INTRODUCTION

Major depressive disorder (MDD) is a highly prevalent psychiatric disorder with negative consequences for quality of life, rendering it a significant public health problem (Avenevoli, Swendsen, He, Burstein, & Merikangas, 2015). Exposure to childhood adversity, such as parental harsh discipline, has been consistently associated with an increased risk for depression in children and adolescents (McLeod, Weisz, & Wood, 2007; Yap & Jorm, 2015). At the neural level, the striatum, a subcortical structure that is centrally involved in hedonic tone and reward processing, has been strongly implicated in depression (Tremblay et al., 2005). However, few studies have examined the associations among parental harsh discipline, the striatum, and depressive symptoms in children. Indeed, while an abundance of neuroimaging work has focused on the role of extremely adverse parenting, such as child abuse or neglect, few studies have examined how the developing brain may be shaped by variations in parental care within the normal range (Belsky & de Haan, 2011).

Increases in depressive symptoms during middle childhood have been found to precede the onset of depression (Keenan et al., 2008;
Luby, Gaffrey, Tillman, April, & Belden, 2014), which typically occurs in adolescence (Avenevoli et al., 2015). Thus, a focus on middle childhood can bolster understanding of the observable precursors to the onset of psychopathology, and help to identify biomarkers of increased risk. As such, the goal of the current study was to examine the links among parental harsh discipline, striatal volume, and depressive symptoms in children.

1.1 | Parental harsh discipline and depression in children and adolescents

Within the developmental psychopathology framework, interpersonal theories posit that parenting quality contributes to children's risk for depression. One important parenting dimension, harsh or punitive discipline, encompasses parental use of an overly critical or punitive approach during interactions with their children. Such parenting practices have been consistently linked with higher risk for depression (e.g., a significant increase in depressive symptoms, diagnosis of MDD) in children and adolescents (Bender et al., 2007; Lau, Rijsdijk, Gregory, McGuffin, & Eley, 2007; Yap & Jorm, 2015). Indeed, parental harshness has emerged as the parenting dimension most strongly associated with risk for depression in children and adolescents (McLeod et al., 2007; Yap & Jorm, 2015).

1.2 | Parental harsh discipline and striatal volume in children and adolescents

Parental harsh discipline, which represents a chronic stressor, may increase children's risk for depression by altering reward processing and increasing anhedonia. In animal models, chronic stressors have been found to induce low reward responsiveness, anhedonia-like behavior and impairment in reward circuitry, including the striatum (Pizzagalli, 2014). The striatum can be subdivided into a dorsal portion, which includes the dorsal caudate and putamen, and a ventral portion, which includes the nucleus accumbens (Delgado, 2007; Fareri & Tottenham, 2016; Pizzagalli, 2014). The dorsal and ventral striatum have distinct reward processing roles, with ventral regions more strongly associated with reward anticipation and dorsal regions associated with reward-related learning and linking incentives to actions (Delgado, 2007; Pizzagalli, 2014).

Extreme forms of early adversity have been linked with differences in striatal structure and function (Fareri & Tottenham, 2016; Teicher, Samson, Anderson, & Ohashi, 2016). Individuals with a history of maltreatment or institutional/orphanage rearing consistently demonstrate diminished striatal activation in response to reward (Dillon et al., 2009; Goff et al., 2013; Hanson, Hariri, & Williamson, 2015; Mehta et al., 2010). Child maltreatment has also been linked with altered striatal morphology, with significant findings for the caudate and putamen (Teicher & Samson, 2016). But, these studies have indicated both increases and decreases in striatal volume, potentially due to differences in age, sex or concurrent psychopathology across samples (Teicher & Samson, 2016).

Normative variation in parental care has also been linked with striatal structure and function in children. Normative variation in positive parenting (e.g., maternal warmth, authoritative parenting) has been linked with striatal activation in adolescents (Casement et al., 2014; Guyer et al., 2015). In addition, maternal hostility at 3 years has been found to predict more negative frontal-striatal connectivity during a reward processing task at 10 years (Kopala-Sibley et al., 2018). More frequent maternal aggressive behavior has also been associated with altered structural development of the nucleus accumbens in adolescent males (Whittle et al., 2016). However, to our knowledge, there are no studies focused on parental harsh discipline and striatal morphology in middle childhood.

