


Children with maltreatment exposure exhibit rumination-like spontaneous thought patterns: association with symptoms of depression, subcallosal cingulate cortex thickness, and cortisol levels

Ferdinand Hoffmann,¹ Roman Linz,² Nikolaus Steinbeis,³ Martin Bauer,¹ Felix Dammering,¹ Claudia Lazarides,¹ Heiko Klawitter,¹ Lea Bentz,^{1,4} Sonja Entringer,^{1,5} Sibylle M. Winter,⁴ Claudia Buss,^{1,5} and Christine Heim^{1,6} 

¹Charité – Universitätsmedizin Berlin, Institute of Medical Psychology, Berlin, Germany; ²Research Group “Social Stress and Family Health“, Max Planck Institute for Human Cognitive and Brain Sciences, Leipzig, Germany; ³Division of Psychology and Language Sciences, University College London, London, UK; ⁴Charité – Universitätsmedizin Berlin, Department of Child and Adolescent Psychiatry, Psychotherapy and Psychosomatics, Berlin, Germany; ⁵Development, Health, and Disease Research Program, University of California, Irvine, Orange, CA, USA; ⁶Center for Safe & Healthy Children, The Pennsylvania State University, University Park, PA, USA

Background: Childhood maltreatment is associated with pervasive risk for depression. However, the immediate cognitive and neural mechanisms that mediate this risk during development are unknown. We here studied the impact of maltreatment on self-generated thought (SGT) patterns and their association with depressive symptoms, subcallosal cingulate cortex (SCC) thickness, and cortisol levels in children. **Methods:** We recruited 183 children aged 6–12 years, 96 of which were exposed to maltreatment. Children performed a mind wandering task to elicit SGTs. A subgroup of children underwent structural magnetic resonance imaging ($N = 155$) for SCC thickness analyses and saliva collection for quantification of free cortisol concentrations ($N = 126$) was collected. Using network analysis, we assessed thought networks and compared these networks between children with and without maltreatment exposure. Using multilevel analyses, we then tested the association between thought networks of children with maltreatment exposure with depressive symptoms, SCC thickness, and cortisol levels. **Results:** Children exposed to maltreatment generated fewer positively valenced thoughts. Network analysis revealed rumination-like thought patterns in children with maltreatment exposure, which were associated with depressive symptoms, SCC thickness, and cortisol levels. Children with maltreatment exposure further exhibited decreased future-self thought coupling, which was associated with depressive symptoms, while other-related and past-oriented thoughts had the greatest importance within the network. **Conclusions:** Using a novel network analytic approach, we provide evidence that children exposed to maltreatment exhibit ruminative clustering of thoughts, which is associated with depressive symptoms and neurobiological correlates of depression. Our results provide a specific target for clinical translation to design early interventions for middle childhood. Targeting thought patterns in children with maltreatment exposure may be an effective strategy to effectively mitigate depression risk early in life. **Keywords:** Childhood maltreatment; depression; thought patterns; rumination; subcallosal cingulate cortex; cortisol.

Introduction

Childhood maltreatment is one of the most potent and pervasive risk factors for the development of major depressive disorder (MDD) throughout the lifespan (Nelson, Klumparendt, Doebler, & Ehring, 2017). Particularly, ruminative thinking, which relates to repetitive, unwanted, past-oriented thoughts with a negative affective tone, mediates the relationship between exposure to childhood maltreatment and depressive symptoms (i.e., Raes & Hermans, 2008). Indeed, rumination seems to represent a vulnerability marker for developing depression and also shows a relation to the duration of depressive episodes and relapse probability (Nolen-Hoeksema, Wisco, & Lyubomirsky, 2008).

Measuring spontaneous thoughts, so-called self-generated thoughts (SGTs), that occur independently from external stimulation from the environment, is a naturalistic method to assess adaptive versus maladaptive thinking, including rumination with higher ecological validity compared to questionnaire methods (Hoffmann, Banzhaf, Kanske, Bempohl, & Singer, 2016; Ruby, Smallwood, Engen, & Singer, 2013). Depressed adults tend to exhibit less positive and more negative, past-oriented, and self-related thoughts (Hoffmann et al., 2016). Maltreated adolescents show SGTs that are reminiscent of depressive rumination, with particularly fewer positive thoughts, which relate to subclinical depressive symptoms (Hoffmann et al., 2018). It is unknown whether maltreatment exposure already affects SGTs in middle childhood, shifting thought patterns toward maladaptive and ruminative thinking. Middle

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childhood represents a critical developmental period predicting later mental health and problem behaviors (Mah & Ford-Jones, 2012), while also being a sensitive period of brain development (Knudsen, 2004). Maladaptive SGT patterns early in development might predispose children to develop depression later in life. Identifying these maladaptive SGT patterns early in middle childhood might thus be crucial for early preventive treatments which could be particularly effective in this developmental phase, mitigating depression risk. A few studies have investigated mind wandering in children with and without psychopathologies using online thought sampling methods (i.e., Cherry, McCormack, & Graham, 2022; Frick, Asherson, & Brocki, 2020), but without focusing on specific SGT contents and their complex patterns. So far, no study has used network analytic approaches to SGTs to gain more precise insights into how maltreatment exposure affects thought patterns in children and how such patterns are associated with depression risk.

Network approaches are particularly suitable to investigate SGTs, which can be conceptualized as a thought network, in which SGTs interact and act in concert forming adaptive as well as maladaptive thought patterns, such as rumination. Univariate approaches as well as multivariate clustering approaches, applied in past studies (Hoffmann et al., 2018; Ruby et al., 2013), arguably fail to apprehend the complexity of SGTs and their interactions and, hence, lack precision in capturing spontaneous thought patterns. In addition, network analytic approaches allow to uncover the importance and influence of specific thoughts within the network (Borsboom et al., 2021; McNally, 2021). A precise understanding of these features of thoughts is, however, necessary for devising precise targets for interventions that change these maladaptive cognitive styles towards adaptive thinking.

