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Bumping heart and sweaty palms: physiological hyperarousal as a risk factor for child social anxiety

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Background: Physiological hyperarousal in social situations is a characteristic of individuals with social anxiety disorder (SAD), but so far it has been rarely studied as a biological risk for SAD. Here, we investigate whether children at high risk for SAD (because of their parents' SAD) display physiological hyperarousal while interacting with a stranger. Also, we examine whether early physiological hyperarousal is related to later child social anxiety. **Method:** One hundred and seventeen children took part in the stranger-approach task when they were 2.5 and 4.5 years old. Heart rate (HR), heart rate variability (HRV), and electrodermal activity (EDA) were measured before, during, and after the conversation with a stranger. Both parents' lifetime SAD status and SAD severity were assessed before the birth of the child. Both parents and children reported on children's social anxiety symptoms when children were 7.5. **Results:** Children of parents with the lifetime SAD diagnosis did not differ in their physiological activity from children of parents without lifetime SAD. However, children of parents with more severe SAD displayed heightened EDA throughout the task procedure. Increased HR and reduced HRV during the stranger-approach and elevated EDA throughout the task phases were linked to later child social anxiety. **Conclusions:** Parents' severity of SAD is related to child physiological hyperarousal early in their childhood. In addition, physiological hyperarousal in early childhood predicts later child social anxiety. Together, these findings suggest that early physiological hyperarousal in social situations may pose a risk for later child social anxiety and that physiological hyperarousal, and EDA in particular, may be a biological mechanism in the intergenerational transmission of SAD. **Keywords:** Social anxiety disorder; physiological hyperarousal; heart rate; heart rate variability; electrodermal activity.

Introduction

Evolutionary relevant fight-or-flight response prepares our bodies to cope with a perceived threat, that is, to fight the threat or to flee from the threat (Cannon, 1914). This reaction to perceived threat is reflected in increased physiological arousal due to the activation of sympathetic and/or withdrawal of parasympathetic autonomic nervous system (Berntson, Cacioppo, Quigley, & Fabro, 1994). The activation of the sympathetic system may be indexed through increased electrodermal activity (EDA), whereas parasympathetic withdrawal may be measured through reduced high-frequency heart rate variability (HF-HRV). Increased heart rate (HR) is thought to be a reflection of both sympathetic activation and parasympathetic withdrawal (Kreibig, 2010). This mechanism is evolutionary adaptive when we confront a real threat to survival (e.g. seeing a snake while walking through a forest) because it prepares us for fighting or fleeing the dangerous circumstances (Cannon, 1914). However, excessive physiological arousal, that is, physiological hyperarousal, may be a less adaptive response reflecting elevated fear in certain situations. Physiological hyperarousal is related to various psychopathologies with disturbances in the fear response (Gray, 1987). The disorder characterized by extreme fear of other people's negative evaluations is called social anxiety disorder (SAD) (American Psychiatric Association, 2013). People with SAD typically perceive social situations in which there is a possibility of making a negative impression on others, such as a public performance or an interaction with a stranger, as threatening. Because of the perceived threat, people with SAD are often physiologically hyperaroused in these social situations (American Psychiatric Association, 2013).

Although it is known that physiological hyperarousal in social situations is a characteristic of adults with SAD, much less is known about the role of physiological hyperarousal in the etiology of SAD. Specifically, it is possible that children who are innately prone to physiologically hyperreact to social situations experience these situations as more negative because the physiological hyperarousal feels uncomfortable and interferes with behaving adequately. Subsequently, children who are hyperaroused in social situations may start avoiding these situations, which in turn can lead to heightened social anxiety levels, and eventually to SAD (Bögels, Mulkens, & De Jong, 1997; Bögels et al., 2010; Clark & Wells, 1995).

The majority of past studies have investigated physiological hyperarousal in older children (aged 7–12) who already developed SAD or high levels of social anxiety symptoms (Siess, Blechert, & Schmitz, 2014). The studies with clinical samples found that either heightened physiological basal activity (in the

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absence of a challenge), physiological hyperarousal during a socially threatening situation (i.e. hyperresponsiveness to threat relative to baseline), or both are characteristics of children with SAD in comparison to healthy controls (Krämer et al., 2012; Schmitz, Krämer, Tuschen-Caffier, Heinrichs, & Blechert, 2011). A few studies that investigated physiological hyperarousal in children with heightened social anxiety found similar results. For example, Schmitz, Tuschen-Caffier, Wilhelm, and Blechert (2013) found higher autonomic basal activity indexed as higher low-frequency (LF) HRV during the baseline preceding the stressful task in children with higher levels of social anxiety. Moreover, Beidel (1988) and Matthews, Manuck, and Saab (1986) found increased HR during challenging tasks in children with higher levels of social anxiety.