1.3 | Striatal volume and depression

In fMRI work, adults and adolescents with MDD have been consistently found to exhibit a pattern of low striatal response to reward, primarily in the ventral striatum (Forbes & Dahl, 2012; Luking, Pagliaccio, Luby, & Barch, 2016). Differences in striatal volume have also been documented in MDD. In two meta-analyses of adults, the results indicated small to moderate volume reductions in the caudate and putamen among depressed patients relative to healthy individuals (Kempton et al., 2011; Koolschijn, van Haren, Lensvelt-Mulders, Hulshoff Pol, & Kahn, 2009), although another recent meta-analysis did not find striatal differences (Schmaal et al., 2016). In adolescents, depressive symptoms have been associated with smaller dorsal striatal volume (Auerbach et al., 2017; Matsuo et al., 2008; Shad, Muddasani, & Rao, 2012; Vulser et al., 2015; Whittle et al., 2014). In addition, smaller nucleus accumbens volume has been linked with depression in adolescent girls (Whittle et al., 2014) and more severe anhedonia in adolescents (Auerbach et al., 2017). Given that the majority of the research has focused on adult or adolescent MDD, research is needed that focuses on the neural correlates of increased depressive symptoms in middle childhood. Further, differences in striatal structural development may represent a mechanism through which parental harsh discipline increases children’s risk for depression (Goff & Tottenham, 2015). Parental harsh discipline may reduce striatal response to reward, leading to anhedonia and an increased risk for depression (Pizzagalli, 2014).

1.4 | Current study

The goal of the current study was to examine the associations among parental punitive discipline, striatal volume, and depressive symptoms in middle childhood. Children who ranged from 5–9 years of age (63% female) participated in high-resolution, T1-weighted MRI scans. Gray matter volume for the caudate, putamen, and nucleus accumbens was extracted. Parents completed a parenting questionnaire and assessments of their children's depressive symptoms (n = 20 with both parenting and MRI data; n = 48 with both MRI and depressive symptom data).
We hypothesized that more frequent parental punitive discipline would be associated with smaller striatal volume in children, which would be linked with greater depressive symptoms. In addition, we tested whether these associations held after controlling for parental depressive symptoms, given the heritability of reward processing and depression (Bogdan & Pizzagalli, 2009). The dorsal and ventral striatum were examined separately based on evidence of their distinct roles in reward processing (Delgado, 2007; Farei & Tottenham, 2016; Pizzagalli, 2014). Finally, we explored whether striatal volume mediated the association between parental punitive discipline and children’s depressive symptoms (see Figure S1).

Elevated depressive symptoms in middle childhood have been linked with an increased likelihood of developing depression during adolescence (Keenan et al., 2008). Understanding the correlates of increases in depressive symptoms in middle childhood and the neural mechanisms underlying such increases may lead to earlier identification of children at risk for depression and more effective prevention and treatment strategies.

2 | METHODS

2.1 | Participants

Participants were recruited in New York, NY through local community children’s events and posting flyers. Interested families were contacted by phone and screened for eligibility. Inclusionary criteria for children were as follows: (a) between 5 and 9 years of age, (b) born after 37 weeks of gestation, (c) born from a singleton pregnancy, (d) no history of medical or psychiatric problems, (e) spoke primarily English in the home, (f) no contraindications for MRI scanning.

2.1.1 | Sample characteristics

Children ranged from 5.12 to 9.93 years of age (63% female). They were diverse in terms of race/ethnicity (47% Hispanic/Latino; 29% African American; 20% European American) and socioeconomic background, with parental education ranging from less than a high school diploma to a postgraduate degree (10–20 years of education) and family income ranging from $6,500–$350,000 (see Table 1).

2.1.2 | Sample sizes

Of the 85 families who enrolled in the study and participated in a mock scan, MRI data were acquired for 66 children (see Figure S2 for flow chart). Out of the 51 children with usable MRI data (see below), there were 48 whose parents completed questionnaires about child mental health. A parenting measure was added to the protocol mid-study, and 28 parents completed this measure. These 28 families did not differ from the larger sample in terms of child age, sex, race/ethnicity, family income, or parental education. Child MRI data was available for 71% of the families who completed the parenting measure (n = 20).