Neurobiological models of depression and rumination strongly implicate the involvement of the subcallosal cingulate cortex (SCC; Hamilton, Farmer, Fogelman, & Gotlib, 2015; Mayberg, 1997). The SCC is involved in processes such as emotion regulation, autobiographical memory, and reward-based learning, all of which have been associated with the development of mood disorders and are altered after childhood maltreatment (McCrory, Gerin, & Vidling, 2017). SCC activation and functional connectivity have also been associated with rumination in healthy controls and individuals with MDD (Hamilton et al., 2015), as well as in maltreated adolescents (Hoffmann et al., 2018). In addition, structural imaging studies have reported decreased SCC gray matter volume and thickness in individuals with MDD (Drevets, Savitz, & Trimble, 2008; Wei et al., 2020) as well as in adults and children exposed to maltreatment (McLaughlin, Weissman, & Bitrán, 2019; Teicher, Samson, Anderson, & Ohashi, 2016). Taken together, the SCC seems to play a

critical role in depression and rumination, while being sensitive to childhood maltreatment effects. So far it remains unknown how particular thought patterns of maltreated children interact with SCC thickness contributing to increased depression risk.

On a physiological level, rumination has been linked to alterations of the hypothalamus–pituitary–adrenal (HPA) axis (Zoccola & Dickerson, 2012), in terms of increased reactive and basal cortisol levels (Zoccola & Dickerson, 2012). One study in healthy adults found that in particular negatively valenced thoughts with a past focus and a self- and other relatedness were associated with increased cortisol levels after a social stressor and at baseline (Engert, Smallwood, & Singer, 2014). In contrast, thoughts focused on the future and self had an attenuating effect on reactive and basal cortisol levels. Research further suggests that changes in the neuroendocrine stress response system mediate the association between exposure to child maltreatment and risk for depression (Heim & Nemeroff, 2001). So far it remains unknown how particular thought patterns of maltreated children interact with neuroendocrine changes contributing to increased depression risk.

Using a novel network analytic approach to characterize SGTs, the first aim of this study was to investigate and compare the spontaneous thought networks and their properties between maltreated and non-maltreated children aged 6–12 years. Identifying potentially maladaptive thoughts patterns in maltreated children already in middle childhood could point toward an early marker of depression risk that could be targeted by preventive treatments. We employed a mind wandering task adapted for children that has been proven to be a reliable objective momentary measure of the amount and the specific content of SGTs (Hoffmann et al., 2016; Ruby et al., 2013). To shed light on how specific thought patterns in children exposed to maltreatment might relate to depression risk, our second aim using multilevel data was to explore how thought patterns of maltreated children are associated with depressive symptoms as well as with key candidate neurostructural and physiological markers of depression and rumination, i.e., SCC thickness and cortisol levels. For that purpose, structural magnetic resonance brain imaging data and saliva were collected within a subsample of children.

We hypothesized that children in middle childhood who experienced maltreatment exhibit a spontaneous thought network highlighting ruminative thinking patterns in terms of altered interactions between affective self-related and past-oriented thoughts, which, in turn, is associated with depressive symptoms. We secondly hypothesized that SCC cortical thickness and cortisol levels are associated with maltreatment-related ruminative thought patterns.

Methods

Participants

We recruited 96 maltreated children (Mean age = 9.08, $SD = 1.68$) from a broad range of local child welfare and protection services, including government offices for child welfare, family assistants and counselors, and agencies of the child welfare sector. We recruited 87 healthy non-maltreated children (Mean age = 8.72, $SD = 1.42$) from the community via newspaper and Internet advertisement (for details see Supporting Information).

Measures

Maltreatment exposure. The Maltreatment Classification System, a widely used, well-validated, and highly reliable coding scheme, was used for scoring children's maltreatment histories based on the semi-structured Maternal Maltreatment Classification Interview (MMCI; Cicchetti, Toth, & Manly, 2003). The MCS assesses six maltreatment subtypes (i.e., physical neglect including failure to provide, lack of supervision and moral-legal/educational neglect as well as sexual abuse, physical abuse, and emotional maltreatment). Maltreatment maximum severity (1–5) and chronicity were computed. Chronicity was calculated as the ratio of developmental periods affected by maltreatment relative to the total lived developmental periods of the child (0–100%) (for more details see Supporting Information). An additional ranked maltreatment group variable was calculated based on the maltreatment maximum severity scores: 0 = no maltreatment, 1 = mild maltreatment, 2–3 = moderate maltreatment, 4–5 = severe maltreatment.

Cognitive ability and socioeconomic status. Cognitive ability was assessed with the Snijders-Oomen Nonverbal Intelligence Test for Children aged 2–8 (SON-R 2–8; Tellegen, Laros, & Petermann, 2018) and the Snijders-Oomen Nonverbal Intelligence Test children and adults (SON-R 6–40; Renner, 2016). Socioeconomic status (SES) was assessed based on the Winkler and Stolzenberg Index (Winkler & Stolzenberg, 1999). The multidimensional index score represents the sum (range 3–21) of three metric components, that is, education and occupational qualification, occupational status, and net income of the household (range 1–7 each).

Depressive symptoms. The child self-report version of the Center for Epidemiological Studies Depression Scale for Children (CES-DC; Fendrich, Weissman, & Warner, 1990) was administered to measure depression symptoms. Total scores on the CESD-DC can range from 0 to 60. A total score of ≥ 16 has been described as being of clinical relevance, indicating the need for further verification of depression according to the DSM diagnostic system (Fendrich et al., 1990). We additionally used the well-validated Schedule for Affective Disorders and Schizophrenia for school-age children, Kiddie-SADS Present and Lifetime Version (K-SADS-PL; Kaufman, Birmaher, Brent, Rao, & Ryan, 1996) to screen for depression diagnoses in our sample. The K-SADS-PL is a semi-structured interview conducted with the caregivers based on DSM-IV (for additional details see Supporting Information).