Some studies, however, failed to find significant differences in physiological hyperarousal between children with SAD and healthy controls (Alkozei, Creswell, Cooper, & Allen, 2015; Anderson & Hope, 2009; Anderson, Veed, Inderbitzen-Nolan, & Hansen, 2010). Inconsistencies across these findings may be explained by methodological differences. For example, different aspects of physiological hyperarousal (e.g. sympathetic vs. parasympathetic system indices) were measured and different tasks were used to evoke social fear (e.g. speech task and difficult puzzle task) in different studies. Nevertheless, all past studies investigated physiological hyperarousal in children who were already diagnosed with SAD or had elevated levels of social anxiety. In other words, physiological hyperarousal was measured as a *symptom* of already developed social anxiety (disorder) rather than a *risk* for later social anxiety, and eventually SAD.

In the only study that investigated physiological hyperarousal in young children at high and low risk for SAD (using the same sample of children as the present study), no significant differences in physiological hyperarousal while singing in front of a small audience and watching-back the performance in the presence of the audience were found between children of parents with and without SAD (Nikolić, de Vente, Colonnesi, & Bögels, 2016). Physiological hyperarousal indexed as reduced HRV and increased EDA was, however, related to children's own social anxiety. Of note, this study was cross-sectional, precluding any conclusions about the predictive value of physiological hyperarousal in later social anxiety.

A few studies have investigated physiological hyperarousal in relation to later behavioral inhibition, which is a risk factor for SAD (Kagan, 1997; Kagan, Reznick, & Snidman, 1988). The findings revealed that physiologically reactive children display inhibited behaviors later in childhood. Therefore, physiological hyperarousal may also be a marker of the development of social anxiety (disorder).

This Study

The aim of the present study was to investigate whether physiological hyperarousal in young children's development is a risk factor for later social anxiety, and eventually SAD. Specifically, we examined whether children at high risk for SAD (because of their parents' lifetime SAD) display physiological hyperarousal, indexed as elevated baseline activity and/or increased activity during the stranger-approach task relative to baseline (reactivity to the task) as well as slower recovery after the task relative to baseline. Because SAD is known to accumulate in families, children of parent(s) with SAD are assumed to be at higher risk for developing SAD themselves when compared to children of parents with no SAD (Beidel, 1988; Stein, Chartier, Lizak, & Jang, 2001). For example, family studies showed that first-degree relatives of individuals with SAD have higher rates of SAD than relatives of control groups (Fyer, Mannuzza, Chapman, Liebowitz, & Klein, 1993; Fyer, Mannuzza, Chapman, Martin, & Klein, 1995).

We also investigated whether physiological hyperarousal in early childhood is related to later child social anxiety. Given that social anxiety symptoms in childhood are predictive of later SAD diagnosis (Chronis-Tuscano et al., 2009; Goodwin, Fergusson, & Horwood, 2004), elevated social anxiety symptoms are assumed to pose a risk for the development of SAD.

We assessed physiological activity when children were 2.5 and 4.5 years old during baseline, a stranger-approach task, and recovery, and we measured child social anxiety at the age of 7.5. Parents' lifetime SAD was assessed during pregnancy. By adopting a prospective design, we aimed to shed more light on the possible etiological role of physiological hyperarousal in social anxiety. We chose to measure physiological activity in toddlerhood and early childhood because SAD typically does not manifest at this early age (Ollendick & Hirshfeld-Becker, 2002; Rapee, 1995). Still, this period is developmentally adequate because children of this age are able to fear exposure situations as they acquire abilities for self-awareness and are able to perceive themselves as social objects (Lewis, 2003). Social anxiety was measured at a later age when evaluative fears are well established because children are able to understand social rules and norms and are aware of the possibility that others may evaluate them negatively (Leary, Britt, Cutlip, & Templeton, 1992; Lewis, 2003). The stranger-approach task was employed in this study because individuals with SAD fear interaction with novel persons; therefore, this task typically evokes social fear in children with social anxiety (American Psychiatric Association, 2013). Finally, we measured HR, HRV, and EDA of children to be able to capture physiological hyperarousal due to both sympathetic activation and parasympathetic withdrawal. We expected physiological hyperarousal, indexed as increased HR, reduced HRV, and elevated EDA to be

a characteristic of children at high risk for SAD and to pose a risk for later child social anxiety. Specifically, we expected children of parents with SAD to display elevated physiological activity during baseline and increased physiological activity during the stranger-approach task relative to baseline as well as less recovery relative to baseline. We also assumed that early physiological hyperarousal (basal activity and activity in the task and recovery relative to baseline) is linked to later child social anxiety. Because past literature offers inconsistent findings regarding physiological hyperarousal in different phases of the task (e.g. only higher reactivity to the task, but not baseline hyperarousal), we modeled an interaction between physiological activity and task phase to account for the possibility that children at high risk for SAD display physiological hyperarousal not in all, but only in some phases of the task (e.g. only in response to the stranger, but not in baseline).