<table>
<thead>
<tr>
<th>TABLE 1</th>
<th>Descriptive statistics for sample characteristics (N = 51)</th>
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<tbody>
<tr>
<td></td>
<td>M</td>
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<tr>
<td>Child age (years)</td>
<td>7.48</td>
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<tr>
<td>Parental education (years)</td>
<td>14.40</td>
</tr>
<tr>
<td>Family income (U.S. dollars)</td>
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<tr>
<td>Child sex (female)</td>
<td>62.75</td>
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<tr>
<td>Child race/ethnicity</td>
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<tr>
<td>African American, non-Hispanic/Latino</td>
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<tr>
<td>Hispanic/Latino</td>
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<tr>
<td>European American, non-Hispanic/Latino</td>
<td>19.61</td>
</tr>
<tr>
<td>Other</td>
<td>3.92</td>
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</tbody>
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2.2 | Procedure

Parents and children visited the lab twice within a month. During the first visit, parents completed questionnaires and children participated in a mock scanning session to familiarize them with MRI scanning. During the second visit, children participated in an MRI scan. Informed consent/assent was provided by all families, and all study procedures were approved by the Institutional Review Boards at the New York State Psychiatric Institute and Teachers College, Columbia University.

2.3 | Image acquisition and processing

MRI data were acquired on a 3-Tesla General Electric MR750 scanner with a 32-channel head coil. A high-resolution, T1-weighted fast spoiled gradient echo scan was acquired (sagittal acquisition; TR = 7.1 ms; TE = min full; inversion time [TI] = 500 ms; flip angle = 11 degrees; 176 slices; 1.0 mm slice thickness; FOV 25 cm; inplane resolution = 1.0 by 1.0 mm). All images were visually inspected for motion artifacts and ghosting, resulting in the exclusion of 15 participants’ data from analyses. There was no manual editing of imaging data that were deemed usable.

Images were processed using standard automated procedures in the FreeSurfer software suite (version 6.0) (http://surfer.nmr.mgh.harvard.edu/) (Dale, Fischl, & Sereno, 1999; Fischl & Dale, 2000). Automated segmentation of subcortical volumes in FreeSurfer has been shown to be robust to anatomic variability and to have accuracy comparable to manual labeling techniques (Fischl et al., 2002; Makowski et al., 2018). Gray matter volume was extracted for the caudate, putamen, and nucleus accumbens. Dorsal striatal volume was calculated by summing caudate and putamen volume. All striatal segmentations passed visual inspection for major errors.
2.4 | Measures

2.4.1 | Parental punitive discipline

On the Parenting Behaviors and Dimensions Questionnaire (PBDQ) (Reid, Roberts, Roberts, & Piek, 2015), parents are asked to rate how frequently they use a series of parenting behaviors on a 6-point scale ranging from 1 (never) to 6 (always). The Punitive Discipline scale (5 items; \( \alpha = 0.86 \)) was used in this study (e.g., “I lose my patience when my child does something to upset me,” “I threaten my child with punishments that I would never actually use” and “I punish my child more severely than I mean to”). The PBDQ has evidence of reliability and validity (Reid et al., 2015).

2.4.2 | Child depressive symptoms

The Revised Child Anxiety and Depression Scale—Parent Version (RCADS-P) (Chorpita, Moffitt, & Gray, 2005) is a 47-item parent-report measure in which parents are asked to rate items on a 4-point scale ranging from 0 (never) to 3 (always). Scores on the Major Depressive Disorder subscale (10 items; \( \alpha = 0.64 \)), which was used in this study, were log-transformed to correct for positive skew. The RCADS-P has been found to have adequate internal consistency and validity (Ebesutani, Tottenham, & Chorpita, 2015). The RCADS-P was added to the protocol once a number of families had already participated. More specifically, 27% (\( n = 13 \)) of parents completed the RCADS-P over the phone at a later date, after the MRI scanning session, while 73% (\( n = 35 \)) of parents did so during the first testing session as described above. Supplemental analyses controlling for when the RCADS-P was completed yielded results that were the same as the main results presented below.

2.4.3 | Parental depressive symptoms

The Patient Health Questionnaire-9 (PHQ-9) (Kroenke, Spitzer, & Williams, 2001) is a 9-item self-report measure of depressive symptoms. Parents indicate how often they have experienced depressive symptoms using a 4-point scale ranging from 0 (not at all) to 3 (nearly every day). Item responses are then summed to create a total score (\( \alpha = 0.84 \)). The PHQ-9 has well-established internal consistency, test-retest reliability, and validity (Kroenke et al., 2001; Lee, Schulberg, Raue, & Kroenke, 2007).