Magnetic resonance imaging (MRI)

Structural MRI analysis. Mean cortical thickness of the SCC (in mm) was extracted with the automated Freesurfer pipeline for 74 maltreated and 76 non-maltreated children (see Supporting Information for MRI acquisition and preprocessing), using the cortical parcellation based on the Destrieux

atlas (Destrieux, Fischl, Dale, & Halgren, 2010), similarly to previous studies (Wei et al., 2020).

Cortisol measure

Saliva for the assessment of cortisol concentrations was collected for 72 maltreated and 54 non-maltreated children (for details see Supporting Information).

Experimental procedure

Mind wandering task. We used an adapted mind wandering paradigm for children in which participants made nondemanding letter discriminations during which intermittent questions probed their SGTs (i.e., 'Were you thinking about something in the past?'; for details see Supporting Information). The letters were presented for 1,000 ms. Stimuli were separated by a fixation cross of varying duration (2,200–4,400 ms). The number of thought probes and their presentation were randomly determined to avoid any expectancy biases (Ruby et al., 2013). Next to the visual depiction of the thought probe questions on the screen, the questions were also played back to children as an audio message. Children rated their current thoughts using a nine-point Likert scale on seven dimensions using a slider: off-task, positive valence, negative valence, self-related, other-related, past-oriented, and future-oriented. Each thought dimension question was accompanied by pictures on the scales associated with the thought dimension to aid children's intuitive understanding (Figure S1).

Statistical analysis

Univariate analysis of SGTs. We first performed a univariate analysis of the SGT ratings using linear mixed models in SPSS v22 to investigate possible group differences between the maltreated and non-maltreated children with a random intercept and the number of a particular sampling point within the session, as well as sex and age as covariates (Hoffmann et al., 2016). To account for multiple comparisons, false discovery rate (FDR) correction was applied to reduce type 1 error ($p < .05$).

Multivariate network analyses of SGTs. Thought networks in maltreated and non-maltreated children: Two types of networks were computed for both groups. (a) A regularized concentration network using a graphical least absolute shrinkage and selection operator (GLASSO; Epskamp & Fried, 2018) and (b) a relative importance network (for details see Supporting Information). Concentration networks showing the relational pattern resulting from multivariate partial correlations were calculated using the R package 'qgraph' (Epskamp, Cramer, Waldorp, Schmittmann, & Borsboom, 2012). We opted for a hyperparameter of $\gamma = 0.25$ which gives a good balance between sparsity and specificity (Epskamp & Fried, 2018).

Four centrality indices were computed with the R package graph (Epskamp et al., 2012) to determine the importance of each node (i.e., thought) in the graphical LASSO network. (a) 'Betweenness centrality', (b) 'Closeness centrality', (c) 'Node strength', and (d) 'Expected influence'. For each index, higher values reflect greater centrality.

Relative importance networks were computed with the R package relaimpo (Grömping, 2007), which are based on the proportion of variance (e.g., R^2) one node explains in another node after controlling for all other nodes. Therefore, each edge depicts the relative importance of a node as a predictor of another node. More specifically this is done in a sequential fashion in that each node is taken in turn as a dependent

variable and an all possible subset regression analysis using the other nodes as predictors is used to obtain incoming directed edge weights for the respective node based on a relative importance metric (lmg) between 0 and 1. Edges in this network are weighted and represent predictive directionality with arrows.

In a final step, we used a network model to associate thought patterns *within* the group of maltreated children with depressive symptoms, maltreatment severity and chronicity and with SCC thickness and cortisol levels. For this analysis, a GLASSO network was computed at a liberal $\gamma = 0$, for increasing sensitivity.

Exploration of important thought edges in maltreated children and their association with depressive symptoms. Based on the results of the network comparison of maltreated and non-maltreated children's thought networks we further investigated future-self thought coupling in maltreated children in relation to depressive symptoms. Taking advantage of multiple thought probes per participant, we ran mixed effect models with a random intercept and slope to derive measures of individual thought-to-thought associations. Informed by the findings of the relative importance networks indicating the direction of thought-to-thought associations in the network of non-maltreated children we ran a model in which self-related thoughts were predicted by future-oriented thoughts.

Results

Demographic features and sample characteristics

Table 1 presents the demographic features and sample characteristics (see also Supporting Information and Table S1). Maltreated children showed significantly decreased cognitive ability and had lower SES, while showing increased depressive

Table 1 Demographic features and sample characteristics for maltreated and non-maltreated children

Measure	Maltreated children (<i>n</i> = 96) Mean (<i>SD</i>)	Non-maltreated children (<i>n</i> = 87) Mean (<i>SD</i>)	<i>p</i>
Age (years)	9.08 (1.68)	8.72 (1.41)	.11
IQ	96.56 (15.16)	110.00 (16.30)	<.01
SES	10.78 (5.00)	18.07 (3.13)	<.01
Sex (% female)	<i>n</i> (%) 42 (44)	<i>n</i> (%) 38 (44)	<i>p</i> .56
Maltreatment maximum severity	2.76 (1.08)	0 (0)	<.01
Maltreatment maximum chronicity (%)	66.67 (29.31)	0 (0)	<.01
Depressive symptoms	11.85 (8.44)	8.31 (7.58)	<.01
Depressive symptoms above cutoff	<i>n</i> (%) 20 (22)	<i>n</i> (%) 10 (12)	<i>p</i> .11
Depression diagnosis according to DSM	0 (0)	0 (0)	–

symptoms compared to non-maltreated children. On average non-maltreated as well as maltreated children were below the CES-DC cutoff of 16 (see Table 1). Ten non-maltreated and 20 maltreated children were above this cutoff, these frequency differences were, however, not significant. No children within the total sample met the DSM-IV criteria for a depression diagnosis based on the K-SADS-PL.

