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Empathic Stress in the Mother–Child Dyad: Multimodal Evidence for Empathic Stress in Children Observing Their Mothers During Direct Stress Exposure

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Relationship closeness determines the propensity to spontaneously reproduce another's emotional and physiological stress response. We investigated whether psychosocial stress in mothers is causally linked to such empathic stress in children. Mothers ($N = 76$) completed either a standardized laboratory stressor or a stress-free control task, while their middle childhood-aged children (8–12 years old) were watching. Mother–child dyads simultaneously provided multiple cortisol, heart-rate, high-frequency heart-rate variability (HF-HRV), and subjective stress samples. We found that stress-group children had a greater propensity to show physiologically significant cortisol release, especially boys. Watching stressed mothers also triggered stronger subjective, state empathy, and HF-HRV stress responses, with the latter relying on elevated trait cognitive empathy ratings. Only in the stressed dyads, children's HF-HRV resonated with those of their mothers'. We conclude that young children, although only mildly stressed, spontaneously reproduce maternal stress.

Public Significance Statement
Children between the ages of 8–12 years spontaneously reproduce their mothers' stress on a physiological and psychological level. Furthermore, boys appear to be more sensitive to maternal stress than girls. In general, empathic stress is likely an adaptive response, motivating appropriate helping behavior and creating social cohesion. In situations of chronic exposure, it may also increase the child's stress load.

Keywords: empathy, empathic stress, mother–child dyad

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The acute stress response to internal and external perturbations is driven by sympathetic nervous system (SNS) and hypothalamic–pituitary–adrenal (HPA) axis activation (Chrousos, 2009). Whether or not a stress response is triggered at any given moment, is not solely dependent on individual experiences. As we live in a social world, we also share the experiences of the people around us. As one example of such interindividual sharing, research over the past 10 years has provided strong evidence for the phenomenon of empathic stress (Engert et al., 2019), an emotional and physiological stress response caused by the mere observation of another individual undergoing stress. While the empathic sharing of affective states is a highly adaptive ability allowing to interpret possibly threatening surroundings and motivate appropriate behavior (Engert et al., 2019; Kanske, 2018), the frequent reproduction of others' physiological stress responses may

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elicit chronic stress and subsequent detrimental effects on the psychological and physiological health of the empathic individual (WHO, 2000). In the current study, we examined the phenomenon of stress resonance in the mother–child dyad. We followed a multimodal approach, for the first time integrating simultaneously assessed stress responses on the level of subjective, autonomic, and HPA axis activity in both mothers and children. Given the closeness of the bond and the strong dependency of children on their parents, empathically resonating with their mother's chronic stress may be especially salient for children's development.

Always considering dyads of individuals, with one directly stressed and one observing dyad partner, stress resonance has been studied across different sample characteristics (e.g., adult vs. mother–child dyads) and contexts (e.g., acute stress vs. everyday life). In adults, Buchanan et al. (2012) were first to show stress resonance at the level of an endocrine response. In the context of the Trier Social Stress Test (TSST; Kirschbaum et al., 1993), a standardized psychosocial stress paradigm, laboratory assistants administering the test showed proportional release of the main HPA axis output hormone cortisol with the actually stressed targets. For completely passive observers of the TSST, higher probability of stress resonance was shown to depend on the relationship closeness between target and observer (real-life partners vs. strangers), the modality of observation (real-life vs. virtual) (Engert et al., 2014), the amount of support from the real-life partner (low vs. high), physical proximity between target and observer (close vs. distant; Phan et al., 2019), and the social identities of target and observer (Schury et al., 2020).

While later in life, romantic partners often act as our closest associates, the relationship between a child and its mother is, if not closer, far greater in dependency (Bretherton, 1992). Given the importance of the bond, the mother–child dyad has been of particular interest in the study of stress resonance. Thus, if held by their stressed mothers, infants were shown to resonate with their mothers' sympathetic responses to a TSST-like task (Waters et al., 2014). Stress resonance was also found in the reverse direction. Mothers displayed proportional cortisol release after depriving their 16 months old toddlers of a toy (Atkinson et al., 2013), or when watching their 17 months old toddlers in a Strange Situation Procedure (Atkinson et al., 2013), their 24–51 months old children balancing on a beam (Sethre-Hofstad et al., 2002), or their preschoolers completing difficult cognitive tasks at home (Ruttle et al., 2011). Due to the relative weakness of the utilized stressors in these studies, although aroused, neither children nor mothers showed significant increases in cortisol levels, and thus no full-blown stress responses. Challenging the assumption that the resonance between two people is boosted in a situation of acute stress, one study showed a reduction in mother–child resonance when mothers watched their children in a stressful rather than a stress-free situation (Hibel et al., 2015).

Stress resonance as discussed in the previous sections should be understood as a state of morphogenic covariation or transmission rather than synchrony (Butler, 2011), given the specific roles of a stressed target and a passive observer in most laboratory settings (Engert et al., 2014; Erkens et al., 2019; Hibel et al., 2015; Phan et al., 2019; Schury et al., 2020; Sethre-Hofstad et al., 2002; Waters et al., 2014). Thus, the stress experienced by the target is presumed to be transmitted (or contagious; Waters et al., 2014) to the observer. In contrast, studies focusing on the everyday life setting usually cannot differentiate between (a) situations of acute stress or relaxation and (b) targets and observers. Diurnal cortisol covariation should thus be understood as a state of synchrony rather than of transmission or stress resonance. Crediting external validity to laboratory-based investigations, however, stress resonance in the TSST was associated with higher diurnal cortisol covariation in couple's everyday lives, even if partners were not physically together during the time of cortisol sampling (Engert, Ragsdale, & Singer, 2018). In the mother child dyad, Pratt et al. (2017) found a positive link between the amount of diurnal cortisol release in 6-year-old children and the extent of maternal covariation in diurnal cortisol secretion. Even in adolescents, cortisol covariation with mothers was found across 2 weekdays, increasing in strength as overall more time was spent together (Papp et al., 2009).

Children are especially vulnerable to the effects of continuous allostatic load (McEwen, 2008), which may accumulate and lead to chronic stress across childhood (Thompson, 2014). Previous studies have provided strong evidence for adverse effects of early life chronic stress on emotion regulation (Kim et al., 2013), memory (Bremner & Narayan, 1998; Evans & Schamberg, 2009), coping (Evans & Kim, 2013), and health across the lifespan (Shonkoff et al., 2012; for a review see Lupien et al., 2009). Importantly, child chronic stress is not just an acute health concern, but it programs the development of the stress system (Byrd-Craven & Clauss, 2019). Quantity and quality of stress exposure, as well as the type of coping attained across childhood, can last a lifetime (Thompson, 2015). In the context of shared experience, empathic stress may facilitate understanding another's troubles and motivate appropriate helping behavior (Engert et al., 2019), possibly reducing overall allostatic load inside a social group, such as a family. However, if acute stress cannot be alleviated with the help of the empathic agent, chronic stress is likely to spread rather than dissipate. Especially young children have limited possibilities to alleviate their parents' stress, which is often caused by events in adult everyday life, such as work- or relationship-related experiences. In this situation of high dependency and low control, children may be particularly vulnerable to empathically reproduce their caretaker's chronic stress.

In the current study, we investigated emotional and physiological stress resonance during acute psychosocial stress in mother–child dyads, thus extending our previous results in adults (Engert et al., 2014) to the family context. Given the relevance of the mother–child relationship for children's long-term mental health (Bretherton, 1992; Winston & Chicot, 2016), and the central role of chronic stress in the development of mental and physical disorders (Chrousos, 2009; McEwen, 2008), we focused on the transmission of stress from mother to child. Thus, contrary to most of the summarized mother–child studies, rather than assessing mothers' reactions to children's stress experience, children's reactions to mother's acute stress were assessed. To this purpose, mothers underwent the TSST as a potent laboratory stressor, while their children watched through a one-way mirror. In light of the multidimensional and complex nature of the stress system Engert, Kok, et al., 2018, measurements of subjective–psychological, cortisol, sympathetic, and parasympathetic activity were collected simultaneously in a multimodal approach in children and mothers. Importantly, to show stress resonance in the mother–child dyad in the absence of touch (Waters et al., 2014), depending rather on higher order socioemotional and sociocognitive abilities (Tousignant et al., 2017), contact between mothers and children was minimized throughout the testing procedure. With this paradigm, we replicated our earlier study in healthy adults (Engert et al., 2014). Children between the ages of 8–12 years were tested to assure adequate writing and reading capacities needed to complete multiple questionnaires, and to acquire a relatively homogenous sample in terms of childhood development.

