Research on Child and Adolescent Psychopathology
https://doi.org/10.1007/s10802-023-01057-w

A Dynamic Systems Analysis of Dyadic Flexibility and Shared Affect in Preschoolers with and Without Major Depressive Disorder

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Accepted: 14 March 2023

Abstract

Preschool onset Major Depressive Disorder (PO-MDD) is a severe disorder often leading to chronic impairment and poor outcomes across development. Recent work suggests that the caregiver-child relationship may contribute to PO-MDD symptoms partially through disrupted caregiver-child interactions. The current study uses a dynamic systems approach to investigate whether co-regulation patterns in a dyad with a child experiencing PO-MDD differ from dyads with a child without the disorder. Preschoolers between the ages of 3–7 years-old ($N = 215$; $M(SD) = 5.22(1.06)$; 35% girls; 77% white) were recruited for a randomized controlled trial of an adapted version of parent-child interaction therapy. An additional sample ($N = 50$; $M(SD) = 5.17(.84)$' 34% girls; 76% white) was recruited as a control group. Dyads completed two interactive tasks and affect was coded throughout the interaction. State Space Grids (SSG) were used to derive measures of dyadic affective flexibility (i.e., affective variability in dyadic interactions) and shared affect. PO-MDD dyads did not differ from controls in dyadic affective flexibility. However, there were significant differences in shared positive and neutral affect. PO-MDD dyads spent less time and had fewer instances of shared positive affect and spent more time and had more instances of shared neutral affect than the community control group. These comparisons survived multiple comparisons correction. There were no differences for shared negative affect. Findings suggest that children experiencing PO-MDD have differing dyadic affective experiences with their caregivers than healthy developing children, which may be a mechanism through which depressive states are reinforced and could be targeted for treatment.

Keywords Depression · Caregiver-child interactions · State Space Grids · SSG

Preschool onset Major Depressive Disorder (PO-MDD) is considered a severe psychological disorder affecting approximately 2% of young children that can lead to chronic functional impairment and poor outcomes across domains of functioning (Luby et al., 2014; Whalen et al., 2017; Wichstrom et al., 2012). Over the past decade, numerous empirical studies document the validity, functional impairment, neurobiological correlates, and homotypic continuity of PO-MDD that often lead to ongoing impairment and poor functioning across the child's developmental course (Donohue et al., 2019; Whalen, Sylvester, & Luby, 2017). While most young children have difficulties navigating negative emotions, young children with depression have greater difficulties regulating their sadness and experience negative moods more often and for longer than non-depressed children (Cole et al., 2008). Recent work suggests that parenting and the caregiver-child relationship may contribute to the onset and maintenance of PO-MDD (Donohue et al., 2022; McLeod et al., 2007; Whalen et al., 2021), but most of this work has used static measures of parenting and the general caregiver-child relationship, offering little information about the specific patterns of caregiver-child interaction that may be driving the increased risk for PO-MDD. One potential mechanism by which the caregiver-child relationship may contribute to child symptoms is difficulties in the caregiver-child co-regulation of emotion. The current study uses a dynamic systems approach to investigate whether co-regulation patterns in dyads with a child experiencing PO-MDD differ from dyads with a child without the disorder, as

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Published online: 31 March 2023

this may be a mechanism for the maintenance and worsening of symptoms and could serve as a robust target for treatment. To our knowledge, this is the first study to use this approach to explore caregiver-child interactions in children with PO-MDD.

Early in life, the development of regulatory abilities happens mainly in the context of caregiver-child interactions (Fox & Calkins, 2003; Sroufe, 1996). Through labeling emotions, modeling regulatory strategies, and coaching or co-regulating, caregivers facilitate the acquisition of regulatory skills (Eisenberg, 2020; Eisenberg et al., 1998; Morris et al., 2017; Thompson, 2014). While caregivers play a crucial role in their children's developing regulatory abilities, children also actively contribute to these interactions and co-regulatory attempts (Feldman, 2007; Feldman et al., 1999; Moore et al., 2013; Tronick, 2007). Because of this, the caregiver-child dyad is considered a mutually regulating system where the caregiver and child are continuously influencing each other's behaviors and emotional states through shared affect and contingent responding (Cole et al., 2003; Feldman, 2007; Granic, 2000; Lunkenheimer et al., 2020; Tronick, 2007). Importantly, these reciprocal influences early in life have been found to be crucial for many developmental milestones beyond emotion development, including social competence more broadly (Feldman et al., 2013), language (Donnelly & Kidd, 2021), as well as general developmental outcomes (Feldman, 2015). In the context of emotion, dyadic affective flexibility – the affective variability in dyadic interactions – aids in the co-regulation of the caregiver-child dyad by facilitating children's learning of self-regulation and adaptive social interactions (Granic & Lamey, 2002; Hollenstein et al., 2004; Lunkenheimer et al., 2012). High dyadic affective flexibility supports children's learning of regulatory skills by giving the dyad the opportunity to practice regulating a more extensive range of affective states, a skill key to achieving emotional competence (Lunkenheimer et al., 2012). Work on dyadic affective flexibility in mother-child dyads demonstrates that greater flexibility is adaptive, with several studies finding that greater dyadic flexibility is linked to more overall positive interactions and fewer behavioral problems in the child (Granic et al., 2007; Lunkenheimer et al., 2011, 2013).