SCC thickness

There was no significant group difference in total SCC cortical thickness ($F(1, 145) = 1.49, p = .24$; maltreated children: $5.78 \text{ mm} \pm 0.61$, non-maltreated children: $5.80 \text{ mm} \pm 0.71$; controlled for SES and IQ). Using the ranked maltreatment group variable there was a significant maltreatment effect on the SCC thickness ($F(1, 143) = 3.03, p = .032$; controlled for SES and IQ), with severely maltreated children showing the smallest cortical thickness.

Cortisol levels

There was no significant group difference in cortisol levels ($F(1, 122) = 0.86, p = .77$; maltreated children: $0.15 \text{ nmol/L} \pm 0.1$, non-maltreated children: $0.16 \text{ nmol/L} \pm 0.07$; controlled for SES and IQ). Using the ranked maltreatment group variable, there was also no significant maltreatment effect on cortisol levels ($F(1, 120) = 1.94, p = .13$, controlled for SES and IQ).

SGT analyses

Univariate analysis of SGTs. Maltreated children exhibited significantly decreased positively valenced thoughts, relative to non-maltreated children ($b = 9.41, SE = 3.11, p_{\text{FDRcorr}} = .021$, Cohen's $d = 0.22$; Figure 1 and Table S2). The maltreatment effect remained after controlling for SES and IQ ($b = 10.44, SE = 4.29, p = .015$). There were no group differences in other thought dimensions (see Table S3 for additional exploration of sex * maltreatment interactions), as well as accuracy and reactions times on the mind wandering task (see Supporting Information).

Multivariate network analyses of SGTs. Thought networks in maltreated and non-maltreated children: Marked differences in the graphical LASSO networks were observed between both groups (Figure 2; initial correlation matrices in Tables S4 and S5). In maltreated children, negatively valenced thoughts were widely connected in the network. Negatively valenced thoughts were positively associated with past-and future-oriented as well as self-related thoughts, hinting at a ruminative thought pattern. Most evidently, self-related and future-

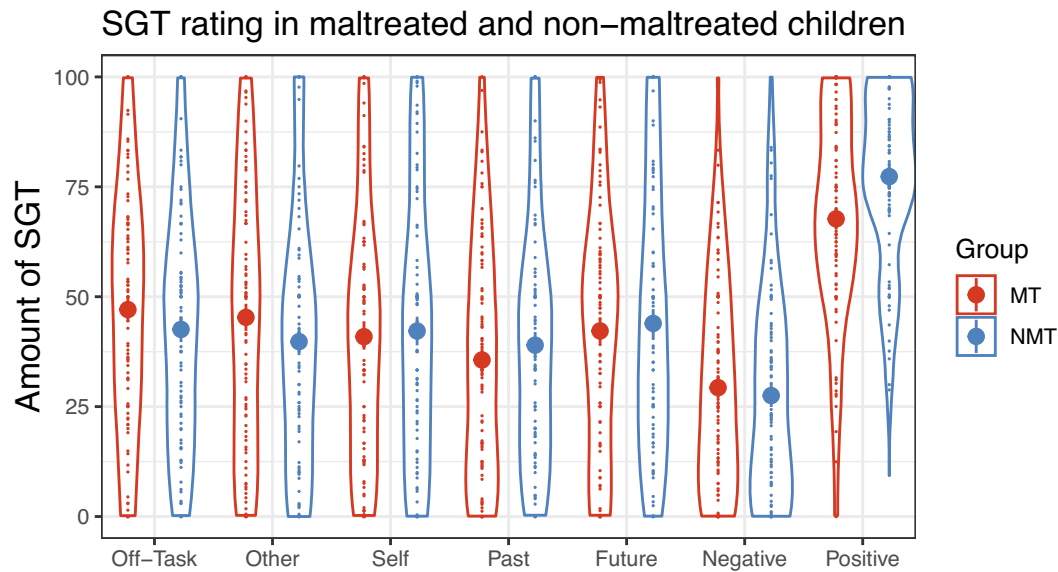


Figure 1 Self-generated thought (SGT) rating levels across the different dimensions for maltreated (MT) and non-maltreated (NMT) children. Maltreated children showed significantly reduced positively valenced thoughts