Next to stress resonance, in which observer and target exhibit proportional stress responses, we examined vicarious stress. Vicarious stress has been defined as the production of an empathic stress response in an observer that arises independent of whether or not the target produced a stress response himself or herself (Engert et al., 2014, 2019). In contrast to resonance, vicarious stress describes an empathic response resulting from witnessing another person in a situation perceived as stressful only by the observer.

As our main, and preregistered, hypothesis, we expected to find greater emotional and physiological resonance as well as vicarious stress in children observing their mothers in a situation of distress rather than rest. As empathic brain and cortisol responses are linked to subjective empathy measures (questionnaire scores and affect ratings) in adults (Buchanan et al., 2012; Engert et al., 2014; Schurz et al., 2021), the magnitude of both resonant and vicarious stress was expected to be modulated by child trait and state empathy, with higher empathy scores facilitating the occurrence of empathic stress. Last, we examined associations of empathic stress with children's age, sex, and closeness to their mothers in an exploratory analysis.

Materials and Method

Transparency and Openness

This study was preregistered before data analysis; the preregistration can be accessed at 10.17605/OSF.IO/F3WKE. Data was collected before preregistration. We report how we determined our sample size, all data exclusions, all manipulations, and all measures in the study. Analyses were performed in R 4.1.2 (R Core Team, 2021). Analysis scripts are publicly accessible at https://osf.io/whpbr/. Data is accessible upon reasonable request. The materials used in this study are widely available.

Participants

Our sample consisted of $N = 76$ mothers (age $M = 40.2$, $SD = 3.33$, age range = 31–45) and their children (37 girls, 39 boys, age $M = 9.95$, $SD = 1.42$, age range = 8–12). Of the 76 mothers, 39 were randomly assigned to the stress group, and 37 to a stress-free control group. The stress group included 20 girls and 19 boys. The control group included 17 girls and 20 boys. Participation for this study was promoted in and around Leipzig, specifically targeting schools and after school care. Interested mothers were screened via telephone interviews. Mothers were asked about their and their children's sex. No information on ethnicity was collected, but dyads were excluded due to nonfluency in German. Furthermore, mother–child dyads were excluded from participation if mothers were younger than 31 or older than 45, pregnant, menopausal, smokers (greater than five cigarettes a day), regular recreational drug abusers, unwilling to abstain from alcohol intake for at least a week or reported previous experience with psychosocial stress testing. Dyads were also excluded if either mothers or children reported onset of menopause (mothers), onset of menarche (daughters), an abnormal body mass index (<18.5/>30), or dyslexia. In terms of current physiological and psychological health, dyads were excluded in case of significant health problems, recent stressful life events such as separation or death of a partner/parent, ongoing psychotherapy, diagnosed mental disorders in the last 2 years, or usage of medication affecting HPA axis activity (e.g., steroids). The age ranges of mothers (mothers 30–45 years) and children (8–12 years) were chosen to minimize the influence of hormonal fluctuations (onset of menarche and menopause), and create relatively homogenous groups, both in terms of developmental status in children, and of life stage when experiencing motherhood (i.e., mothers where required to be at least 18 years of age when having their first child).

The study was approved by the Research Ethics Board of Leipzig University (ethic number: 084/18-ek). Mothers gave written informed consent for both themselves and their children and were financially compensated for their time and effort (between 25 and 30 €, depending on the length of their testing session). Mothers and children were informed that they could withdraw from the study at any point in time. Children received a small gift for participation.

TSST and Stress-Free Control Task

Mothers were randomly assigned to either the TSST or a stress-free reading control task. The TSST is a standardized psychosocial laboratory stressor (Kirschbaum et al., 1993), consisting of an anticipation phase of flexible length (5 min in the current study), a 5-min mock job talk, and a 5-min arithmetic task completed in front of a gender-mixed committee. The committee members are introduced as trained behavioral analysts and instructed to remain unempathic to the participants' struggles. Psychosocial stress induction in the TSST is driven by the components of socioevaluative threat, unpredictability, novelty, and uncontrollability (Dickerson & Kemeny, 2004).

In the reading control task, mothers were alone in the room and instructed to silently read a magazine during the anticipation phase. Afterwards, they were asked to read out loud from a nature book for 10 min, choosing their own reading speed. During both 15-min tasks (stress and control), children watched their mothers form behind a one-way mirror. Given this setup, children in stress and control groups had the same extent of visual and auditory exposure to their mothers.

Measures of Acute Stress Reactivity

Cortisol

To capture HPA axis activity, salivary cortisol was sampled using Salivettes (Sarstedt, Nümbrecht, Germany). For each measurement, participants were asked to put the saliva collection swab in their mouth for 2 min and refrain from chewing. Afterwards, Salivettes were stored at −30 °C. A time-resolved fluorescence immunoassay with intra- and interassay variabilities of less than 10% and 12% was used to determine cortisol activity (nmol/L) (Dressendörfer et al., 1992).

Autonomic Activity

All participants were equipped with a Zephyr Bioharness 3 chest belt (Zephyr Technology, Annapolis, MD, United States), which recorded a continuous electrocardiogram (ECG) at 250 Hz for altogether 75 min (from −30 to +45 min relative to stressor onset). Activity of the SNS was operationalized via heart-rate (Grassi et al., 1998), expressed in beats per minute (bpm). Activity of the parasympathetic nervous system, specifically vagal activity, was assessed via high-frequency heart-rate variability (HF-HRV; Berntson et al., 1997). HRV is the variance in the time interval between two consecutive heart beats over time, represented in the ECG by the variance in length of the RR interval. It is suggested to reflect the functioning of autonomic control over the heart and the heart's capacity to respond to it (Acharya et al., 2006). To specifically measure the parasympathetic influence on the heart, we assessed power in the high-frequency spectral range of HRV (0.15–0.4 Hz), representing the respiration frequency range (Berntson et al., 1997).

The 75-min ECG recording was split into nine 5-min timeframes linked to specific phases of the testing protocol (Figure 1). The first two timeframes (from −28 to −18 min) represented the baseline phase, recorded before participants entered the testing room. Timeframe 3 covered the 5 min of the anticipation phase (from −7 to −2 min), Timeframes 4 and 5 covered the stress or control tasks (from 0 to +10 min). To account for the time it took participants to move between rooms, Timeframes 6 and 7 started approximately 5 min after termination of the stress phase (from +15 to +25 min). Finally, Timeframes 8 and 9 started 10 min after Timeframe 7 (from +35 to +45 min). For each of the nine timeframes, we calculated event averages for heart-rate and HF-HRV per participant.

ECG data extraction was performed with the software Matrix Laboratory (Matlab, Version R2014a). Raw recordings were manually checked for artifacts (e.g., movement artifacts, ectopic beats) using python-based in-house software, and subsequently corrected by three independent laboratory assistants. The in-house software provided a graphical user interface illustrating the ECG signal to identify QRS complexes and artifacts. Beats identified as artifacts were cut together with the previous unproblematic and clearly identifiable QRS complex. Timeframes in which more than 10% of the recording had to be cut were excluded from further analysis. Average heart-rate (expressed in bpm) and HF-HRV (expressed in square milliseconds) were then calculated for the 5-min timeframes of each experimental phase using Artiifact (Kaufmann et al., 2011), reflecting event averages in the respective timeframes. HF-HRV was estimated using a window width of 120 s, with a window overlap of 75% at an interpolation rate of 4 Hz, adhering to the Nyquist criterion. For $N = 16$ children, neither heart-rate nor HF-HRV could be extracted from Phases 1 and 2 due to insufficient ECG-recording quality.