Methods

Participants

One hundred and seventeen children (54 boys) who took part in an ongoing longitudinal study on the development of anxiety participated in this study (de Vente, Majdandzic, Colonnesi, & Bogels, 2011). Children visited the research laboratory separately with their mother and with their father when they were 4 months, 1 year, 2.5 years, 4.5 years, and 7.5 years old. For this study, child data from the visit with the mother, when the child was 2.5 years old (*M* age = 29.29 months, *SD* = 1.80) and when the child was 4.5 years old (*M* age = 53.50 months, *SD* = 0.71) were used. Additionally, the questionnaire data when the child was 7.5 years old (*M* age = 89.50 months, *SD* = 0.71) were used. Families were recruited during the pregnancy with a first child through midwives, advertisements in magazines, and leaflets at pregnancy courses and baby shops. All parents spoke Dutch or English fluently. Children were excluded from participating in the longitudinal study if their birth weight was <2,000 g or if they had any neurological deficits. Parents were mostly Caucasian (93%) with a relatively high educational level (*M* = 6.97, *SD* = 1.17 on the scale 1 = *primary education* to 8 = *university*). The study was approved by the Ethics Review Board of the University of Amsterdam. Parents provided informed consent prior to participation in the study.

Setting and Procedure

The stranger-approach task from the Laboratory Temperament Assessment Battery (Lab-TAB, Goldsmith & Rothbart, 1996) was conducted at 2.5 and 4.5 years visit. This task was part of a larger battery of tasks conducted to observe child temperament. Physiological activity was measured during the 120-s baseline, during the stranger-approach task, and during the 60-s recovery. During the task procedure, the child was seated in a small chair. First, the basal physiological measures were obtained. Then, a male stranger entered the laboratory room, approached the child, sat down opposite of the child, and engaged the child in a standardized friendly conversation following the Lab-TAB protocol (Goldsmith & Rothbart, 1996). For practical reasons, different adults were trained to perform the stranger role according to the standard Lab-TAB standards, that is, the same conversation starters, comments, and questions. The mother was seated behind the child throughout the task procedure and was instructed to remain neutral. The first 60 seconds of the stranger-approach task were used to standardize the length of the task.

Measures

Physiological data recording. All measures were recorded and analyzed with the Vsrrp98 software (Molenkamp, 2011) on a personal computer running Windows 7. The actual data acquisition in the program was performed by a National Instruments NI6224 data acquisition card sampling at a rate of 200S/s per channel. All physiological measures were computed for the following task phases of the stranger-approach task: 2-min baseline; 1 min during the stranger-approach task; and 1-min recovery. Cardiovascular measures were recorded using a standard Lead-II configuration. The raw ECG signal was filtered at a high-pass frequency of 0.5 Hz, second-order Butterworth. After this filter, a second-order bandpass filter at 17 Hz was applied (to extract the r-tops from the signal). After filtering, the QRS detector was applied with time between 5 and 150 ms. Two parameters were computed: heart rate (HR) was calculated as the number of R waves per minute and heart rate variability (HRV) was calculated as the square root of the mean squared differences of successive normal-to-normal (NN) intervals (RMSSD) – a commonly used HRV measure that is indicative of high-frequency HRV (Malik, 1996; Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996). Electrodermal activity was recorded with two 3M Red Dot electrodes placed on the child's left foot at 2.5 years and with two curved Ag/AgCl electrodes placed on the middle phalanx of the middle and index finger of the child's left hand at 4.5 years. Electrodermal activity was measured as skin conductance level reported in micro-Siemens. In addition, spontaneous fluctuations in electrodermal activity were measured as the number of spontaneous skin conductance responses (a number of fluctuations from a baseline exceeding 0.15 micro-Siemens) and maximum skin conductance response. These two measures were highly correlated throughout the task phases (range $r = .58–.67$, all $p < .001$ at 2.5 years and range $r = .36–.48$, $p \leq .001$ at 4.5 years), standardized, and averaged into a composite to represent spontaneous fluctuations of EDA.

Parents' social anxiety disorder. The parent's diagnostic status of lifetime SAD was determined at the prenatal measurement via the Anxiety Disorders Interview Schedule for adults (adult ADIS-A) (Brown, Barlow, & Di Nardo, 1994), a semistructured clinical interview that assesses anxiety disorders and other psychopathology. Interviewers made ratings on the ADIS Clinician Severity Rating (CSR; 0 = not at all, 8 = very, very much). Diagnoses with ratings of ≥4 are considered to be of a clinical level. The interview was conducted by two trained and experienced psychologists and the third one recoded 10% of the interviews. The percentage interinterviewer agreement for SAD diagnoses was 95%. Past and current SAD diagnoses were combined into lifetime SAD diagnosis. The child was considered to be at risk for SAD if one or both parents met criteria for a lifetime SAD (categorical approach). Additionally, following DSM-5 (American Psychiatric Association, 2013), the dimensional approach to SAD was adopted by using SAD severity ratings. Severity ratings of current and past SAD of mothers and fathers were combined into a measure of parents' lifetime SAD severity.

