78$, $p = .08$, $r_{effect\ size} = .01$. Among dyads with no history of maternal MDD, mother zygomaticus activity was a stronger predictor of change in children's zygomaticus activity among dyads in which the child had lower CDI scores (−1 *SD*), $t(24{,}073.12) = 13.45$, $p < .001$, $r_{effect\ size} = .09$, than among dyads in which the child had higher CDI scores (+1 *SD*), $t(24{,}044.61) = 8.42$, $p < .001$, $r_{effect\ size} = .05$. Therefore, among dyads with no maternal history of MDD, those dyads in which the child also had low levels of depressive symptoms were characterized by stronger concurrent and lagged (mother predicting child) synchrony of positive facial affect (zygomaticus) during the Issues Discussion.

Finally, there were no significant effects of child CDI scores on the lagged synchrony analyses of children's facial affect predicting changes in mothers' facial affect for either muscle group in either discussion.

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