As the Zephyr bioharness system is conceptualized for adults, and we anticipated data loss due to movement artifacts in the children, heart-rate data was additionally measured at discrete time-points (in parallel to cortisol assessments) in mothers and children using an Omron RS2 HEM-6161-D bracelet (OMRON Healthcare, Mannheim, Germany). Since data loss was acceptable, extraction of HF-HRV is only possible based on a continuous ECG, and continuous data is generally preferable to discrete data points, we decided to exclude bracelet heart-rate data from the current analysis. Importantly, patterns of significance remained identical, independent of whether continuous or discrete heart-rate data were used (see the results in the online supplemental materials).

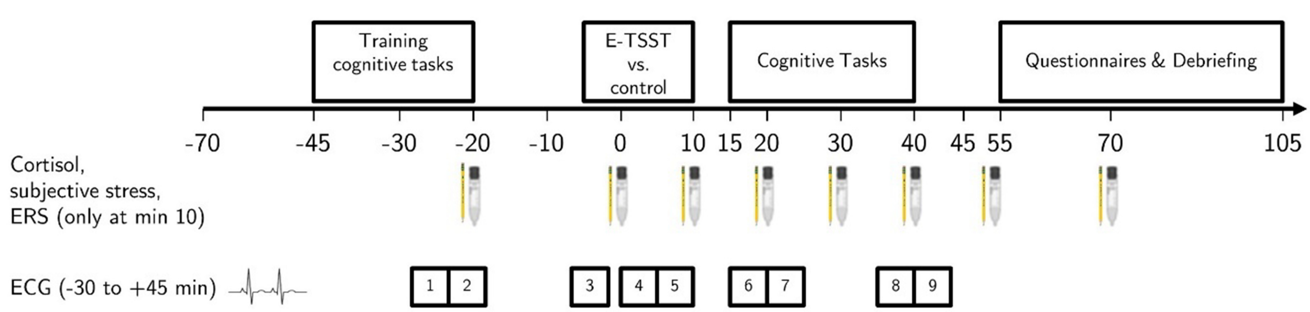
Subjective Stress and State Empathy

In both mothers and children, self-reported stress was measured eight times alongside salivary cortisol using a single item ("How stressed do you feel at this moment?") 7-point Likert-type scale ranging from 0 (*no stress*) to 7 (*high stress*). This was a novel and self-devised measure of subjective stress. We chose this one-item scale rather than an established stress questionnaire to keep subjective data collection short and simple for the children. State empathic concern and personal distress in the children were measured with the 14-item Emotional Response Scale (ERS; Batson et al., 1997) immediately after termination of the stressor or control task. The ERS lists six adjectives related to feelings of empathic concern and eight adjectives related to feelings of personal distress. Results are given on a scale ranging from 1 (*not at all*) to 7 (*very much*). Internal consistency of the empathic concern ($\alpha = 0.83$) and personal distress ($\alpha = 0.89$) subscales was acceptable. $N = 2$ children in the control group had trouble understanding the adjectives list and were excluded from relevant analyses because they gave only extreme answers.

Trait Questionnaires

Mothers and children also completed a set of paper–pencil questionnaires, which were administered in randomized sequence to

Figure 1
TSST Testing Timeline



Note. Participants arrived at −70 min before stressor/control task onset. Baseline cortisol and subjective stress samples were collected at −20 min. Cortisol and subjective stress were resampled at −10, −2, +10, +20, +30, +40, +55, and +70 min. State empathic concern and personal distress were assessed at +10 min. An ECG to capture sympathetic and parasympathetic nervous system activity was continuously recorded from −30 min prior until +45 min after stressor/control task onset and divided into 5-min timeframes (1–9). For each timeframe, a mean average of heart-rate and HF-HRV was calculated per participant. Timeframes 6 and 7 covered the first, and Timeframes 8 and 9 covered the second portion of cognitive testing in children. TSST= Trier Social Stress Test; ECG = electrocardiogram; HF-HRV = high-frequency heart-rate variability; ERS = Emotional Response Scale. See the online article for the color version of the figure.

control for potential order effects. The Inclusion of Other in the Self Scale (IOS; Aron et al., 1992) was used to gauge self-reported closeness between mothers and children. It uses seven Venn diagram-like pairs of circles (one representing the self, one representing the other) with varying overlap (ranging from separate circles to almost complete overlap). The participant choses which of the circle pairs best describes their relationship with the designated other. Trait empathy in children was measured with the Empathy Questionnaire for Children and Adolescents (EmQue-CA; Overgaauw et al., 2017). The EmQue-CA consists of three subscales termed affective empathy, cognitive empathy, and intention to comfort, measured across 14 items on a three-point scale ranging from 1 (*not true*) to 3 (*true*). In addition to the three subscales, an overall trait empathy score can be averaged across all items. Internal consistency of the overall trait empathy scale was acceptable ($\alpha = 0.67$). While Cronbach's α of the cognitive empathy subscale ($\alpha = 0.76$) was good, the affective empathy ($\alpha = 0.54$) and intention to comfort ($\alpha = 0.47$) subscales showed mediocre internal consistency and were therefore dropped from further analysis. The cognitive empathy scale assesses the ability to infer, rather than automatically reproduce, others affective states (e.g., "When a friend is angry, I tend to know why").

Experimental Design and Procedure

The study design closely resembles the empathic TSST approach introduced in Engert et al. (2014). Testing took place on weekdays in the years 2018 and 2019. As cortisol secretion follows a circadian rhythm (Kirschbaum & Hellhammer, 1994), all sessions were scheduled between 3 p.m. and 7 p.m. Mothers and children were separated upon arrival. To equalize blood sugar levels, they were offered a snack and a glass of juice (approximately 45 min before baseline cortisol samples were collected). Throughout the remainder of the testing session, they refrained from eating or drinking anything except water. Mothers then took a drug test and were informed about the nature of the experiment (depending on whether they were randomly assigned to the stress or stress-free control groups). Children were familiarized with the testing procedures, and learned to perform two cognitive tasks, which they repeated later in the testing session (these cognitive data are not subject of the current publication). They then rested for approximately 30 min (mothers) or 20 min (children) in their waiting rooms to overcome potential stress triggered by the unfamiliar laboratory situation. Fifty minutes after arrival, baseline measurements of subjective stress and salivary cortisol were collected (at −20 min relative to onset of the TSST/control task at 0 min). Ten minutes before onset of the TSST/control task (-−10 min), mothers were brought to the testing room. Children followed shortly afterwards and were seated behind a one-way mirror overviewing the testing situation. Thus, mothers could not see their children, but were informed of them watching. At −7 min, mothers received detailed instructions about the upcoming task, and either started preparing for the TSST (stress group) or quietly waited (control group) (anticipation phase). At −2 min, the second set of subjective stress and cortisol samples was collected, followed by the actual stress or control tasks (stress phase). After termination of the stress/control tasks, mothers returned to their waiting rooms for the remainder of the testing session (recovery phase). Children were accompanied to a separate testing room to complete the previously trained computer-based cognitive tasks. Further measurement time-points were scheduled at +20, +30, +40, +55, and +70 min. All measurements were taken simultaneously in mothers and children. From −30 until +45 min, a continuous ECG was recorded in both parties to assess sympathetic and parasympathetic activity (see Figure 1 for the testing timeline).

Statistical Analysis

Data Processing and Estimation of Stress Reactivity

To handle possible outliers and skewness, cortisol, heart-rate, and HF-HRV data were ln-transformed and subsequently winsorized to three standard deviations (Adam & Kumari, 2009; Reifman & Keyton, 2010). To statistically test our main hypotheses of greater child stress reactivity in the experimental (i.e., mother stress) than the control (mother rest) group, we calculated cortisol, heart-rate, HF-HRV, and subjective stress change-scores for mothers and children.

First, the highest individual value (*peak measurement*) was extracted for both mothers and children for a given stress marker. For cortisol, the highest individual data-point was selected from the assessments at +10, +20, or +30 min, as cortisol typically peaks between 20 and 30 min after stressor onset (Kudielka et al., 2009). For heart-rate, the timeframe with the highest event average and for HF-HRV the timeframe with the lowest event average were selected from Timeframes 3, 4, and 5, which covered anticipation and stress phases. As HF-HRV *decreases* with stress, the "peak" stress response was represented by the lowest event average. For subjective stress, the highest data-point was selected from the assessments at 0 or +10 min. Selection of individual peak measurements were limited to the aforementioned data-points because samples collected later than +30 min for cortisol and +10 min for subjective stress would likely be due to stressful stimuli outside the TSST, and therefore not reflect stress reactivity. Accordingly, ECG timeframes from 6 onwards were also excluded from analysis.