Child social anxiety symptoms. Social anxiety symptoms of the child were reported by both parents and by the child when the child was 7.5 years old. Mothers and fathers filled out SCARED-C, a valid and reliable instrument to measure symptoms of child anxiety disorders (Birmaher et al., 1997; Dutch translation and modification Muris, Merckelbach,

Schmidt, & Mayer, 1999). The modified social anxiety subscale (Bögels & van Melick, 2004) consists of nine items, for example, 'My child feels nervous when she/he goes to a party' and possesses good reliability, $\alpha = .80$ (Bögels & van Melick, 2004). The reliability in our sample was also good, $\alpha = .86$ for mothers and $\alpha = .83$ for fathers. Mothers' and fathers' ratings of their child social anxiety were highly correlated, $r = .61$, $n = 82$, $p < .001$, standardized, and then averaged into a composite score of child social anxiety reported by parents.

Children filled in the Picture Anxiety Test (PAT; Dubi & Schneider, 2009), a valid and reliable pictorial test to assess young children's anxiety symptoms based on DSM criteria. Social anxiety is assessed with three pictures depicting situations related to SAD. Each picture includes two color illustrations representing two different responses of a child in a fearful situation. The reliability of the social anxiety subscale in our sample was acceptable, $\alpha = 69$.

Data analyses. The data were normally distributed. The repeated measurements of physiological responses during three phases of the task (i.e. 1 = baseline, 2 = stranger-approach, and 3 = recovery) at two time points (1 = 2.5 and 2 = 4.5 years) led to a hierarchical dataset. We, therefore, used multilevel regression models consisting of repeated measurements of task phases (level 1), nested in time (level 2), nested in individuals (level 3) to analyze the data. For each physiological measure, a multilevel model with restricted maximum likelihood (REML) estimation was conducted. These mixed-effects models were fitted separately with parents' SAD diagnosis, parents' SAD severity, and later child social anxiety symptoms reported by parents and reported by the child as predictors of the physiological activity of the child. Scores on continuous predictors and outcomes were standardized. The random effects of intercept, task phase, and time were tested in each model and were kept in the model if significant ($p < .050$). Initially, we tested the models with the main effects of the predictor, task phase, and time, and the interaction effect between the predictor and task phase predicting children's physiological activity. We did not model an interaction effect between the predictor and time because it was not theoretically relevant for our research questions. We determined whether the additional variable accounted for a significant change in variance based on the significance of *F*-tests. When no variance was explained by the two-way interactions, the interaction effects were excluded from the final models. The significance of effects was evaluated at $\alpha < .05$. The multilevel models equation can be found in Appendix S1.

In addition to multilevel models, we ran hierarchical regression models to assess physiological hyperarousal as a risk for later child social anxiety. We averaged all the predictors (physiological variables in different task phases) across two time points to predict social anxiety measured at a later point. All the analyses were performed in IBM SPSS Statistics for Windows, Version 22.0 (IBM Corp., 2013).

Results

Preliminary analyses

Of 117 children who visited the laboratory with the mother when they were 2.5 years old, 29 children refused to have electrodes attached for the physiology measurements. For 11 children, recording of physiological measures failed. Finally, for two children, the stranger-approach task was not conducted due to the procedural errors. These 42 children did not differ in their social anxiety reported by both parents and children at the age of 7.5 and in their parents' SAD diagnosis and severity from children for whom physiological data were recorded. At the age of 4.5, 6 out of 117 children did not visit the laboratory with the mother. Additionally, seven children refused to have electrodes attached and for six children, the physiological recording failed. These 19 children did not differ in their social anxiety reported by both parents and children at the age of 7.5 and in their parents' SAD diagnosis and severity from children with recorded physiological data. At the age of 7.5, the data about child social anxiety reported by both parents and children were missing for 19 children. The parents of these children did not differ in their SAD diagnosis and SAD severity from parents of children for whom the data about social anxiety were obtained.

Of 117 children, 72 children (62%) had at least one of the parents being diagnosed with lifetime SAD. Although our study employed a community sample, a high prevalence of SAD is likely a result of self-selection of the sample. Our study entitled 'Development of shyness and self-confidence' for recruitment seemed to attract parents with a history of social anxiety. Children with one or both parents with SAD diagnosis did not differ in their own social anxiety from children of parents without a SAD diagnosis. Finally, there were no significant differences regarding parents' SAD diagnosis and SAD severity, children's social anxiety, and physiological activity between boys and girls. Therefore, gender was not included in the following models. Table 1 reports on descriptive statistics of study variables. Table S1 displays correlations between predictors and outcomes.

Because of the missing data on physiological variables at both time points, six children were not included in any of the models in the main analyses. Of the remaining 111 children, all children had information on parents' SAD diagnosis, 10 children did not have information on child social anxiety reported by parents, and 26 children did not have information on child social anxiety reported by the child resulting in 111 children being included in the models with parents' SAD, 101 children being included in the models with child social anxiety reported by parents, and 85 children being included in the models with child social anxiety reported by the child.