On the other hand, when caregiver-child dynamics are characterized by high mutually negative and rigid interactions, the risk for child behavioral problems increases (Dumas et al., 2001; Lunkenheimer et al., 2011, 2016; Rubin et al., 1991). Dysfunctional caregiver-child dynamics are characterized by greater difficulty attuning during co-regulatory attempts and may be most problematic in early childhood, when children are still developing emotion regulation skills and greatly depend on their caregivers to co-regulate with them (Fox & Calkins, 2003; Hoffman, Crnic, & Baker, 2006). While there is a dearth of work on caregiver-child dynamics in the context of child depression, there is significant evidence that caregiver - primarily mothers - depression has enduring effects on the caregiver-child relationship, increasing risk for children's later psychopathology (Cummings et al., 2005; Downey & Coyne, 1990; Goodman et al., 2011, 2020). Indeed, caregivers (most often mothers) with depressive symptoms tend to show lower levels of positive affect with their children (Tronick & Reck, 2009), but this work is limited to caregiver effects and has not fully considered caregiver and child affective dynamics in depressed children during dyadic interactions. However, fully considering the bidirectional nature of caregiver-child interactions can help us understand factors that contribute to child psychopathology in the absence of caregiver psychopathology. Interactions with a young child experiencing depression may be more challenging for the caregiver, making it difficult for the caregiver to maintain a positive interaction. This, in turn, could result in less dyadic positive shared affect and less affective flexibility, further worsening children's negative affect and depressive symptoms. The bidirectional nature of this interaction may be very powerful in early childhood, setting off a cycle of interactive effects.

A Dynamic Systems Approach to Studying Co-regulation

Given the dynamic and reciprocal nature of caregiver-child interactions, a greater understanding of how children's symptomatology may influence caregiver-child interactions would greatly benefit from a dynamic systems approach. State Space Grids (SSG) were developed to measure dynamic systems as they unfold in real-time using the dyad as the unit of analysis (Hollenstein, 2007; Lamey et al., 2004). SSG offers a richer understanding of caregiver-child interactions by mapping the moment-to-moment fluctuations of affect and behavior throughout an interaction for both caregiver and child. This offers a significant advantage over the typically used static measures of the global positive or negative nature of the relationship. SSGs in caregiver-child interactions have been used to study affective flexibility and shared affect as it relates to children's developing self-regulation and psychopathology symptoms (Granic et al., 2007; Hollenstein et al., 2004). Capitalizing on this technique, Hollenstein and colleagues (2004) found that less dyadic flexibility (i.e., rigidity; with mothers) was associated with preschoolers internalizing and externalizing symptoms both concurrently and longitudinally. In another seminal study in this area, Granic and colleagues (2007) found that aggressive children who showed significant improvements in symptomatology after treatment also

saw an increase in dyadic flexibility. Lastly, in a recent study conducted with mothers, greater dyadic flexibility in healthy dyads was associated with better child self-regulation, as long as the interactions were primarily positive (Lobo & Lunkenheimer, 2020).

Conversely, studies examining the role of caregiver (primarily mothers) depressive symptoms using SSGs demonstrates that higher caregiver symptoms are associated with lower dyadic affective flexibility, suggesting that caregiver depressive symptomatology is linked with different dyadic patterns from those seen in healthy dyads (Lunkenheimer et al., 2013). The finding that caregiver depressive symptoms is linked with decreased dyadic flexibility suggests that dyadic interaction patterns may look qualitatively different in dyads with a member experiencing depressive symptoms. In dyads with a young child presenting symptoms, dysfunctional caregiver-child interactions may play a significant role in the development and maintenance of clinical disorders. While the role of caregiver depressive symptoms has been well explored, we have no knowledge of data exploring the effects of child depressive symptoms on dyadic-level measures of affect and co-regulation in early childhood. Understanding how caregiver-child affective flexibility differs between dyads with a child experiencing MDD and children who are not may help delineate malleable factors within the dyad that contribute to increased symptoms.