Second, baseline measurements were extracted for each marker to control for possible baseline differences in the individual peaks. For cortisol and subjective stress, the baseline was derived from the first sample (−20 min). For heart-rate and HF-HRV, baselines were averaged across Timeframes 1 and 2, during which participants were resting.

Third, stress reactivity change scores (Δ) were calculated for mothers and children by subtracting the baseline from the peak measurement (nadir for HF-HRV) of a given stress marker, resulting in one baseline to maximum difference score per marker (Kudielka et al., 2004; Miller et al., 2018).

Last, mother and child change scores were checked for skewness. Importantly, while mother-change scores adhered to assumptions of normality, the children's scores revealed significant nonnormal distributions. Child cortisol and heart-rate change scores were positively skewed, while HF-HRV and subjective stress change scores were negatively skewed. Thus, empathic child stress reactivity was modeled using residualized change scores, which were built by regressing the respective child stress marker baseline onto the peak measurement and extracting model residuals.

Concerning covariates, participant age, self-reported closeness to mothers, trait cognitive empathy, state empathic concern, and state personal distress were z-standardized to handle possible issues of multicollinearity in our multiple linear regression modeling approach detailed below.

Manipulation Check

To assure successful stress induction in the TSST, group differences between mothers' raw cortisol change scores were compared via a one-sided Fisher's exact test. In detail, we compared the proportions of mothers reaching what has been defined as a physiologically significant release of cortisol from baseline (>1.5 nmol/L; Miller et al., 2013) in stress and control groups.

Group Differences in Vicarious Stress, Stress Resonance, and Influences of Covariates

Likewise, to test for group differences in children's vicarious cortisol release, raw cortisol change scores were compared via a one-sided Fisher's exact test. We again compared the proportions of children reaching the criterion of significant cortisol release from baseline (>1.5 nmol/L; Miller et al., 2013) in stress and control groups.

Regression Modeling

Children's residualized change scores were used as dependent variables in our multiple linear regression modeling. For all stress markers, the *base model* included the following predictors: experimental group, mother difference change score (of the same stress marker as used for the child), and a group by mother change score interaction. Given the definition of stress resonance expecting a proportional relationship between a target's (the mother) and an observer's (the child) stress reaction, stress resonance was reflected in associations of mother reactivity and child reactivity in our models. Thus, the group main effects allowed to test for group differences in vicarious stress (i.e., the level of stress marker activation exhibited by the children). The group by mother change score interaction allowed to test for group differences in mother–child stress resonance (i.e., the extent to which children's stress marker activation was proportional to that of their mother's). Covariates were added iteratively, and each resulting model was compared to the previous, simpler model by means of model fit comparison using analysis of variance. The most complex models included three-way interactions of a covariate by experimental group by mother change score, resulting in models revealing influences of covariates on both vicarious stress (covariate by group interaction) and stress resonance (covariate by group by mother change score interaction). Only models including covariate main effects or interactions that significantly improved base model fit are reported. Possible covariates included child sex, child age, child state empathy, as well as child trait empathy and IOS scores. Standardized regression coefficients (β), confidence intervals (CIs) and *p*-values are reported.

The linear model of child subjective stress reactivity continued to reveal nonnormality of residuals, despite the usage of residualized change scores. Therefore, we modeled high versus low child subjective stress reactivity via multiple logistic regression. A base model including a group by mother change score interaction revealed high multicollinearity (variance inflation factor >10), probably due to a complete separation problem (both child group and mother change score contain equivalent information). Thus, we dropped mother change score from the base model and used Firth bias correction (Heinze & Schemper, 2002) to adequately assess differences in subjective vicarious stress. All other analysis steps were conducted similarly to the physiological stress markers. Model fit comparisons were estimated via χ^2 tests. *OR*, CIs, and *p*-values are reported.

As, like subjective stress, linear child state personal distress models revealed nonnormality of residuals, we again computed multiple logistic regression to predict high versus low or no personal distress using Firth bias correction.

Deviation From the Preregistered Modeling Approach

The preregistered comparison of mother–child intradyad correlations for each stress marker between groups was dropped from analysis, because children adhered to a different testing protocol than mothers after the stress test (completion of cognitive tasks in children vs. rest in mothers). Consequently, conducting covariation analysis across all measurement time-points would not have been meaningful. Importantly, group effects on mother–child stress resonance were nevertheless included in the above described multiple linear regression modeling approach.

Missing Data

Regarding heart-rate and HF-HRV, there were four children and one mother with missing data points in baseline Phase 1 but not Phase 2. Here, baselines were only derived from Phase 2. Furthermore, 29 dyads (16 control group; 13 stress group) had missing data points in both baseline Phases 1 and 2 ($N = 15$ mothers, $N = 16$ children, $N = 2$ both) and were therefore excluded from data analysis via listwise deletion. The resulting subsample for heart-rate and HF-HRV consisted of $N = 24$ control group and $N = 23$ stress group dyads, suggesting no selective dropout due to our manipulation. Demographic statistics of this subsample can be found in Table S1 in the online supplemental materials.

Additionally, there were two missing state empathy (ERS) data points due to children having trouble understanding the scale. If models including either state empathic concern or personal distress revealed greater fit than simpler models, estimates were compared to models excluding both participants. If model fit was driven by the outliers, we report the reduced model.

Power Analysis

Power analysis was performed in G*Power 3.1.9.7 (Faul et al., 2007). Overall, sample size estimation was derived from our previous work showing medium-to-large effect sizes of empathic stress when comparing stranger and familiar dyads (Engert et al., 2014). From a theoretical standpoint, comparing familiar dyads in a control group (with no stress induction) to an experimental group should yield comparable, if not greater, effect sizes.

Regarding the conducted one-sided Fisher's exact test examining proportional differences in physiologically significant cortisol responders, we expected to find a small number of responders even among the control group children due to the unfamiliarity of the laboratory environment (5%). In the stress group, we expected a proportion of 40% of responders, as previously reported in healthy adults (Engert et al., 2014). With a power of 0.8 at an α level of 0.05, a minimum sample size of $N = 40$ (20 in each group) was determined.

For significance testing of single regression coefficients in our multiple regression model (increase in R^2), expecting a small-to-medium effect size of partial $R^2 = .1$, a power of 0.8 and an α level of 0.05, a minimum sample size of $N = 73$ was determined. Thus, only small effect sizes (partial $R^2 < 0.1$) were at risk of being falsely rejected as insignificant.

For the logistic regression models with a single binomial predictor (group), probabilities of $P(Y = 1| X = 1) = 0.10$ versus $P(Y = 1| X = 1) = 0.40$ to find significant empathic stress responders in control versus stress groups, a power level of 0.8, and an α level of 0.05, a minimum sample size of $N = 54$ was determined.

Results

Descriptive Results and Manipulation Check

Groups consisted of $N = 37$ mother–child dyads in the control, and $N = 39$ mother–child dyads in the stress group. Stress and control groups did not differ in mother age, child age, child gender, child trait empathy, or child perceived closeness to the mother (see Table 1). We found significant differences between boys and girls in cognitive empathy, with higher scores in boys than girls ($d = 0.56$, 95% CI [0.09, 1.10]).

A significant stress response Is defined as an increase in cortisol of >1.5 nmol/L from baseline levels (Miller et al., 2013). Demonstrating successful stress induction, $N = 28$ mothers (71.8%) in the stress group reached this level of physiological significance in cortisol release. In the control group, only $N = 6$ mothers (16.2%) surpassed the 1.5 nmol/L threshold. A one-sided Fisher's exact test revealed a significant odd ratio difference between the two groups ($p < .001$). Average cortisol values throughout the testing session in mothers of stress and control groups are depicted in Figure 2.