Main analyses

Time and phase effects. In all models, the task phase effect was significant for HRV and EDA levels and fluctuations (Tables 2 and 3). Heart rate variability significantly increased during recovery relative to baseline, but did not differ from the baseline to the task phase. Electrodermal activity (level and fluctuations) significantly increased during the task and recovery relative to baseline, all $p < .001$ indicating that the manipulation was successful. The time effect

Table 1 Means and standard deviations of the study variables

	2.5 years old		4.5 years old	
	n	*M* (*SD*)	*n*	*M* (*SD*)
HR				
Baseline	73	121.67 (18.18)	98	109.61 (20.49)
Stranger-approach	74	119.34 (17.53)	95	108.95 (17.53)
Recovery	73	120.53 (17.21)	95	108.00 (17.32)
HRV				
Baseline	71	31.34 (15.67)	97	42.47 (21.65)
Stranger-approach	72	35.36 (19.81)	94	42.91 (21.74)
Recovery	67	36.53 (18.27)	94	45.67 (23.26)
EDA level				
Baseline	54	6.52 (2.52)	81	5.36 (2.82)
Stranger-approach	49	8.47 (3.63)	74	6.80 (3.85)
Recovery	45	8.39 (3.86)	74	6.52 (3.77)
EDA fluctuation				
Baseline	54	0.28 (0.86)	81	0.00 (0.86)
Stranger-approach	48	0.40 (0.85)	74	0.00 (0.83)
Recovery	45	0.26 (0.92)	74	0.01 (0.82)

	7.5 years old		
	n	*M* (*SD*)	
Social anxiety (parent-report)	104	−0.00 (.92)	(Range: −1.09 to 3.03)
Social anxiety (child-report)	86	0.73 (0.67)	(Range: 0.00 to 3.00)

Child social anxiety reported by mothers and fathers was standardized and averaged into a composite score of parents' reports of child social anxiety. EDA, electrodermal activity; HRV, heart rate variability.

was significant for HR, HRV, and EDA levels and fluctuations. Heart rate was on average higher, HRV lower, EDA level higher and fluctuations lower during the task at 2.5 years compared to the task at 4.5 years. This likely reflects children's biological maturation (Massin & Von Bernuth, 1997).

Parents' SAD diagnosis and severity. In the models with parents' SAD diagnosis predicting child physiological activity, we did not find an effect of group (high vs. low risk for SAD) or an interaction effect of the group and task phase on any of the physiological variables (Table 2). In the models with parents' SAD severity predicting child physiological activity, there was a significant main effect of parents' SAD severity on children's EDA levels (Table 2). Children of parents with more severe SAD had elevated EDA levels throughout the task.

Child social anxiety. In the models with child social anxiety reported by both parents, an interaction effect with the task phase occurred for HR, $F(2,147) = 4.68$, $p = .011$ and for HRV, $F(2,143) = 4.80$, $p = .010$. Children with higher levels of social anxiety at 7.5 displayed increased HR during stranger-approach relative to baseline (Table 3), indicating physiological reactivity to the social challenge. Also, although children with higher levels of social anxiety displayed only a trend toward reduced HRV during stranger-approach relative to baseline (Table 3), the interaction was significant because these children displayed significantly reduced HRV during stranger-approach relative to the recovery phase, $\beta = -.17$, $SE = 0.05$, $p = .002$.[1]

In the models with child social anxiety reported by children, there was a significant main effect of child social anxiety on EDA levels (Table 3). Children with higher levels of social anxiety had elevated EDA levels throughout the task phases. Figure 1 displays children's physiological activity in relation to child social anxiety.

Regression analyses

Multilevel models account for the longitudinal nature of the data and the dependency of repeated measures and, thus, are powerful way of analyzing data with repeated measurements. However, they do not allow for the assessment of risk because repeated-measure variables are modeled as an outcome instead of a predictor (Chen, Ferguson, Meeker, McElrath, & Mukherjee, 2015). Because we wanted to assess the predictive value of earlier physiological hyperarousal for later child social anxiety, we ran hierarchical multiple regression models in addition to multilevel models. In each hierarchical model, we regressed child social anxiety (reported by parents and by children separately) on physiological variables, now averaged across two time points. We first modeled the physiological variable during baseline and then added the values for the activity during the task and recovery to test if they add to the prediction over and above the baseline. In the model of HR predicting child social anxiety reported by parents, baseline HR did not predict later child social anxiety alone, $R^2 = 02$, $F(1,96) = 1.48$, $p = .227$. However, adding HR during the stranger-approach explained a significant amount of variance in later child social anxiety, $\Delta R^2 = 0.06$, $\Delta F(1,95) = 6.63$, $p = .012$. Increased HR while interacting with a stranger predicted child social anxiety, $\beta = .36$, $p = .012$, controlling for lower HR baseline, $\beta = -.38$, $p = .008$. Thus, children who reacted the most from baseline to the stranger-approach showed increased social anxiety symptoms later in childhood. Heart rate during recovery did not significantly add to the prediction. The models with HRV and EDA levels and fluctuations did not explain a significant amount of variance in child social anxiety reported by parents.