Another commonly used SSG measure is shared affect or the ability to initiate and sustain matching affective displays (e.g., caregiver and child concurrently displaying positive affect; Guo et al., 2015; Lunkneheimer et al., 2011). Measures of shared affect are complimentary to affective flexibility as they can show dyadic patterns not visible when focusing only on affective flexibility (Guo et al., 2015, 2017). Work on shared affect has focused mainly on positive interactions, showing that interactions characterized by shared positive affect are associated with better child outcomes (Lobo & Lunkenheimer, 2020). Differences in the valence of affective displays may be an essential aspect differentiating dyads with a child experiencing MDD from children without a diagnosis. One potential meaningful difference in these dyads may be shared neutral affect, as there is evidence suggesting that in the context of (at least maternal) depression, higher levels of both shared neutral and negative affect are common (Downey & Coyne, 1990). While healthy dyadic interactions are characterized by both periods of shared affective states and periods of mismatch (e.g., child negative and caregiver neutral or positive; Tronick, 2007), healthy caregiver-child interactions early in life are generally positive in nature. While negative affect would undoubtedly be important to consider in caregiver child interactions, laboratory-based tasks may not offer enough affective range to fully probe differences across the entire negative affect spectrum. Instead, in the context of these tasks, a lack of developmentally expected shared positive affect may be manifested as an increased duration of neutral states. Thus, interactions characterized by high frequency and duration of shared neutral affect and low shared positive states may indicate dysfunctional patterns of interaction within these tasks. This in turn, may be a way through which depressive states are reinforced in the child.

Current Study

The current study aimed to examine moment-to-moment caregiver-child affective flexibility and shared affect in young children with and without a PO-MDD diagnosis and their primary caregiver. Specifically, we explored whether dyads with a depressed child differed in dyadic affective flexibility and shared affective displays across positive, neutral, and negative states. We utilized data from the baseline assessment of a randomized clinical trial for a novel treatment for PO-MDD, allowing us to test for potential differences in dyadic patterns before dyads underwent treatment (Luby et al., 2018, 2019). The trial was registered with ClinicalTrials.gov (NCT02076425) and tested an adapted version of parent-child interaction therapy (PCIT; Luby et al., 2018) with the addition of a novel emotion development module designed specifically for young children with PO-MDD. Based on existing work showing caregiver depression is associated with decreased affective flexibility and shared positive affect (Downey & Coyne, 1990; Tronick & Reck, 2009), we hypothesized that depressed children would show less affective flexibility, less shared positive, and more shared neutral and negative affect with their caregivers than children without a diagnosis, even when accounting for caregiver depressive symptoms. Analyses also controlled for externalizing symptoms to further disentangle the role of depressive symptoms versus other types of behavioral problems. To account for potential differences associated with high levels of caregiver depressive symptoms, we followed-up with analyses exploring whether patterns of shared affect and dyadic flexibility within the PO-MDD group differed between dyads with a caregiver experiencing high versus low levels of depressive symptoms.

Method

Participants

Preschoolers between the ages of 3.03–7.00 years ($M = 5.22$, $SD = 1.06$; 75 girls (35%)) were recruited to be part of a randomized controlled trial from day cares, preschools,

primary care and mental health practices in the St. Louis metropolitan area and were screened using the validated Preschool Feelings Checklist (Luby et al., 2004), a measure of early childhood depression between 2014 and 2017. All study procedures were approved by the Washington University in St. Louis Medical School Institutional Review Board. To be invited for an in-person assessment, children needed to have an elevated parent-report score on the PFC and elevated depressive symptoms, administered via a semi-structured interview by phone. MDD/MDD-NOS diagnosis was confirmed during the baseline assessment using a structured interview (described below). Exclusion criteria included autism spectrum disorder, significant neurological or medical conditions or developmental delays, active treatment of PO-MDD (i.e., children in ongoing psychotherapy or on antidepressant medication), unstable caregiving role or if child or family symptom severity indicated need for immediate care (see Luby 2018 for CONSORT diagram). The participating caregiver provided consent for themselves and their child to be part of the study before study procedures took place. Following baseline assessment, dyads were randomly assigned to the PCIT-ED or waitlist condition. This manuscript includes data from 215 parent-child dyads with a depressed child who participated in the baseline assessment prior to randomization. The racial breakdown of the MDD sample was: 76.7% white, 12.1% Black or African American, 0.5% Asian, 10.7% more than once race. A total of 11.2% of the sample identified as Hispanic/Latinx. The income breakdown for the families in the MDD group included 29% with an income below $50,000, 17% with an income between $50,000–80,000, and 54% with an income above $80,000.