Group Difference in the Proportion of Physiologically Significant Empathic Cortisol Responders

Cortisol

Applying the same conservative rules as in the mothers, the percentage of physiologically significant cortisol stress responders among the children of stress and control groups was determined. $N = 7$ (17.9%) of the stress group children (five boys, two girls) showed physiologically significant cortisol release between +10 and +30 min after stressor onset. In the control group, only one child (2.7%) surpassed this threshold. A one-sided Fisher's exact test revealed a significant odd ratio difference between the two groups ($p = .034$), suggesting greater odds of a significant child cortisol response in the stress group in comparison to the control group. Interestingly, the mother of the one child reaching the >1.5 nmol/L threshold in the control group showed significant cortisol release herself. In the reduced heart-rate and HF-HRV subsample, $N = 6$ children with significant cortisol release were still present in the stress group and $N = 1$ child with significant cortisol release remained in the control group.

Group Differences in Stress Resonance and Vicarious Stress and Influence of State and Trait Empathy

As described above, empathic stress can be divided into two related constructs, vicarious stress and stress resonance. Vicarious stress is defined as a stress response in reaction to observing another individual in a stressful situation, irrespective of the *target's* actual stress response. Stress resonance is defined as a proportional stress response in target and observer. As child change difference scores showed nonnormal distributions, residualized change scores were used as dependent variables in the implemented regression analyses. By including the respective stress marker baseline as a controlling factor, our modeling approach nevertheless allowed to test for group differences in cortisol, heart-rate, and HF-HRV *reactivity*, both in vicarious stress (group main effect) and stress resonance (group by mother change score interaction). Simplest models showing best fit are reported (see Table 2).

Cortisol

For child cortisol reactivity, we found no significant main effect of group (β = 0.35, 95% CI [−0.31, 1.00], $p = .297$) and no significant group by mother change score interaction (β = -0.08, [−0.58, 0.43], $p = .765$), suggesting no differences in child vicarious stress (see Figure 3A) or stress resonance across groups.

Heart-Rate

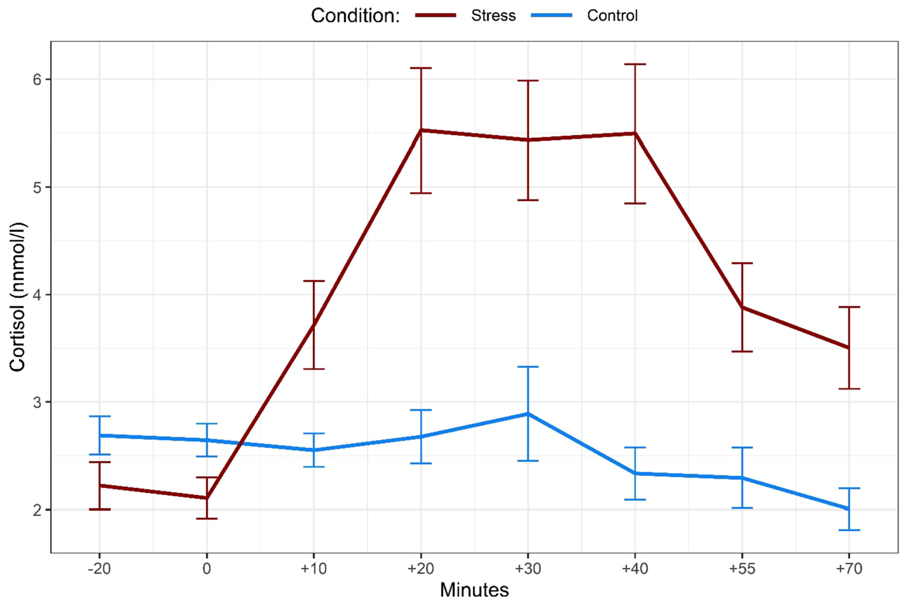
For child heart-rate reactivity, we found no significant main effect of group (β = 0.37, 95% CI [−0.83, 1.58], $p = .537$) and no significant group by mother change score interaction (β = 0.60, [−0.72, 1.91], $p = .367$), suggesting no differences in child vicarious heart-rate (see Figure 3B) or heart-rate resonance across groups.

Table 1
Characteristics of the Final Sample (Only Children; N = *76 Dyads) Across Groups and Gender*

Characteristics	Control group ($n = 37$)	Stress group ($n = 39$)	Difference
Mother			
Age	40.0 (3.19)	40.5 (3.50)	$d = -0.15$, 95% CI [−0.66, 0.33]
Child			
Age	9.89 (1.41)	10.0 (1.45)	$d = -0.08$, 95% CI [−0.53, 0.40]
Girls	17 (45.9%)	20 (51.3%)	$\chi^2 = 0.05$, $p = .814$
Trait cognitive empathy	2.16 (0.54)	1.97 (0.63)	$d = 0.32$, 95% CI [−0.15, 0.83]
Perceived closeness	5.68 (1.18)	5.97 (1.04)	$d = -0.27$, 95% CI [−0.69, 0.20]
	Girls ($n = 37$)	Boys ($n = 39$)	
Trait cognitive empathy	1.90 (0.51)	2.22 (0.63)	$d = 0.56$, 95% CI [0.09, 1.10]
Perceived closeness	5.92 (1.01)	5.74 (1.21)	$d = -0.157$, 95% CI [−0.60, 0.34]

Note. Descriptive statistics of mother's age and children's questionnaire data are presented. Only means (with *SD*s) or total numbers (with percentages) are shown. Differences in gender proportions across groups were tested via a χ^2 test of independence. Group mean differences are presented via Cohen's *d* with 95% CIs. Negative values of Cohen's *d* indicate lower scores in the control than stress group or lower scores in boys than girls. CI = confidence interval.

Figure 2
Cortisol Trajectories of Mothers



Note. Raw cortisol (nmol/l) of mothers in stress and control groups across time. *SE*s (of the group mean) are presented for each measurement time-point. As expected, there was a significant group difference in cortisol reactivity. See the online article for the color version of the figure.

HF-HRV

For child minimum HF-HRV, we found no significant main effect of group (β = −0.11, 95% CI [−0.73, 0.51], $p = .723$) suggesting no differences in child vicarious HF-HRV reactivity across groups (see Figure 3C). However, there was a group by mother change score interaction (β = 0.71, [0.04, 1.37], $p = .038$) and a group by trait cognitive empathy interaction (β = −0.55, [−1.09, −0.02], $p = .044$). In detail, concerning the group by mother change score interaction, higher HF-HRV reactivity in mothers was associated with higher HF-HRV reactivity in the children of the stress group, but not the children of the control group. Thus, parasympathetic resonance between mothers and children was boosted by witnessing mothers' stress (Figure 4). Concerning the group by trait cognitive empathy interaction, children with higher levels of trait cognitive empathy exhibited higher vicarious HF-HRV stress reactivity, that is, stronger reduction in HF-HRV in the stress, but not the control group (see Figure S1 in the online supplemental materials).

State Empathic Concern

For child state empathic concern, we found a marginal main effect of group (β = 0.38, 95% CI [−0.07, 0.83], $p = .094$). Thus, empathic concern was not significantly higher in children of the stress compared to the control group (Figure 3D), although a trend was observed. We found a significant gender by group interaction (β = −0.54, 95% CI [−0.99, −0.09], $p = .019$). In detail, group differences were driven by the boys, who differed significantly between the two groups (with higher empathic concern for the boys in the stress compared to the control group). There was no difference between girls across groups, or between boys and girls in the stress group (see Figure 5B).

State Personal Distress

For child state personal distress, odds for showing low state personal distress (assessed immediately after the TSST) were higher than odds for showing high state personal distress ($OR = 0.22$, 95% CI [0.09, 0.53], $p = .003$) across all children. A group main effect indicated a reverse pattern, with increased odds for showing high personal distress, in the children of the stress group (see Figure 3E; $OR = 5.02$, 95% CI [1.60, 15.78], $p = .003$).

Subjective Stress

For child subjective stress reactivity odds for showing no or low subjective stress reactivity were higher than odds for showing high subjective stress reactivity across all children ($OR = 0.38$, 95% CI [0.19, 0.78], $p = .005$). Again, a group main effect indicated a reverse pattern, with increased odds for showing high subjective stress reactivity, in the stress group (see Figure 3F; $OR = 3.04$, 95% CI [1.18, 7.83], $p = .018$; Table 3).