The model with EDA level during baseline accounted for a significant amount of variance in child social anxiety reported by children, $R^2 = 0.06$, $F(1,68) = 4.28$, $p = .042$. Higher EDA baseline levels predicted greater child social anxiety, $\beta = .24$, $p = .042$. Electrodermal activity during stranger-

Table 2 Parameter estimates of the multilevel models of child physiological activity regressed on parents' sad diagnosis and severity

	HR		HRV		EDA level		EDA fluctuation	
	β (*SE*)	*p*	*β* (*SE*)	*p*	*β* (*SE*)	*p*	*β* (*SE*)	*p*
SAD Diagnosis Model								
Intercept	−.27 (0.13)	.035	.14 (0.14)	.308	−.67 (0.15)	<.001	.01 (0.13)	.941
SAD diagnosis	.10 (0.14)	.445	−.09 (0.16)	.578	.27 (0.17)	.120	.13 (0.14)	.354
Time	**−.60 (0.14)**	**<.001**	**.34 (0.11)**	**.004**	**−.46 (0.13)**	**.001**	**−.46 (0.13)**	**<.001**
Phase								
2	−.07 (0.04)	.122	.08 (0.05)	.096	**.50 (0.05)**	**<.001**	**.21 (0.08)**	**.010**
3	−.06 (0.04)	.186	**.21 (0.05)**	**<.001**	**.46 (0.05)**	**<.001**	**.20 (0.08)**	**.011**
SAD*Phase								
2	–	–	–	–	–	–	–	–
3								
SAD Severity Model								
Intercept	−.20 (0.09)	.032	.09 (0.10)	.374	−.50 (0.10)	<.001	.09 (0.10)	.356
SAD severity	.00 (0.06)	.989	−.08 (0.08)	.356	**.20 (0.09)**	**.024**	.05 (0.07)	**.436**
Time	**−.60 (0.14)**	**<.001**	**.34 (0.11)**	**.004**	**−.46 (0.13)**	**.001**	.46 (0.13)	**<.001**
Phase								
2	−.07 (0.04)	.123	.08 (0.05)	.096	**.50 (0.05)**	**<.001**	.21 (0.08)	**.010**
3	−.06 (0.04)	.188	**.21 (0.05)**	**<.001**	**.46 (0.05)**	**<.001**	**.20 (0.08)**	**.010**
SAD*Phase								
2	–	–	–	–	–	–	–	–
3								

Task phase: 1 = baseline, 2 = stranger-approach, and 3 = recovery. Time: 1 = 2.5 years old, 2 = 4.5 years old. For SAD, 2 (no lifetime SAD) = reference. For Time, 1 (Time 1, 2.5 years) = reference. For Task Phase, 1 (baseline) = reference. EDA, electrodermal activity; HRV, heart rate variability; SAD, social anxiety disorder. Significant effects are indicated in bold text.

Table 3 Parameter estimates of the multilevel models of child physiological activity regressed on child social anxiety reported by parents and by children

	HR		HRV		EDA level		EDA fluctuation	
	β (*SE*)	*p*	*β* (*SE*)	*p*	*β* (*SE*)	*p*	*β* (*SE*)	*p*
SA Parents' reports								
Intercept	−.18 (0.10)	.071	.13 (0.10)	.224	−.44 (0.11)	<.001	.13 (0.10)	.219
SA	−.07 (0.08)	.331	.09 (0.09)	.333	.11 (0.09)	.200	.04 (0.07)	.604
Time	**−.58 (0.16)**	**<.001**	**.30 (0.12)**	**.013**	**−.44 (0.14)**	**.003**	**.50 (0.13)**	**<.001**
Phase								
2	**−.09 (0.05)**	**.049**	.07 (0.05)	.181	**.50 (0.05)**	**<.001**	**.20 (0.08)**	**.012**
3	**−.09 (0.04)**	**.050**	**.20 (0.06)**	**.001**	**.43 (0.07)**	**<.001**	**.19 (0.08)**	**.018**
SA × Phase								
2	**.14 (0.05)**	**.003**	−.09 (0.05)	.087	–	–	–	–
3	.07 (0.04)	.124	.07 (0.06)	.185				
SA Children's reports								
Intercept	−.15 (0.10)	.121	.13 (0.11)	.254	−.48 (0.12)	<.001	.14 (0.10)	.182
SA	−.13 (0.07)	.060	.11 (0.09)	.230	**.20 (0.09)**	**.026**	−.01 (0.07)	.829
Time	**−.50 (0.15)**	**.001**	**.35 (0.12)**	**.004**	**−.45 (0.15)**	**.004**	**.47 (0.14)**	**.001**
Phase								
2	**−.11 (0.05)**	**.034**	.07 (0.06)	.246	**.51 (0.05)**	**<.001**	**.16 (0.08)**	**.058**
3	**−.09 (0.05)**	**.075**	**.13 (0.06)**	**.037**	**.47 (0.07)**	**<.001**	**.18 (0.08)**	**.034**
SA × Phase	–	–	–	–	–	–	–	–

Task phase: 1 = baseline, 2 = stranger-approach, and 3 = recovery. Time: 1 = 2.5 years old, 2 = 4.5 years old. For Time, 1 (Time 1, 2.5 years) = reference. For Task Phase, 1 (baseline) = reference. EDA, electrodermal activity; HRV, heart rate variability. Significant effects are indicated in bold text.

approach and recovery did not explain additional amount of variance in child social anxiety. The models with HR, HRV, and EDA fluctuations did not explain a significant amount of variance in child social anxiety reported by children.