In parallel, a community sample of preschoolers 4.01–7.19 years-old ($M = 5.17$, $SD = 0.84$; 17 girls (34%)) was recruited from the St. Louis metropolitan region from daycares, primary care practices and local flyers posted online and in person. Children needed to score below clinical threshold on the Child Behavior Checklist (CBCL, T-score < 70 for total CBCL score) and were matched on gender, age, ethnicity and socio-economic status. The current manuscript includes data from 50 parent-child community dyads who participated in a one-time session similar to the baseline assessment for the MDD group. The racial breakdown of the community group was: 76% white, 10% Black or African American, 4% Asian, 10% more than once race. A total of 12% of the sample identified as Hispanic/Latinx. The income breakdown for the families in the community sample included 25% with an income below $50,000, 25% with an income between $50,000–80,000, and 50% with an income above $80,000.

Measures

Child depression. Childhood depression diagnosis was confirmed using The Kiddie Schedule for Affective Disorders and Schizophrenia- Early Childhood (KSADS-EC; Gaffrey & Luby, 2012). The KSADS-EC is a semi-structured diagnostic interview administered to caregivers of children ages 3.0–6.9 years, with good construct validity and test-re-test reliability. All diagnostic interviews were conducted by trained master's level clinicians who established inter-rater reliability prior to study start. Interviews were videotaped, reviewed for reliability and calibrated for accuracy, and interrater reliability was computed on a monthly basis (depression diagnosis: K = 0.74).

Child externalizing symptoms. Externalizing behaviors in the child were assessed via caregiver report by using the externalizing behaviors subscale of the Child Behavior Checklist (CBCL; Achenbach & Rescorla, 2000). Caregiver completed the 1.5-5 or the 6–18 version based on the age of the participating child. The externalizing problems subscale reflects rule breaking behavior and aggressive behavior. T-scores were used as covariate in analyses.

Caregiver depression. Depressive symptoms in the participating caregiver were self-reported using the Beck Depression Inventory–II (BDI-II; Beck et al., 1996). The BDI-II consists of 21 questions assessing depressive symptoms during the previous two weeks. Items are summed to yield a total score. Higher scores indicate more severe depressive symptoms. Based on BDI suggested cutoff of 20 (Beck et al., 1996), a total of 26 parents (12%) in the MDD group and two parents (4%) in the community control group had moderate to severe symptoms of depression.

Income-to-Needs ratio. The income-to-needs ratio was calculated as the total family income at the time of the visit divided by the federal poverty level based on family size (McLoyd, 1998).

Observational Tasks and Coding

Tasks. Two observational tasks were used in the current study to assess caregiver-child affect (Kochanska & Aksan, 1995, 2004). First, in the Marble Run Task, dyads were asked to build a standing marble run based on a picture. The second task, the Etch-a-Sketch task, required the dyad to work together to get through a maze on an etch-a-sketch by having each member of the dyad control a dial of the etch-a-sketch. Both of these tasks were designed to elicit mild stress levels, were expected to elicit negative emotions in the child and required caregiver involvement for completion. Caregiver and child affect were coded using procedures described below.

Coding. All videotapes were coded using the Dyadic Parent-Child Interactions in Early Childhood, PCIT-ED edition manual (Whalen & Gilbert, 2017). This manual was adapted from the Dyadic Interaction Coding Manual (Lunkenheimer et al., 2011) and has been used in previous manuscripts from the lab (Brady et al., 2022; Whalen, Gilbert, & Luby, 2021). The coding scheme includes independent assessment of affective displays and functional control/compliance behaviors (not considered here) in the caregiver and child. A team of coders independently coded each video using Noldus Observer XT software (Zimmerman et al., 2009). Coders were blind to diagnostic and treatment status of participants and to study hypotheses and were randomly assigned the videos. Master coders (authors DW and KB) coded 20% of the videos (chosen at random) to confirm that inter-observer agreement was maintained throughout time. All coders achieved reliability higher than 80% with the master coders before they were able to code videos independently. Caregiver and child affective codes were organized into positive, neutral, and negative affective categories for each of the tasks. These general codes for positive, neutral, and negative caregiver and child affect were used to calculate the dyadic affective measures described below.

State Space Grids. Caregiver-child dyadic patterns were assessed using State Space Grids (SSG) in GridWare 1.15 (Lamey et al., 2004), consistent with most work on SSGs (e.g., Guo et al., 2015; Lunkenheimer et al., 2013; Lunkenheimer et al., 2021). Caregiver and child affect were mapped onto SSGs with three affective displays (positive, neutral, and negative) on the x-axis for the child and the y-axis for the caregiver, resulting in a total of nine possible combinations of affective displays. The trajectories of affective displays across the two tasks were plotted for the entire duration of the tasks. Each circle in the SSG grid indicates an event, and its size indicates the duration of time spent in that state. Thus, larger circles indicate longer time spent in that state. Lines between circles indicate transitions from one state to the other (see Fig. 1 for an example).