Exploratory Analysis: Influences of Covariates on Child Vicarious Stress and Stress Resonance

Cortisol

A group by sex interaction (β = −1.22, 95% CI [−2.07, −0.36], $p = .006$) had a significant effect on child vicarious cortisol reactivity. In detail, boys showed higher cortisol reactivity than girls in the stress, but not in the control group. Furthermore, girls showed higher cortisol reactivity in the control compared to the stress group, while boys did not differ between groups (see Figure 5A). Irrespective of

Table 2
Multiple Linear Regressions on Child Cortisol, Heart-Rate, HF-HRV Residual Change Scores, and State Empathic Concern

Predictors	*B*	95% CI	*p*
Child cortisol reactivity			
(Intercept)	−0.05	[−0.54–0.45]	.853
Group (stress)	0.35	[−0.31–1.00]	.297
Δ Mother	0.23	[−0.15–0.62]	.232
Gender (girl)	0.43	[−0.18–1.04]	.166
Age	0.26	[0.06–0.47]	**.012**
State personal distress (ERS)	0.28	[0.07–0.50]	**.009**
Group (Stress) × Δ Mother	−0.08	[−0.58–0.43]	.765
Group (Stress) × Gender (Girl)	−1.22	[−2.07 to −0.36]	**.006**
Observations	76		
R^2/R^2-adjusted	0.304/0.233		
Child heart-rate reactivity			
(Intercept)	−0.43	[−1.49–0.63]	.422
Group (stress)	0.37	[−0.83–1.58]	.537
Δ Mother	−0.37	[−1.58–0.84]	.544
Perceived closeness (IOS)	−0.36	[−0.65 to −0.07]	**.016**
Group (Stress) × Δ Mother	0.60	[−0.72–1.91]	.367
Observations	47		
R^2/R^2-adjusted	0.158/0.078		
Child HF-HRV reactivity			
(Intercept)	0.23	[−0.24–0.69]	.335
Group (stress)	−0.11	[−0.73–0.51]	.723
Δ Mother	−0.06	[−0.61–0.49]	.833
Trait cognitive empathy	0.28	[−0.12–0.68]	.170
Group (Stress) × Δ Mother	0.71	[0.04–1.37]	**.038**
Group (Stress) × Trait Cognitive Empathy	−0.55	[−1.09 to −0.02]	**.044**
Observations	47		
R^2/R^2-adjusted	0.314/0.231		
Child state empathic concern			
(Intercept)	−0.49	[−0.93 to −0.05]	**.030**
Group (stress)	0.38	[−0.07–0.83]	.094
Gender (girl)	0.63	[−0.03–1.28]	.059
Group (Stress) × Gender (Girl)	−0.54	[−0.99 to −0.09]	**.019**
Observations	74		
R^2/R^2-adjusted	0.112/0.074		

Note. Standardized beta coefficients (*B*) with 95% CIs and *p*-values are presented. *p*-values < .05 are presented in bold. CI = confidence interval; ERS = Emotional Response Scale; IOS = Inclusion of Other in the Self Scale; HF-HRV = high-frequency heart-rate variability.

group, higher child age ($\beta = 0.26$, 95% CI [0.06, 0.47], $p = .012$) and state personal distress ($\beta = 0.28$, [0.07, 0.50], $p = .009$) were associated with higher cortisol reactivity.

Heart-Rate

Irrespective of group, higher perceived closeness to the mother ($\beta = -0.36$, 95% CI [−0.65, −0.07], $p = .016$) was associated with lower heart-rate reactivity.

HF-HRV

We found no effects of any of the covariates on child HF-HRV reactivity.

State Empathic Concern

Apart from sex driving the group difference in state empathic concern, we found no further effects of the assessed covariates.

State Personal Distress

Irrespective of group, higher perceived closeness to the mother ($OR = 0.39$, 95% CI [0.22, 0.70], $p < .001$) was associated with decreasing odds for showing high personal distress.

Subjective Stress

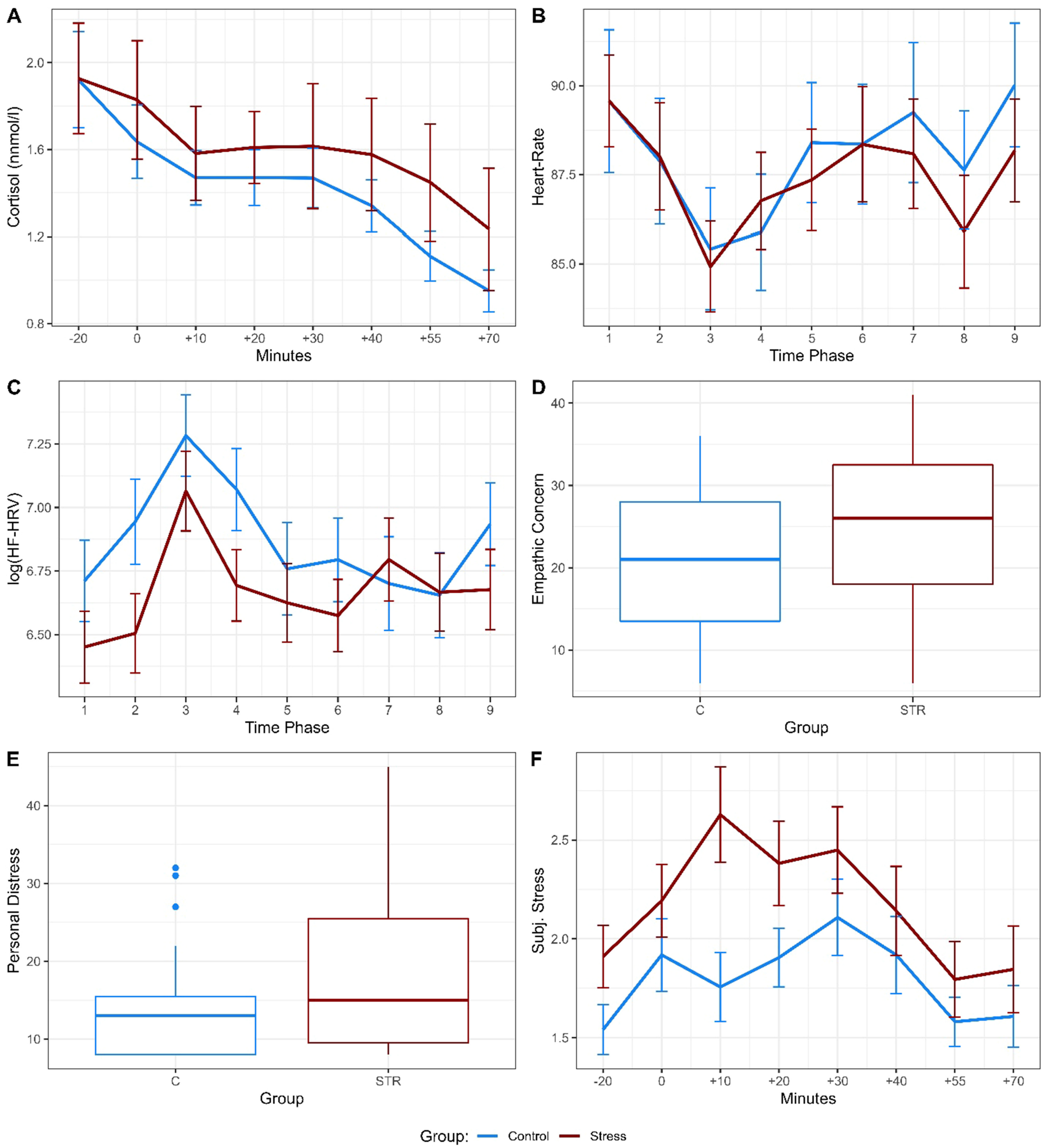
We found no effects of any of the covariates on child subjective stress reactivity.