Discussion

The present study investigated whether children at risk for SAD (because of their parents' SAD) display heightened physiological arousal in early childhood and whether physiological hyperarousal in early childhood predicts later child social anxiety. First, we examined whether children at high risk for SAD (because of their parents' SAD) display physiological hyperarousal while interacting with a stranger at the age of 2.5 and 4.5 when compared to children at low risk for SAD. Also, we investigated whether physiological hyperarousal in toddlerhood and early childhood is linked to later child social anxiety. We did not

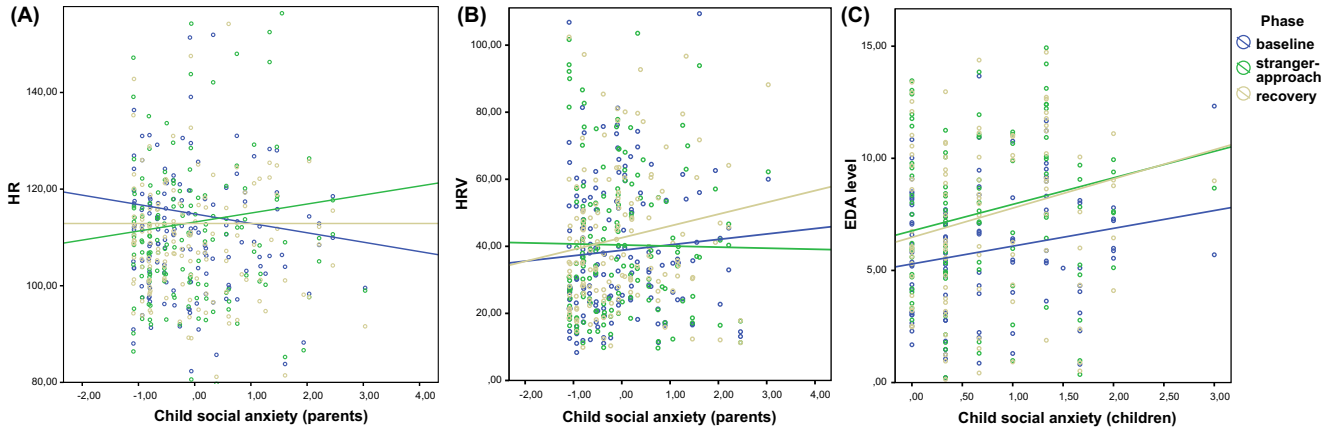

Figure 1 Child social anxiety predicting child (a) HR, (b) heart rate variability (HRV), and (c) EDA. Levels of HR, HRV, and EDA in three phases was averaged across 2.5- and 4.5-year measurements [Colour figure can be viewed at wileyonlinelibrary.com]

find evidence for physiological hyperarousal in children at high risk for developing SAD because of their parents' diagnosis of SAD. However, our results showed that children of parents with more severe SAD display elevated EDA levels throughout the task. Furthermore, our findings offered evidence that early physiological hyperarousal is related to later social anxiety. That is, we found that physiological hyperarousal measured as increased HR and reduced HRV while interacting with a stranger as well as elevated EDA throughout the task phases is linked to higher levels of child social anxiety in late childhood, at the age of 7.5. Although a few studies have investigated early physiological activity in relation to behavioral inhibition (Kagan, 1997; Kagan et al., 1988), our study is the first to offer the evidence that children at risk for SAD show physiological hyperarousal in early childhood and that this early physiological hyperarousal poses a risk for later child social anxiety. Thus, physiological hyperarousal may be involved in the development of heightened social anxiety, and possibly later SAD.

Similar to one previous study with the same sample of children that measured physiological hyperarousal of children at high risk for SAD in a social performance situation (Nikolić et al., 2016), we did not find evidence that physiological hyperarousal while interacting with a stranger in early childhood marks children whose parents are diagnosed with SAD. However, elevated EDA throughout the task phases was found in children of parents with more severe SAD. It seems that SAD severity is a more sensitive measure than SAD diagnosis because it is a continuous variable that, unlike categorical SAD diagnosis variable, accounts for different levels of severity. Also, the SAD severity score accounts for SAD severity of both mothers and fathers, and is, thus, higher, if both the mother and the father have SAD diagnosis, whereas SAD diagnosis variable does not differ for children with one versus two parents with SAD.

Similar to this study, elevated EDA during baseline and social performance task was found in the same sample of children of parents with more social anxiety symptoms (Nikolić et al., 2016). Also, heightened EDA during baseline and fearful tasks was previously found in children at risk for developing anxiety disorders in general (Merikangas, Avenevoli, Dierker, & Grillon, 1999; Turner, Beidel, & Roberson-Nay, 2005). It is, therefore, possible that EDA is a more sensitive measure of physiological activity than cardiovascular measures (Turner et al., 2005). Also, EDA is a measure of sympathetic activity, whereas HR depends on both sympathetic and parasympathetic activity and HRV is thought to reflect parasympathetic activity (Bradley & Lang, 2007). It is, therefore, possible that physiological hyperarousal in children at risk for SAD is represented only in the heightened activation of the sympathetic branch of the autonomic nervous system.