2.5 | Analytic approach

Using SAS software (version 9.4), multiple linear regression analyses were conducted to examine associations between parental punitive discipline and child depressive symptoms; parental punitive discipline and child dorsal and ventral striatal volume; and child dorsal and ventral striatal volume and child depressive symptoms. All analyses controlled for child age and sex. In addition, analyses involving striatal volume controlled for whole brain volume in terms of total gray and white matter according to the FreeSurfer segmentation, consistent with previous studies (Luby et al., 2013; Noble et al., 2015; Whittle et al., 2013). Controlling for whole brain volume allowed us to be more confident that any associations with striatal

| TABLE 2 | Descriptive statistics and zero-order correlations |
|---|---|---|---|---|---|---|
|   | 1 | 2 | 3 | 4 | 5 | 6 |
| 1 Parental punitive discipline | — | — | — | — | — | — |
| 2 Dorsal striatal volume (mm\(^3\)) | −0.33 | — | — | — | — | — |
| 3 Ventral striatal/ nucleus accumbens volume (mm\(^3\)) | 0.21 | 0.70**** | — | — | — | — |
| 4 Whole brain volume (mm\(^3\)) | 0.09 | 0.66**** | 0.42*** | — | — | — |
| 5 Child depressive symptoms | 0.48** | −0.28* | −0.14 | −0.06 | — | — |
| 6 Parent depressive symptoms | 0.09 | −0.08 | −0.12 | −0.12 | 0.22 | — |
| N | 28 | 51 | 51 | 51 | 48 | 51 |
| M (SD) | 3.16 (1.35) | 17,219.34 (1,801.97) | 1,327.48 (179.42) | 1,095,180.76 (113,748.46) | 3.00 (2.22) | 5.65 (4.36) |
| Range | 1.20–5.80 | 13,526.10–21,310.50 | 992.90–1,773.60 | 810,848.00–1,348,172.00 | 0.00–9.00 | 1.00–20.00 |

Note: Punitive discipline score is the average item score on that scale. Dorsal striatal volume was calculated by summing caudate and putamen volume.

*p < 0.10,
**p < 0.05,
***p < 0.01,
****p < 0.001.
volume were not due to associations with overall brain size. Family income, parental education, and child race/ethnicity were not significantly associated with parental harsh discipline, striatal volume, or child depressive symptoms and were therefore not included as covariates in regression analyses. The significance of the indirect effect (see Figure S1) was assessed using bias-corrected bootstrapping via the PROCESS macro in SAS (Hayes, 2013).

3 | RESULTS

Descriptive statistics and zero-order correlations are presented in Table 2.

3.1 | Parental punitive discipline and child depressive symptoms (n = 28)

More frequent parental punitive discipline was significantly associated with greater depressive symptoms in children, after accounting for child age and sex, \( \beta = 0.48, p = 0.0145, \eta^2_p = 0.22 \). This association remained significant after additionally controlling for parental depressive symptoms, \( \beta = 0.46, p = 0.0189, \eta^2_p = 0.22 \).

3.2 | Parental punitive discipline and child striatal volume (n = 20)

More frequent parental punitive discipline was significantly associated with smaller dorsal striatal volume, \( \beta = -0.35, p = 0.0108, \eta^2_p = 0.36 \) (see Figure 1a), but not with nucleus accumbens volume, \( \beta = 0.14, p = 0.5233, \eta^2_p = 0.03 \). The former association remained significant even after controlling for parental depressive symptoms, \( \beta = -0.38, p = 0.0081, \eta^2_p = 0.40 \).

3.3 | Child striatal volume and child depressive symptoms (n = 48)

Smaller dorsal striatal volume was significantly associated with higher depressive symptoms after accounting for child age, sex, and whole brain volume, \( \beta = -0.42, p = 0.0304, \eta^2_p = 0.10 \) (see Figure 1b), and this association held after additionally accounting for parental depressive symptoms, \( \beta = -0.40, p = 0.0336, \eta^2_p = 0.10 \). However, when both parental punitive discipline (\( \beta = 0.29, p = 0.3331 \)) and dorsal striatal volume (\( \beta = -0.47, p = 0.3670 \)) were included simultaneously, neither remained significantly associated with children's depressive symptoms. Dorsal striatal volume did not significantly mediate the association between parental punitive discipline and children's depressive symptoms (\( n = 20 \), \( ab = 0.16, SE = 0.23, 95\% CI: [-0.21, 0.69] \)). Nucleus accumbens volume was not significantly associated with child depressive symptoms, \( \beta = -0.12, p = 0.4808 \).