Discussion

In the current study, we investigated empathic stress in mother–child dyads, expanding on a behavioral paradigm established in an earlier study in adults (Engert et al., 2014). Children observed their mothers undergo a standardized laboratory stressor, the TSST, or a nonstressful reading control task. Both mothers and children simultaneously provided multiple measurements of cortisol, heart-rate, HF-HRV, and subjective stress. We expected greater vicarious stress and stress resonance in the children of the stress

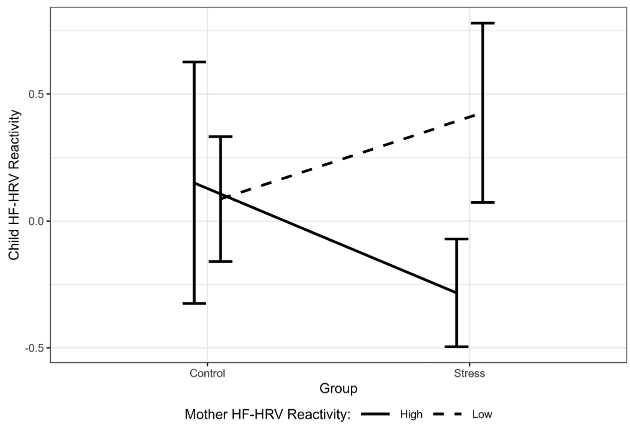
Figure 3

Trajectories of Child Cortisol, Subjective Stress, Heart-Rate, and HF-HRV, as Well as Means of State Empathic Concern and Personal Distress by Group



Note. Raw (A) cortisol, (B) heart-rate, (C) HF-HRV, (D) state empathic concern, (E) state personal distress, and (F) subjective stress for children in the control and stress groups. *SE*s (of the group mean) are presented for each measurement time-point. There were no significant between-groups differences in terms of stress reactivity for cortisol, heart-rate, or HF-HRV (A,B,C). There were significant between-groups differences in terms of state empathic concern and personal distress, measured at +10 min (D,E). Increase in subjective stress (F), measured from baseline to +10 min, was higher in the stress compared to the control group. HF-HRV = high-frequency heart-rate variability. See the online article for the color version of the figure.

Figure 4
Group by Mother HF-HRV Change Interaction



Note. Error bars depict predicted *SE*s. An interaction of group (control vs. stress) and mother HF-HRV change score had a significant effect on child HF-HRV reactivity. Greater decline in mother HF-HRV was associated with lower child minimum values and therefore greater overall HF-HRV reactivity in the stress, but not in the control group. HF-HRV = high-frequency heart-rate variability.

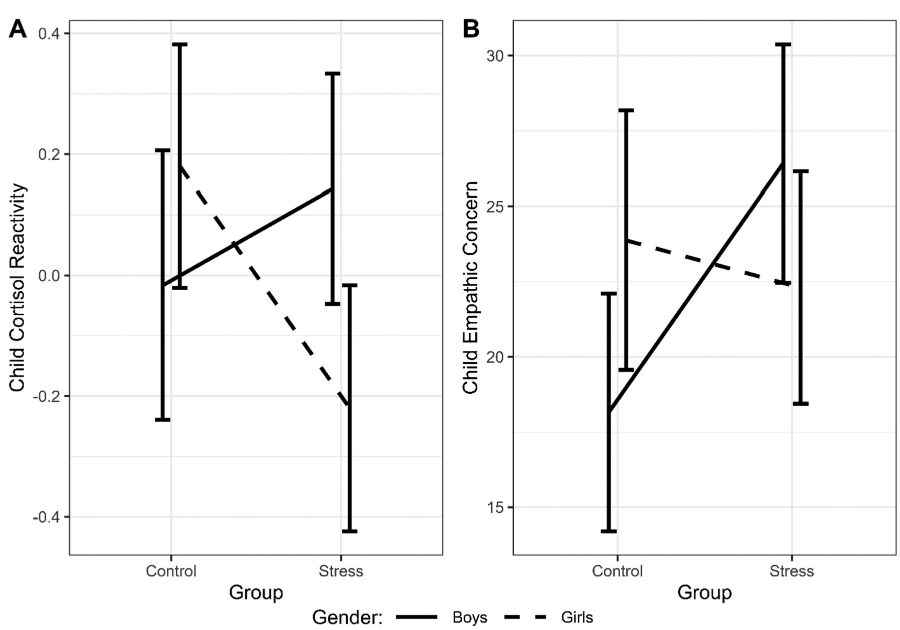
group in comparison to the children of the control group. Furthermore, children's stress response magnitude was expected to show positive associations with child state and trait empathy. Possible links of empathic stress with child age, sex, and perceived closeness to the mother were explored.

Regarding the occurrence of *stress resonance*, higher HF-HRV reactivity in mothers was associated with higher HF-HRV in children only in the stress group. Regarding the occurrence of *vicarious stress*, a greater proportion of cortisol responders, higher state personal distress and higher subjective stress reactivity was found in the children of the stress compared to the control group. Additionally, stress group children with higher levels of trait cognitive empathy showed higher vicarious HF-HRV reactivity, and boys showed greater vicarious cortisol reactivity than girls. A related effect was found for empathic concern, with boys in the stress group showing higher levels than boys in the control group.

Stress Resonance

In line with our hypothesis of higher *resonance* in the stress group, higher HF-HRV reactivity in mothers was linked to higher HF-HRV reactivity in children. We found no group difference in stress resonance for any of the other stress markers. While the lack of heart-rate resonance mirrors previous findings in adults, our earlier study did show cortisol resonance in romantic partner dyads (Engert et al., 2014). Possibly, seeing their mothers in the TSST was not a sufficiently salient stimulus to trigger proportional HPA axis activation in the children, especially in the context of the otherwise challenging laboratory environment. Also, other than HPA axis activity, parasympathetic activity has been linked to complex social cognitions (Quintana et al., 2012; Zammuto et al., 2021) and readily reacts to a variety of cognitive challenges (Manser et al., 2021). To gauge cortisol stress resonance in children outside of mother–child dyads, we suggest that observing other children's responses in the

Figure 5
Child Gender by Group Interactions



Note. Error bars depict predicted *SE*s. Interactions of group (control vs. stress) and gender (boys vs. girls) revealed significant effects on (A) child cortisol reactivity and (B) state empathic concern. (A) Boys showed greater cortisol reactivity than girls in the stress, but not in the control group. (B) Boys in the stress group showed higher empathic concern than boys in the control group.

Table 3
Multiple Logistic Regressions on Child State Personal Distress and Subjective Stress Reactivity

Predictors	Odds ratios	95% CI	p
High versus low state personal distress			
(Intercept)	0.22	[0.09–0.53]	**.016**
Group (stress)	5.02	[1.60–15.78]	**.003**
Perceived closeness (IOS)	0.39	[0.22–0.70]	**<.001**
Observations	74		
High versus low/no subjective stress reactivity			
(Intercept)	0.38	[0.19–0.78]	**.005**
Group (stress)	3.04	[1.18–7.83]	**.018**
Observations	76		

Note. Odds ratios with 95% CIs and p-values are presented. p-values $< .05$ are presented in bold. CI = confidence interval; IOS = Inclusion of Other in the Self Scale.

child-specific version of the TSST (Buske-Kirschbaum et al., 1997) could provide a more salient and comprehensible alternative to the current experimental setup.

Apart from how well the children could relate to the TSST, or how sensitive a respective marker reacted in the context of empathic experience, a likely reason for not finding stronger resonance in the stress group children could be that we minimized contact between mothers and children. This specificity of our study design undoubtedly limited the amount of stress-specific signals that children were able to catch poststressor. Although the perceptual intricacies of stress resonance are still unclear, previous studies suggest a clear association between physical proximity and empathic stress (Engert et al., 2014; Phan et al., 2019; Waters et al., 2014, 2017). Possibly, being placed behind a one-way mirror and being separated through the remainder of the testing session robbed children of important maternal stress signals such as facial expression or odor, hindering emotional mimicry (Hatfield et al., 1994) and olfaction (Bombail, 2019), both suggested as possible pathways of empathy. This issue of poststress distance was further increased by mothers and children being engaged in different tasks immediately after the actual stressor (i.e., rest in mothers, cognitive testing in children), which is reflected in our analysis only targeting measurements until the respective stress marker peaks.

To date, the mother–infant studies by Waters et al. (2014, 2017) are conceptually closest to our current work. And although results are different overall, they are clearly complementary. Thus, Waters and colleagues show the importance of touch in sympathetic arousal spreading from stressed mothers to infants. Building on this finding, our results demonstrate that in a situation in which children passively observe their mothers under acute stress—rather than being in direct contact with the mothers after the latter were exposed to stress—the children synchronize with their mother's stress-induced parasympathetic deactivation. Next to actual mother–child resonance, we find that children are vicariously affected by their mother's stressful experiences on the level of empathic experience, subjective–psychological, and cortisol activation.