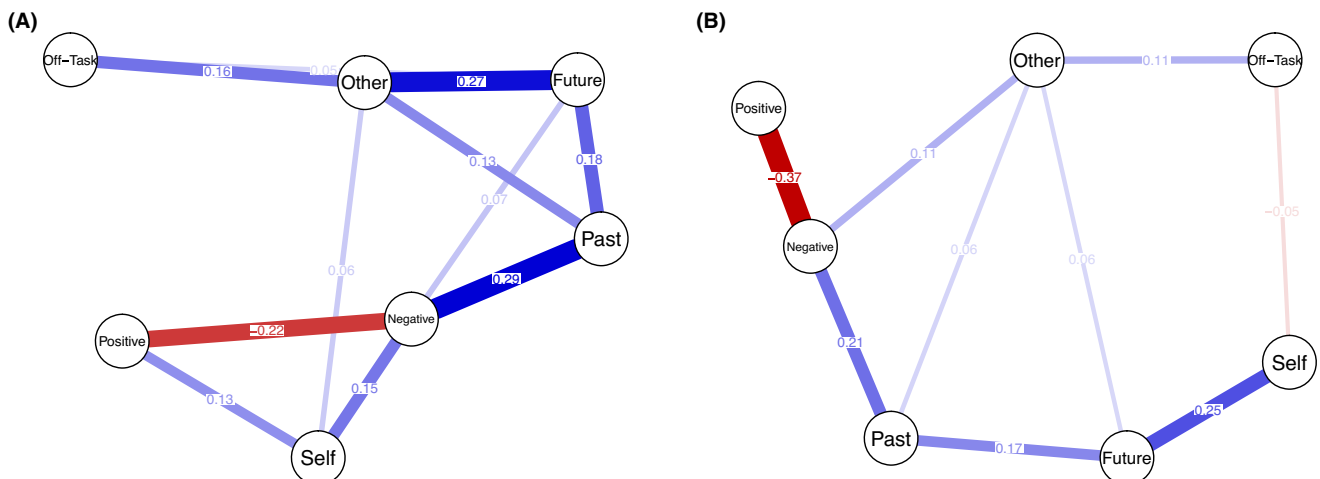


Figure 2 Graphical LASSO networks of self-generated thoughts for (A) maltreated and (B) non-maltreated children in which edge weights reflect relative strength of an association, blue denotes a positive association, and red denotes a negative association. A thicker edge denotes a larger association between two nodes

oriented thoughts were strongly positively associated with each other within the thought network of non-maltreated children, while this association was insignificant in maltreated children (see Supporting Information for more details).

These specific network dynamics were further reflected in the centrality indices (Figure 3): Other-related and past-oriented thoughts showed greater centrality in terms of strength, expected influence, betweenness, and closeness in maltreated children relative to non-maltreated children. Relatively future-oriented thoughts in non-maltreated children showed a greater betweenness. Stability and robustness analyses of these networks indicated that the strongest edges as well as the centrality metrics were fairly stable (see Supporting Information and Figures S2–S5).

To further explore differences between maltreated and non-maltreated children in terms of edge

strengths between thoughts, we employed a network comparison test (Van Borkulo et al., 2022). Uncorrected group comparisons of all edge weights showed that non-maltreated children showed a significantly greater future-self edge strength ($p = .028$). These findings were further substantiated by the relative importance networks (Figure 4). In non-maltreated children, future-oriented thoughts strongly predicted self-related thoughts and negatively valenced thoughts predicted positively valenced thoughts. In maltreated children negatively valenced thoughts strongly predicted past-oriented, self-related and positively valenced thoughts, while also being strongly predicted by past-related thoughts. In addition, other-related thoughts strongly predicted off-task thoughts.

Association of thought patterns within the maltreatment group with depressive symptoms,

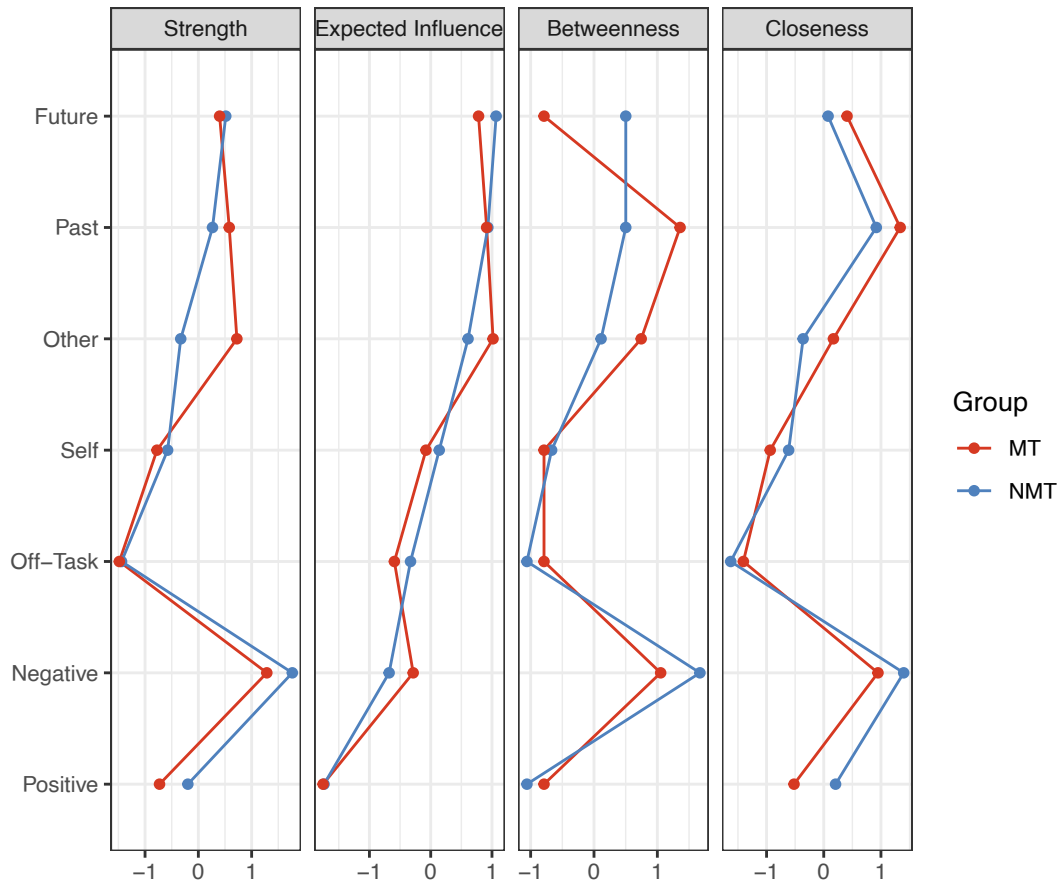


Figure 3 Centrality plots of graphical LASSO networks for maltreated (MT) and non-maltreated children (NMT). Depicting normalized (z-scored) centrality values. For each index, higher values reflect greater centrality, and hence more importance in the network