From the SSG, we derived three grid-level measures that represent dyadic affective flexibility across the entire SSG space: range, dispersion, and transition. These measures have been consistently used as indicators of dyadic flexibility (Granic et al., 2007; Guo et al., 2015; Lunkenheimer et al., 2011, 2021). The *range* represents the total number of unique cells displayed by the dyad. Higher values indicate that the dyad spent more time in different states in the grid, showing greater flexibility in affective displays. *Dispersion* represents the distribution of affective displays across the entire grid and is calculated as the sum of squared proportional durations across all cells, adjusted for the number of cells in the grid. These values are then inverted, so the values range from 0 (indicating all affective displays were within the same cell) to 1 (indicating that the affective displays were distributed equally across all the cells in the grid; Lunkenheimer et al., 2011). Lastly, *transitions* can be defined as the number of moves in affective states (and between cells), with higher values indicating that the dyad moved more frequently between states. A transition is defined as the total number of cell displays minus one, with a display representing at least one event happening within a given cell.

We also derived six measures representing regional-level measures of shared affect across the entire task for positive, neutral, and negative states (i.e., duration and visits to each shared state). *Region duration* measures the extent to which the dyad sustains a particular affective state (e.g., time spent in a shared positive state; Guo et al., 2015; Guo et al., 2017; Lunkneheimer et al., 2013). *Region displays* indicate the tendency of the dyad to initiate a shared affective state by indicating the number of times the dyad moved into a particular region (e.g., shared negative state) from another region of the grid (e.g., caregiver positive and child neutral).

To account for minor differences in the total duration of the task across dyads, all SSG variables were converted to proportions by dividing each SSG variable by the total duration of the task before any analyses were conducted. The

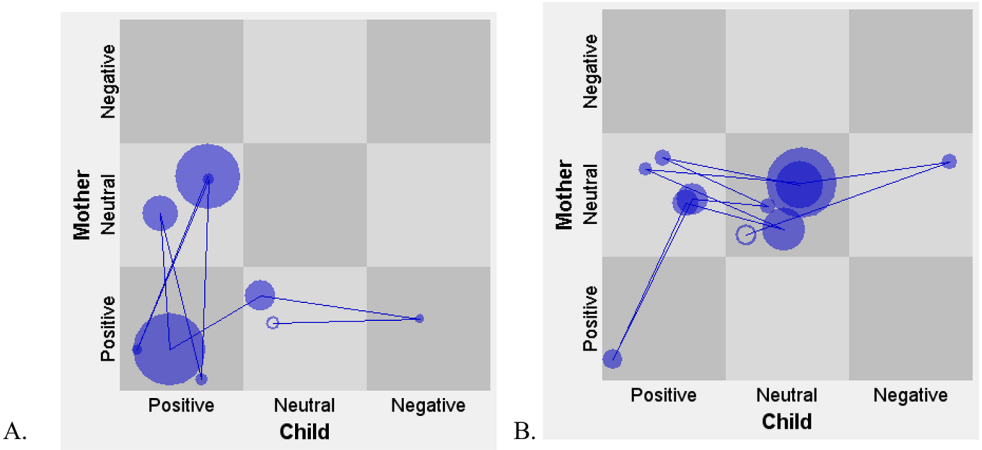

Fig. 1 Representative SSGs depicting trajectories for parent-child behavior in one community control (A) and one MDD (B) dyad during the MR task. Circles vary in size based on the duration of time spent in a particular state. Larger circles indicate more time spent on that state. Lines show transitions between dyadic states

proportion scores for both observational tasks were then averaged into a single score to reduce the number of analyses performed.

Analysis Plan

Primary analyses comparing shared affect between caregiver-child dyads for the community control and MDD groups were conducted using ANCOVAs. Age, income-to-needs, externalizing symptoms, and caregiver depressive symptoms were included as covariates. An ANCOVA was conducted for each SSG-derived dyadic variable with all four covariates. FDR correction for multiple comparisons was used. Kolmogorov-Smirnov and Shapiro-Wilk were conducted on the outcome variables to check for normality. Follow-up analyses within the PO-MDD group were conducted to assess whether PO-MDD dyads with a caregiver reporting moderate to high depressive symptoms differed from PO-MDD dyads with a caregiver reporting low symptoms in all SSG variables.