Vicarious Stress

Vicarious stress is defined as an empathic stress response in an observer that is triggered independent of whether or not the target produced a stress response themselves (Engert et al., 2014, 2019). Compared to previous findings using a similar empathic TSST procedure, the proportion of vicarious stress responders in 8- to 12-year-old children was considerably lower (17.9%) than in adult romantic partners (40.0%; Engert et al., 2014), but equivalent to, or higher than, in adult strangers (10.0%, Engert et al., 2014; 17.0%, Erkens et al., 2019; 15.7%, Schury et al., 2020). Still, while passively observing their mothers undergo an artificial laboratory stressor from a separate room, every fifth to sixth child showed a significant increase in salivary cortisol release. As children were not confronted with a potent psychosocial stressor themselves, a 1.5-nnmol/L increase in cortisol levels (Miller et al., 2013) should be interpreted as a highly conservative threshold.

Contrasting our expectations, state empathy did not enhance child empathic stress. Rather, relatively higher levels of personal distress predicted higher cortisol reactivity irrespective of group, most likely depicting mild stress caused by the testing session itself. Higher trait cognitive empathy than the sample mean, however, predicted greater vicarious HF-HRV reactivity in the stress group, supporting our hypothesized positive association between child trait empathy and empathic stress. We suggest that children reporting a greater tendency to infer their mothers' affective states than the sample mean were also more likely to correctly appraise the TSST situation as uncontrollable and socially threating. In turn, appraisals of uncertainty and threat are known to decrease amygdala inhibition via hypoactivity in the prefrontal cortex, specifically indexed by HF-HRV reactivity (Thayer et al., 2012).

Exploratory Analysis

Male sex stood out as a predisposing factor for empathic stress, with stress group boys exhibiting higher cortisol release than stress group girls, and higher empathic concern than control group boys. No sex effects on empathic stress have been reported in previous adult studies (Engert et al., 2014, 2019), or in studies of mother–child diurnal cortisol covariation (Papp et al., 2009; Pratt et al., 2017).

When directly exposed to the TSST, rather than passively observing it, adult men typically show greater cortisol reactivity than women (Kudielka & Kirschbaum, 2005). In children between the ages of 8 and 12, the opposite pattern has emerged: Female sex is associated with greater cortisol reactivity when directly confronted with a TSST-like psychosocial stress test (see Hollanders et al., 2017 for a review). This pattern of a higher female cortisol response is also reflected in greater basal cortisol levels in pubertal girls than boys (Dahl & Gunnar, 2009), but was not found for prepubescent children (Jessop & Turner-Cobb, 2008). As boys in the stress group also showed greater empathic concern than boys in the control group, and greater cognitive empathy than girls, our finding of higher cortisol empathic stress in boys may be due to emotional and cognitive rather than biological differences. In other words, higher levels of empathic concern and cognitive empathy in stressed boys may have enabled them to better infer their mother's affective state, thus prompting empathic cortisol release. As we did not hypothesize to find greater vicarious cortisol reactivity in boys, and the literature does not offer a clear explanation, this finding should be treated with caution, however.

Last, we found no links of empathic stress with child age or perceived closeness to the mother. Children older than the sample mean showed greater cortisol secretion, likely reflecting differences in pubertal stage (Kiess et al., 1995). Higher perceived mother closeness than the sample mean was associated with reduced heart-rate and personal distress. We suggest that, based on a more secure attachment style, children reporting higher perceived mother closeness may have dealt better with the unfamiliarity of the testing session. Importantly, the IOS scale is a very minimalistic visual measure of mother–child relationship closeness. The extent to which a child's sense of self overlaps with their mother's does not reflect many essential aspects of closeness, such as, for example, the quality or quantity of time spent together. Please note that, similar to findings on sex, these findings were of exploratory nature.

Strengths and Limitations

The current study benefits from a number of strengths. First, in a multimodal approach, we assessed stress markers across hormonal, sympathetic, parasympathetic, and subjective domains in both mothers and children, providing a detailed look into the process of prepubescent empathic stress. Second, our sample includes a stress-free control group, allowing for causal inference in light of maternal stress. Last, we closely followed the testing procedure from a previous study (Engert et al., 2014), extending findings from adult strangers and romantic partners to the mother–child dyad.

There are also several limitations to the study. First, our sample size lacked power to precisely reveal small effects, especially in terms of heart-rate and HF-HRV, where 29 dyads were excluded due to missing data. Although simultaneous and repeated sampling of various stress markers is time-consuming, we suggest future studies to recruit a minimum of 50 stressed parent–child dyads. Second, mothers and children were separated upon arrival and, with children taking part in cognitive testing, did not adhere to the same testing procedure after termination of the stress/control tasks, thus preventing analysis of resonance during stress recovery. To boost possible stress resonance, future laboratory studies should maximize the time parents and children spend together. Third, the utilized standardized laboratory stress situation is quite unique and does not necessarily mirror everyday stress experience. Inferences on mother–child empathic stress in everyday life therefore have to be drawn with caution. Last, we did not assess children's gender. While it would have undoubtedly been interesting to consider this variable, exploring the role of child sex in the occurrence of empathic stress seemed a necessary first step.

Constraints on Generality

Concerning our sample, we investigated a homogenous cohort of German and mostly highly educated mother–child dyads in Germany (Leipzig). Due to the complexity of study instructions, we only included German native speakers, which is why minorities are not represented in our data. Furthermore, given our strict inclusion criteria due to confronting the mothers with a strong psychosocial stressor (TSST), our data does not include major physiological or psychological pathologies. Also, the age range of children was limited to middle childhood (8–12 years) to assure adequate reading and writing abilities. Therefore, the results of this study cannot be generalized to young children or teenagers. Studies attempting to replicate the effects found in our data should therefore keep our exclusion criteria in mind.

Concerning our theoretical and methodological background, our findings are constricted to a specific psychosocial stressor, the TSST. Data collection took place in the laboratory environment, making generalization of results to everyday life difficult. Yet, this study closely resembles a previous study in adult romantic dyads (Engert et al., 2014), in the context of which we could show that cortisol stress resonance in the laboratory was linked to everyday life diurnal cortisol covariation in romantic partners (Engert, Ragsdale, & Singer, 2018). Our TSST protocol is depicted in Figure 1 and includes a resting period of at least 20 min and eight cortisol samples. Due to including cognitive tasks after stress induction for the children, stress recovery was not investigated.

Summary and Conclusion

In summary, our results demonstrate that stress-induced physiological activation can be transferred from mother to child, even in the absence of touch and with minimal mother–child interaction. Compared to adult romantic partners, middle-aged children show a reduced propensity to synchronize with the stress of a significant other, despite the importance of the mother–child bond. Nevertheless, every fifth–sixth child in the stress group showed a vicarious increase in salivary cortisol release, that is, a significant endocrine response due to passively observing their mothers undergo a psychosocially stressful experience. Also, stress group children exhibited vicarious responses in different modalities, including empathic, subjective–psychological, and parasympathetic activation, suggesting that they not only understood the stressfulness of the situation, but were clearly affected by it. Male gender facilitated the propensity to react to maternal stress, both physiologically and emotionally. Last, the parasympathethic nervous system, for which we found mother–child stress resonance, seems to be more sensitive to maternal stress than the other stress markers we examined. We conclude that 8–12 years old children are aware of their mothers' acute stress, yet react to it relatively mildly themselves, possibly protecting them from the distressing influences of adult stress exposure.

An empathic stress response (i.e. stress resonance or vicarious stress), such as any stress response, results in the reallocation of resources and motivates appropriate behavior. But what if, such as in the utilized paradigm, there is no way of alleviating the stressor? The empathic agent is left with emotional and physiological activation, but without a constructive way of using the mobilized energy. Growing up in a home burdened by parent's chronic stress is likely to trigger regular empathic stress responses in the affected children. Cumulating across childhood, such empathic stress may negatively predispose children for chronic empathy-based stress activation and consequent susceptibility for stress-related disease. As the stress system still develops throughout childhood, its frequent and unwarranted activation may have especially long-lasting and maladaptive effects (Thompson, 2015). Thus, future studies are much warranted to further elaborate on the long-term impact of children's empathic stress experience and extend the current laboratory findings to father–child dyads and the real-life family context.

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