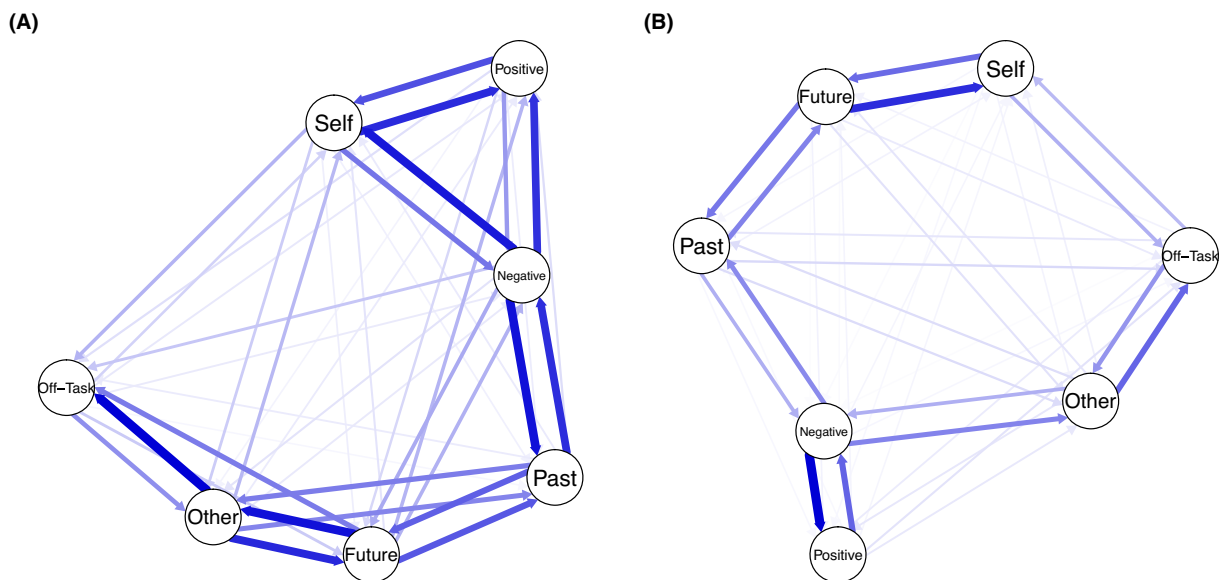


Figure 4 Relative importance graphs of self-generated thoughts for (A) maltreated and (B) non-maltreated children in which edge weights reflect relative contribution the predictor makes to R2 and arrows denote predictive directionality

maltreatment severity and chronicity, SCC thickness, and cortisol levels: Past-oriented thoughts were positively associated with depressive symptomatology, which, in turn, were negatively related to SCC thickness (Figure 5; initial correlation matrix presented in Table S6). Maltreatment severity was positively associated with other-related

thoughts and cortisol levels and negatively with SCC thickness. Maltreatment chronicity was negatively related to positively valenced thoughts. Negatively valenced thoughts showed a positive connection with cortisol levels, which, in turn, were negatively associated with SCC thickness.