Results

Preliminary Analyses

Before conducting our primary analyses, we assessed whether our community control and MDD groups differed in any covariate of interest. No gender differences emerged for either the MDD or the community control group, X^2 (1, $N = 265$) = 0.014, $p = .906$. We also found no differences in age or family's income-to-needs (Table 1). However, age and income-to-needs were retained as covariates given the extant research demonstrating that there are significant differences in caregiver-child interactions based on these variables and to be consistent with previous work using this sample. As expected, the groups did differ on caregiver depression and externalizing symptoms. Caregivers in the MDD group had higher mean levels of depressive symptoms than caregivers in the community control group and children in this group had higher caregiver-reported levels of externalizing symptoms (Table 1).

Primary Analyses

Primary analyses explored whether dyads with a child with MDD differed from community controls in measures of dyadic flexibility and shared (positive, neutral, and negative) affect.

Do Dyads with a Depressed Child Differ in Their Affective Flexibility from Community Controls?

An ANCOVA for each of the following variables: range, dispersion, and transitions was conducted. There were no significant differences in any of the three measures of affective flexibility (Table 2).

Do Dyads with a Depressed Child Differ in Their Shared Affect from Community Controls?

Six ANCOVAs covarying for child's age, family's income-to-needs ratio, caregiver depression, and child externalizing symptoms were conducted on our measures of positive, neutral, and negative shared affect. For each affective valence, two variables were considered: duration of time spent in shared affect and the number of visits to that shared affective state.

There were significant effects of group on duration and displays of a shared positive state, such that the community control group spent more time and had more instances of shared positive states. These comparisons survived FDR correction (Table 2). There were also significant effects of group on duration and displays of a shared neutral state, such that the MDD group spent more time and had more instances of shared neutral states than the community control group. These comparisons survived FDR correction (Table 2). Lastly, there were no significant effects of group on duration or visits to a shared negative state.

Follow-up for Non-normally Distributed Variables

Examination of results from Kolmogorov-Smirnov and Shapiro-Wilk tests revealed that affect variables were not normally distributed. We conducted non-parametric Mann-Whitney U tests on affect variables to confirm the validity

Table 1 Covariates by group with *t*-test comparisons

Variable	Full Sample		Controls ($N = 50$)		MDD ($N = 215$)				
	Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*	*t(df)*	*p*	*d**
Age	5.21	1.02	5.17	0.84	5.22	1.06	−0.29	0.77	−0.05
Income to Needs	2.97	1.33	2.90	1.29	2.98	1.34	−0.41	0.69	−0.07
Child Externalizing**	61.90	13.68	42.69	8.94	66.31	10.37	-14.73	< 0.001	-2.33
Caregiver depression	10.04	9.13	4.58	6.31	11.31	9.23	-4.89	< 0.001	−0.77

*Effect sizes reported as Cohen's d; **T-scores

Table 2 ANCOVA tests comparing caregiver-child affective flexibility and shared affect between the community control and MDD groups with covariates

	Control ($N = 50$)		MDD ($N = 215$)				
	Mean	*SD*	*Mean*	*SD*	*F*(*df*)	*p* (*FDR p*)	Partial η^2
Overall							
Cell Range	0.03	0.02	0.02	0.01	0.57	0.45	0.002
Dispersion	0.004	0.004	0.003	0.001	2.03	0.16	0.01
Transitions	0.06	0.03	0.07	0.03	0.81	0.37	0.003
Positive							
Positive: Duration	0.19	0.19	0.11	0.16	6.74	0.01 (0.02)	0.03
Positive: Visits	0.01	0.01	0.01	0.01	4.69	0.03 (0.05)	0.02
Neutral							
Neutral: Duration	0.21	0.21	0.35	0.25	7.70	0.006 (0.02)	0.03
Neutral: Visits	0.01	0.01	0.02	0.01	8.53	0.004 (0.024)	0.03
Negative							
Negative: Duration	0.03	0.06	0.02	0.04	0.52	0.24	0.002
Negative: Visits	0.003	0.01	0.003	0.01	0.08	0.79	0.00

Note: Duration = time spent in a shared emotional state; Visits = the number of times the dyad moved into a shared stated. All variables are proportion scores

of results as these tests are robust to nonnormality and distribution free. The results of the Mann-Whitney tests replicated the ANCOVA results. Overall affective flexibility as evidenced by the affective range ($U = 5649$, $p = .575$), dispersion ($U = 4762$, $p = .209$), and transitions ($U = 6094$, $p = .141$) did not significantly differ between the community control and MDD groups. Consistent with the ANCOVA results, positive shared affect duration ($U = 3596$, $p < .001$) did differ between the two groups. The control group had a mean rank duration of 168.58, while the control group had a mean rank duration of 124.73. Similar results were seen for positive visits ($U = 3740$, $p < .001$), with the mean rank for the control group (165.70) being higher than for the MDD group (125.40). Neutral shared affect results were also consistent with the ANCOVA results. Both neutral duration ($U = 3463.50$, $p < .001$) and neutral visits ($U = 3303.50$, $p < .001$) differed between the two groups. The MDD group showed higher duration (mean rank = 141.89) and visits (mean rank = 142.63) than the control group (mean rank duration = 94.77; mean rank visits = 91.57). Lastly, also consistent with the ANCOVA results, negative duration ($U = 3740$, $p < .001$) and negative visits ($U = 3740$, $p < .001$) did not differ between the two groups.