Increased HR and reduced HRV while interacting with a stranger were found to be linked to child later social anxiety symptoms reported by their parents. Also, elevated EDA throughout the task phases (i.e. baseline, stranger-approach, and recovery) was related to later child social anxiety symptoms reported by children. Regarding EDA, our results suggest that basal hyperarousal, hyper-responsiveness, and slower recovery in response to social challenges are already present during early childhood in children whose parents have more severe SAD and in children who later develop more social anxiety symptoms. In addition, HR reactivity (increased activity during the task relative to baseline) and HRV reactivity (increased activity during the task relative to recovery) were related to later child social anxiety. These physiological variables reflect not only the activation of sympathetic branch but also the withdrawal of parasympathetic branch of autonomic nervous system. Previous studies found similar evidence for basal physiological hyperarousal (Krämer et al., 2012; Schmitz et al., 2011, 2013) and physiological hyper-responsiveness to a social challenge in children with higher levels of social anxiety or SAD (Beidel, 1988; Matthews et al., 1986).

Our regression analyses revealed that elevated baseline EDA and HR reactivity to the task are not only linked but also prospectively predict later social anxiety. Thus, our study contributes to the current knowledge on physiological hyperarousal in SAD by providing evidence that physiological hyperarousal in early childhood is not only a symptom of already developed social anxiety but also an early risk factor for later social anxiety. Finally, taking together the findings that elevated EDA is found in children of parents with more severe SAD and that elevated EDA also predicts later child social anxiety, our study suggests that elevated EDA may be a biological mechanism of the intergenerational transmission of SAD.

The findings of our study should be considered in view of some limitations. First, we did not use the SAD diagnosis for children when they were 7.5 years old, but rather, social anxiety symptoms reported by parents and children. At this age, the majority of children did not receive a SAD diagnosis, thus, it was not possible to compare children with and without a SAD diagnosis. However, social anxiety symptoms in childhood are predictive of later SAD diagnosis (Chronis-Tuscano et al., 2009). Therefore, we could indirectly, but not directly, conclude about the possibility of physiological hyperarousal being a premorbid factor of SAD. Also, we do not know how specific our findings are to SAD and to what degree the results of the current study may apply to children at risk for other anxiety disorders. Future studies should investigate early physiological hyperarousal as a predictor of SAD in adolescence, when SAD is typically diagnosed and should take into account other anxiety disorders of parents and children. Finally, we did not control for respiration when measuring HRV in children. Although respiration does not dramatically influence the time-domain short-term RMSSD (Schipke, Arnold, & Pelzer, 1999), which is thought to represent high-frequency HR variations (Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996), we cannot rule out that the HRV differences that occurred in our study were partially reflecting differences in respiration rate. Clinical implications of our findings are twofold. First, stable physiological hyperarousal in social situations already during toddlerhood and early childhood may be a factor in identifying children at risk for developing SAD later in life. Second, because physiological hyperarousal likely plays a role in the development of SAD, procedures focusing on bodily symptoms of SAD should be incorporated in the treatment of SAD (e.g. task concentration training) (Bögels, 2006; Bögels & Voncken, 2008).

In conclusion, our study offers evidence that children of parents with severe SAD display physiological hyperarousal, and elevated EDA in particular, and that this physiological hyperarousal is linked to later child social anxiety. Together, these findings suggest that physiological hyperarousal may be a biological mechanism of intergenerational transmission of SAD and that it may be a biological vulnerability factor for the development of SAD. Thus, the developmental psychopathology models of SAD, as well as clinical treatments for SAD, may benefit from including physiological hyperarousal in their assessment.

Supporting information

Additional Supporting Information may be found in the online version of this article:

Appendix S1. Multilevel equations.

Table S1. Correlations between physiological measures and social anxiety of parents and children.

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Key points

- Physiological hyperarousal may pose a risk for the development of SAD, however, studies investigating physiological hyperarousal as a risk for SAD are currently lacking.
- Children of parents with more severe lifetime SAD displayed patterns of physiological hyperarousal indexed as electrodermal activity in early childhood.
- Early physiological hyperarousal was linked to later child social anxiety.
- Physiological hyperarousal may be a biological mechanism of the intergenerational transmission of social anxiety, and eventually SAD.
- Because physiological hyperarousal plays a role in the early development of SAD, clinical treatments of childhood SAD may benefit from setting treatment goals that explicitly target physiological hyperarousal.

Note

1. In Tables 2 and 3, baseline was used as a reference, thus, only increases/decreases in physiological hyperarousal during stranger-approach and recovery relative to baseline are displayed. To better understand the significance of the interaction for HRV, we modeled, post hoc, recovery as a reference and found that, for HRV, the reduction in HRV while interacting with a stranger was significant relative to the recovery phase. This additional information, however, is not displayed in the table.

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