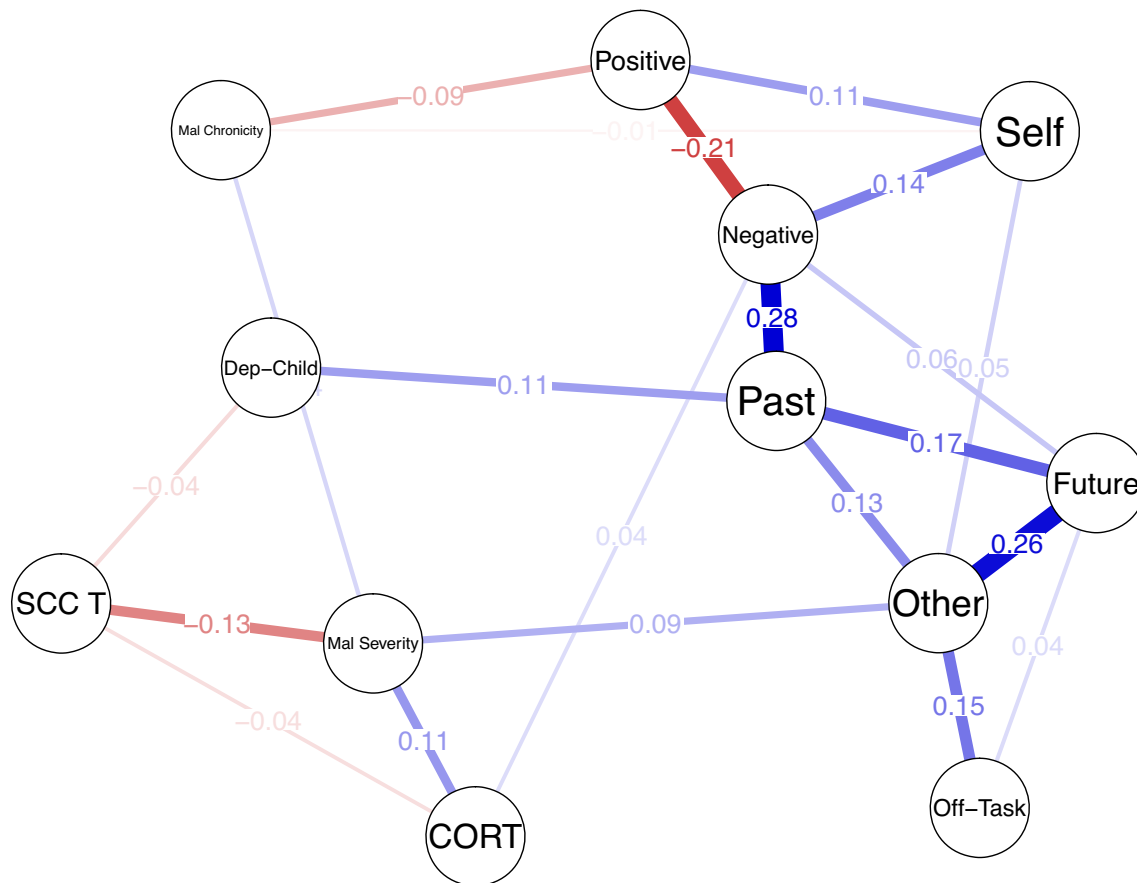


Figure 5 Graphical LASSO network within the maltreatment group showing the association of thought patterns with subcallosal cingulate cortex (SCC) thickness, cortisol levels, maltreatment severity, and chronicity as well as depressive symptoms. SCC T = SCC thickness, CORT = cortisol levels, mal severity = maltreatment severity, mal chronicity = maltreatment chronicity, Dep S = depressive symptoms

Exploration of important thought edges in maltreated children and their association with depressive symptoms. A mixed effect model was run in which self-related thoughts were predicted by future-oriented thoughts (Table S7) to derive an individual measure of future-self thought coupling in maltreated children. More positive future-self thought coupling was associated with decreased depressive symptoms in maltreated children ($r = -.22, p < .05$).

Discussion

In this study, we used a novel network analytic approach to SGTs to investigate and compare the spontaneous thought networks and their properties between maltreated and non-maltreated children aged 6–12 years. We aimed to identify potentially maladaptive thoughts patterns in maltreated children already in middle childhood, which might point toward an early marker of depression risk, that could be targeted by preventive treatments. Combining multilevel data, we further examined how thought patterns within the thought network of maltreated children are associated with depressive symptoms as well as with key candidate neurostructural and

physiological markers of depression and rumination, i.e., SCC thickness and cortisol levels.

In a first step, we found decreased positive-valenced thoughts in maltreated children replicating previous findings in maltreated adolescents (Hoffmann et al., 2018). This suggests that maltreatment exposure might generally lead to decreased positively valenced thoughts throughout middle childhood as well as adolescence, potentially contributing to an increased depression risk. No further group differences in the amount of SGTs were found. We did find a significant continuous effect of maltreatment severity on SCC thickness, with children exposed to the most severe maltreatment, exhibiting the smallest SCC thickness, which is in line with previous findings (McLaughlin et al., 2019; Teicher et al., 2016). There were no group or continuous maltreatment severity effects on cortisol levels.

Analyses of the thought network of maltreated children extended these univariate findings in a significant way, in allowing the visualization and identification of actual thought patterns that possibly contribute to a heightened depression risk. In accordance with our hypothesis, maltreated children exhibited a spontaneous thought network highlighting ruminative thinking that was associated with depressive symptoms. Negatively valenced thoughts

were widely connected with past- and future-oriented as well as self-related thoughts in maltreated children but not in non-maltreated children. This was further supported in the relative importance network in which negatively valenced thoughts predicted past- and future-oriented as well as self-related thoughts, which again was absent in non-maltreated children. Indeed past-oriented and negatively valenced thoughts strongly predicted each other suggesting a cyclic pattern within the thought network of maltreated children. What is important to note is that while a clear rumination-like thought pattern was observed in maltreated children that was linked to maltreatment exposure and depressive symptoms in further analyses, univariate analyses did not show marked differences in the amount of these thoughts, which have been reported in clinically depressed adults (Hoffmann et al., 2016). In fact, no children within our sample met the DSM-IV criteria for a depression diagnosis. This speaks to the potential of network analytic approaches in capturing adaptive and maladaptive spontaneous thought patterns with more precision, than univariate approaches. Maladaptive thought patterns are already present in young, maltreated children even before they might become more pervasive with the onset of depression, so that they can be captured with univariate analyses. Early preventive treatments that target maladaptive thought patterns in maltreated children might thus be very effective, as thought patterns might still be very malleable in middle childhood, a developmental period characterized by great brain plasticity (Knudsen, 2004).

Furthermore, relative to non-maltreated children, maltreated children did not show any future-self thought coupling. Previous research has shown that future-oriented and self-related thoughts are associated with a decreased stress response and basal cortisol levels (Engert et al., 2014). Future-oriented and self-related thoughts might represent some form of autobiographical planning that is adaptive in overcoming stressful situations. This is particularly interesting as maltreated children tend to show an overgeneral autobiographical memory that has been linked to a ruminative thinking style, decreased problem-solving abilities, difficulties imagining future events and as well as increased depression risk (Barry, Chiu, Raes, Ricarte, & Lau, 2018; Puetz et al., 2021). Subsequent analyses focusing on the individual future-self thought coupling of the participants further supported these findings as greater coupling future-self thought coupling was associated with decreased depressive symptoms in maltreated children. This suggests that positive future-self thought coupling might be protective in mitigating depression risk in maltreated children.

Relative to non-maltreated children, maltreated children also showed an increased centrality of other-related and past-oriented thoughts. Interestingly, other-related thoughts were associated with

negatively valenced thoughts in non-maltreated children but not in maltreated children. An increased other focus without negative affective tone in maltreated children may be associated with altered attachment behavior and expectations in social interactions, such as an increased approach tendency that has been linked to childhood maltreatment (White et al., 2020). Future research should further investigate this possibility.