Follow-up for Caregiver Depression

While depressive symptoms were not a significant covariate in any of the models, we ran follow-up analyses in the PO-MDD group only to assess whether dyadic patterns *within* this group differed based on caregiver depression. Groups were created based on a BDI-II cutoff of 20 (indicative of moderate symptoms). A total of 26 caregivers had a BDI-II over the cutoff and were assigned to the high symptoms group, the other 189 caregivers were assigned to the low symptoms group. We ran t-tests as well as non-parametric Mann-Whitney U tests (given the non-normality of the SSG variables) to assess whether the dyads with a depressed child and a caregiver experiencing high symptoms of depression differed from dyads with a depressed child and a caregiver experiencing low symptoms in SSG variables. All analyses were non-significant ($p > .10$ before FDR correction), suggesting that dyads with a caregiver with high symptoms were not driving the PO-MDD effects in our primary analyses.

Discussion

The current study explored whether dyads with a young child experiencing PO-MDD showed different patterns of moment-to-moment affective displays during a caregiver-child interaction compared to community controls using SSGs. The use of this dynamic approach is a notable advancement over previous work that has focused on static measures of the general caregiver-child relationship. Contrary to our expectations, we did not find group differences in dyadic flexibility or shared negative affect. However, consistent with our hypotheses, we did find significant group differences in shared positive and neutral affect, such that the PO-MDD group showed less shared positive and more

shared neutral affect with their caregivers during an interaction than the community controls. While our study is not able to say with certainty what may be driving this lack of shared positive affect, developmental work demonstrating the generally positive nature of caregiver-child interactions supports the idea that a lack of shared positive affect indicates some dysfunction in the caregiver-child relationship.

Our study is the first to demonstrate that the moment-to-moment affective patterns of dyadic interaction of young children with PO-MDD are different than their non-depressed peers, and that this is not influenced by caregiver depressive symptoms or child externalizing symptoms. This represents a notable contribution to the PO-MDD literature. It also points to a modifiable caregiver-child level factor that may influence young children's depressive symptoms and which can serve as a target for early intervention to address symptoms in this group.

As expected, patterns of dyadic interaction differed in our PO-MDD sample compared to the community controls. This is consistent with previous work showing that interactions characterized by low shared positive affect are associated with both caregiver and child behavioral problems (Guo et al., 2017; Lunkenheimer et al., 2013). It is interesting, however, that the differences in our study were specific to shared positive and neutral affect and not dyadic flexibility or negative affect as hypothesized. This suggests that while both groups showed a similar range of affective displays there were qualitative differences in the amount of time they spent in positive and neutral states. While we had hypothesized that children in the PO-MDD would show more shared negative affect with their caregivers, PO-MDD dyads spent a comparable amount of time in shared negative displays with their caregivers. This could be due to the mildly stressful nature of the task resulting in a low incidence of negative states for both groups. The specificity of our finding to shared positive and neutral affect is not unique to our study as others have found similar patterns (e.g., Guo et al., 2015). Our findings suggest that PO-MDD symptoms may be at least partially maintained through a lack of positive affect in the caregiver-child interactions. Future work should aim to further probe this by also exploring the neurobiological processes driving these dyadic patterns as recent work demonstrates that this level of analysis can offer further insight into dyadic interaction patterns across disorders (Quiñones-Camacho et al., 2021; Ratliff et al., 2022).

Most work on depression and caregiver-child affective dynamics has centered on caregiver depression given its notable and enduring effects on child development (Cummings & Davies, 2005; Goodman et al., 2011; Lunkneheimer et al., 2013; Lunkenjeimer et al., 2021). However, young children can experience depression in the absence of caregiver symptoms, as was the case for a significant number of children in our PO-MDD sample. Understanding caregiver-child dynamics that may be contributing to young children's depressive symptoms is of vital importance for the identification of dyadic-level target mechanisms for intervention. While the most adaptive parent-child interactions are characterized by more than just shared positive affect, positive affective displays within the dyad are important for shaping the quality of parent-child interactions. A lack of shared positive affect with an increase of shared neutral affect likely indicates patterns of dysfunction within the dyad. Interestingly, caregiver depression symptoms did not emerge as a significant covariate in any of our primary analyses. We also failed to find differences in dyadic patterns in PO-MDD dyads with a caregiver experiencing high vs. low depressive symptoms. The lack of caregiver effects suggests that child symptoms have a notable effect on caregiver-child dynamics that has not been sufficiently considered in work to date and needs to be accounted for.