4 | DISCUSSION

The goal of this study was to examine associations among parental punitive discipline, striatal volume, and depressive symptoms in children. While previous neuroimaging research has focused on severe forms of early psychosocial adversity (e.g., child maltreatment), fewer studies have been conducted on variations in parental care in the normative range (Belsky & de Haan, 2011). In addition, previous work has focused more on adolescence and clinical samples rather than middle childhood and community samples. In this study, which addressed these gaps in the literature, findings indicated significant associations among parental punitive discipline, dorsal striatal volume, and depressive symptoms in middle childhood.

More frequent parental punitive discipline was significantly associated with smaller dorsal striatal volume in children, consistent with research demonstrating striatal differences following exposure to severe early life stress (Fareri & Tottenham, 2016; Teicher & Samson, 2016). Moreover, these results are consistent with a growing body of research linking normative variation in parental care with children's brain structure (Kok et al., 2015; Luby et al., 2012). They align more specifically with recent work linking negative parenting
More frequent parental punitive discipline, a chronic stressor, may alter children’s striatal structure, leading to decreased positive affect from rewards (and altering other behaviors dependent on the striatum). Chronic stressors have been found to alter striatal structure and function and diminish reward anticipation and responsiveness (Pizzagalli, 2014). There may also be reciprocal influences wherein children’s reward-related behavior (driven in part by striatal circuitry) elicits harsh reactions from parents (Lengua & Kovacs, 2005). This study employed a cross-sectional, correlational design, precluding inferences about causality. Nonetheless, it is noteworthy that parenting effects often remain significant in longitudinal studies (e.g., aggressive behavior, hostility) with reward processing neuroanatomy in adolescents (Whittle et al., 2009, 2016) and frontal–striatal functional connectivity in children (Kopala-Sibley et al., 2018).

Findings from the current study could suggest that dorsal-striatum-mediated aspects of reward processing, such as linking incentives to action (Delgado, 2007), may be associated with depressive symptoms in middle childhood. Associations between parental harshness and children’s striatal structure may depend on whether parental harshness was measured during a sensitive period of enhanced striatal susceptibility to environmental effects (Blankenship, Chad-Friedman, Riggins, & Dougherty, 2019). Dorsal and ventral striatal structure continues to develop across the ages studied here (Wierenga et al., 2014), with regionally heterogeneous developmental trajectories (Raznahan et al., 2014). Further longitudinal work is needed to elucidate the role of developmental timing in these associations and the ways in which parental harshness may relate to rates of striatal structural development.

The striatum may be one component of the underlying neural mechanisms linking parental punitive discipline with depressive symptoms in children, similar to a model focused on more severe early life stress (Goff & Tottenham, 2015). Parental harsh discipline may dampen positive affect and increase anhedonia, thus increasing risk for depression. Here, although we replicated the well-established association between parental harshness and children’s depression symptoms (Yap & Jorm, 2015), the results did not support our exploratory mediation model. Future studies should examine this mediation model using a longitudinal design in a larger sample. There are several limitations of this study that should be taken into account when interpreting the findings. First, parental punitive discipline and child depressive symptoms were both measured via parent report, raising the possibility of shared method variance. Second, measurement of parenting practices via parent self-report is less sensitive than the use of observational measures of parent-child interactions. Third, this study had a small sample size for analyses involving parental punitive discipline, including the mediation analyses (n = 20). Fourth, the use of cross-sectional, non-experimental data precludes the possibility of making causal inferences and constrains inferences that can be made from mediation analyses. Fifth, although FreeSurfer-derived striatal volumes correlate significantly with manual segmentation of striatal regions, they may yield overestimates (Makowski et al., 2018).

In sum, more frequent parental harsh discipline was associated with smaller striatal volume in children, which was associated with increased depressive symptoms. These results are consistent with the notion that normative variation in negative parenting could lead to striatal changes that put children at risk for depression. Striatal alterations that have been linked with an MDD diagnosis in adolescence may be observable in middle childhood before the onset of the disorder.

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**REFERENCES**


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