In a second step, we investigated how maltreated children's thought patterns are associated with depressive symptoms, as well as neurobiological and physiological markers of rumination and depression, namely SCC thickness and cortisol levels. We further included maltreatment severity and chronicity within the network to assess how maltreatment exposure levels modulate thought patterns in maltreated children. Past-related thoughts, which were tightly connected with negatively valenced, other-related, and future-oriented thoughts, were associated with depressive symptoms within the network. Maltreatment severity was linked to increased other-related thoughts while maltreatment chronicity was associated exclusively with decreased positively valenced thoughts. This showed that more severe and more chronic maltreatment exposure is associated with more maladaptive thought patterns in children. Negatively valenced thoughts in turn were associated with increased cortisol levels, which replicates findings in healthy adults (Engert et al., 2014) and is in accordance with more generally reported associations between rumination and HPA functioning (Zoccola & Dickerson, 2012). SCC thickness was not directly linked to spontaneous thought patterns, but indirectly via increased symptoms of depression and cortisol levels, which were associated with decreased SCC thickness. Maltreatment severity was negatively associated with SCC thickness, which is in line with previous studies that reported decreased SCC thickness in individuals with MDD, as well adults and children who experienced maltreatment (McLaughlin et al., 2019; Teicher et al., 2016). This shows that maltreatment experience affects neural structures critically implicated in depression and rumination at a very early age, already in middle childhood (see also Supporting Information for further discussion). In fact studies have shown that depressive rumination is associated with higher functional connectivity of the SCC to the default mode network, and decreased functional connectivity to the fronto-parietal network (Hamilton et al., 2015; Hoffmann et al., 2018). Future longitudinal studies are needed for scrutinizing the exact mechanistic interactions between rumination-like spontaneous thought patterns, SCC function and structure, HPA axis functioning, and the development of depression.

From a clinical perspective, these findings suggest a novel strategy for interventions that specifically target

thought patterns to induce a shift from more ruminative other-related and past-oriented thoughts towards more future-self thoughts in maltreated children. Such interventions could entail rumination-focused cognitive behavioral therapy or mindfulness-based therapy that have been shown to be effective in treating rumination and depressive symptoms (Jain et al., 2007; Watkins et al., 2011). In addition, cognitive trainings might prove to be short-term, cost-effective, low-threshold preventive treatments to change maladaptive thought patterns in maltreated children. Memory specificity training (MeST), for example, increases specificity of autobiographical memories and decreases depressive symptoms and will likely lead to more adaptive socio-temporal thought patterns, in terms of better future-self simulations (Barry et al., 2018).

A number of limitations should be noted. First the sample sizes for the network analyses of the SGTs can be regarded as modest. Future replications would benefit from larger groups of children to further validate the stability of the networks. Nevertheless, the networks in this study were low-dimensional (i.e., few nodes relative to the number of participants), and analyses of stability and robustness indicated that the thought networks were relatively stable, even when a large part of the sample was removed. Second, longitudinal analyses are needed to uncover causal relationships between thought patterns in maltreated children, SCC function and structure, HPA axis functioning, and future depressive symptomatology. Third, future studies should use more robust measures of HPA functioning, such as sampling cortisol across the day, to investigate diurnal cortisol dynamics or use stress reactivity measures (Zoccola & Dickerson, 2012).

Conclusions

This study using a novel network analytic approach to SGTs provides evidence that maltreated children show maladaptive, rumination-like thought patterns within their thought network that can be identified already in middle childhood. These are characterized by greater connectiveness of negatively valenced thoughts with self-related and future- and past-oriented thoughts, greater centrality of other-related and past-oriented thoughts, and an absence of future-self thought coupling. Rumination-like thought patterns in maltreated children were associated with depressive symptoms, as well as with neurobiological and physiological markers of depression and rumination, in terms of SCC thickness and cortisol levels. These findings provide a fine grained and at the same time holistic picture of maladaptive thoughts patterns in maltreated children and how these relate to depressive symptoms. Our findings provide an important translational framework to design early

preventative interventions in middle-aged children. Such interventions should aim to rebalance socio-temporal thought patterns in children who experienced maltreatment to promote long-term mental health.

Supporting information

Additional supporting information may be found online in the Supporting Information section at the end of the article:

Figure S1. Depiction of the seven thought dimension questions presented to the children during the mind wandering task.

Figure S2. Bootstrapped confidence regions of the edge weights for the thought network of maltreated children.

Figure S3. Bootstrapped confidence regions of the edge weights for the thought network of non-maltreated children.

Figure S4. Person-dropping bootstrap procedure for centrality indices in the thought network of maltreated children.

Figure S5. Person-dropping bootstrap procedure for centrality indices in the thought network of non-maltreated children.

Table S1. Random effects linear models investigating the effect of family membership on SGTs.

Table S2. Differences between the maltreated and non-maltreated children in SGT rating levels.

Table S3. Differences between the maltreated and non-maltreated children in SGT rating levels and sex* maltreatment interactions.

Table S4. Correlation matrix of SGTs for non-maltreated children.

Table S5. Correlation matrix of SGTs for maltreated children.

Table S6. Correlation matrix of SGTs, SCC thickness, cortisol levels, maltreatment severity, and chronicity as well as depressive symptoms within maltreated children.

Table S7. Mixed-effects model with random slope and intercept with future-oriented thoughts predicting self-related thoughts.

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Correspondence

Christine Heim, Institute of Medical Psychology, Charité – Universitätsmedizin Berlin, Luisenstr. 57, 10117 Berlin, Germany; Email: christine.heim@charite.de

Key points

- Childhood maltreatment is associated with depression risk, while the underlying cognitive and neural mechanisms during development remain largely unknown.
- We studied the impact of maltreatment on SGT patterns, and their association with neurobiological and physiological markers of rumination, in terms of SCC thickness and cortisol levels.
- Novel network analytic analyses uncovered rumination-like thought patterns in maltreated children already in middle childhood, which were partly associated with SCC thickness, cortisol levels, and depressive symptoms.
- Maltreated children showed decreased future-self thought coupling while other-related and past-oriented thoughts were most central within the network.
- These findings provide an important foundation for translation into early interventions that are applied in middle childhood and that target thought patterns in maltreated children towards more adaptive thinking to promote long-term mental health.

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