Clinically, these findings have several implications. Children with PO-MDD and their caregivers shared more neutral and less positive affect, independent of caregiver depressive symptoms. Although much research has been done examining how caregiver depression influences children's outcomes, in the context of interventions targeting children's depressive symptoms, mild to moderate caregiver depression need not be an impediment to effective intervention (Luby et al., 2018; Schwartz et al., 2022). Interventions that focus on enhancing positive emotions in young children with PO-MDD, such as PCIT-ED (Luby et al., 2018) may be particularly useful to not only improve children's depressive symptoms but also enhance the quality of their relationship with caregivers, and in turn, caregiver symptoms. The findings from the current study provide empirical evidence that could influence how PCIT-ED is implemented. Specifically, PCIT-ED should explicitly emphasize increasing positive affect, particularly dyadic shared affect, and work towards decreasing shared neutral affect during mildly stressful situations, as this may be exceptionally beneficial for these children. Further, these findings will also be useful for future shortened adaptations of PCIT-ED (which are currently in progress) to clarify which components are most essential to emphasize and deliver in a shortened format. Moreover, findings from this study could also help contextualize findings from other parent training interventions, including interventions with emotion-oriented modules (Assenany & McIntosh, 2002; Bierman, McDoniel, & Loughlin-Presnal, 2019; England-Mason & Gonzalez, 2020; Maliken & Katz, 2013; Sanders et al., 2014). Specifically, our findings suggest that these interventions may also wish to consider the benefit of teaching caregivers to over-respond to their child's positive affect in order to heighten and sustain both positive affect and corresponding mutuality (McMakin et al., 2011).

Lastly, it is likely that children with PO-MDD also exhibit low levels of positive affect in other social situations and interactions, as such, increasing positive affect displays may also improve other relationships.

The above results should be considered with the following limitations. This manuscript reports on secondary data analysis of a randomized control trial and should be interpreted in light of the larger RCT inclusion and exclusion criteria. For instance, some criteria used to balance treatment groups (e.g., sex and co-morbid externalizing disorders) in the PO-MDD participants may have selectively excluded others from participation, as the final sample was relatively high in socio-economic status and primarily white. Although coding was conducted on a second-by-second basis, the overall scheme focused on global affective displays. This is in contrast to systems designed to capture minute facial changes and behavioral displays (e.g., FACS). As such, coders ratings may have been influenced by either: (1) overarching impressions of the caregiver or child; and/or (2) a prominent interactional turn that occurred during the task. Moreover, this may have constrained instances of negative affect coded, thus, future research would benefit from using a similar analytic approach with a more fine-grained coding system. Additionally, while developmentally appropriate tasks were chosen for the interaction, the level of negative affect for both groups in the task was generally low, potentially precluding a thorough exploration of group effects on negative shared affect. Finally, although many of our caregivers reported symptoms of depression in the mild to moderate range, our results may not generalize to caregivers with more severe depressive symptoms or current episodes of depression.

In sum, our study found young children experiencing PO-MDD have disrupted affective patterns with their caregivers characterized by decreased positive and increased neutral exchanges that may be contributing to the maintenance and worsening of their MDD symptoms. Our findings represent a unique and noteworthy contribution of child affect to our understanding of risk factors for PO-MDD and dyadic impairments and supports interventions such as PCIT-ED focused on modifying caregiver-child interactions for improving child symptoms.

Acknowledgements L.E.Q.C., D.J.W., J.L.L., and K.E.G. had full access to all the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis. The authors wish to thank the families who participated in the Parent–Child Interaction Treatment Emotion Development (PCITED) study as well as the team of coders who made this work possible. Clinical trial registration information: A Randomized Control Trial of PCITED for Preschool Depression; http://clinicaltrials.gov/NCT02076425.

Funding This work was supported by the National Institute of Mental Health, Grant #s 5R01MH098454-04 (PI: J.L.L.), K23MH115074-01 (PI: K.E.G.), K23MH22325028202-01 (PI: D.J.W.). The funding source had no role in the design and conduct of the study, the collection, management, analysis, and interpretation of the data; the preparation, review, or approval of the manuscript; or the decision to submit the manuscript for publication.

Declarations

Conflict of Interest The authors have declared that they have no competing or potential conflicts of interest.

Ethics Approval Approval for the study procedures was obtained from the ethics committee of Washington University in St Louis School of Medicine. The procedures used in this study adhere to the tenets of the Declaration of Helsinki.

Consent to Participate Written informed consent was obtained from the parents.

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