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Parent–child physiological concordance predicts stronger observational fear learning in children with a less secure relationship with their parent

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A B S T R A C T

Observational fear learning is common in children as they learn to fear by observing their parents. Although adaptive, it can also contribute to the development of fear-related psychopathologies such as anxiety disorders. Therefore, it is important to identify and study the factors that modulate children's sensitivity to observational fear learning. For instance, observational fear learning can be facilitated by the synchronization of biological systems between two people. In parent–child dyads, physiological concordance is important and varies according to the attachment relationship, among others. We investigated the joint effect of parent–child physiological concordance and attachment on observational fear learning in children. A total of 84 parent–child dyads participated in this study. Parents were filmed while exposed to a fear-conditioning protocol, where one stimulus was associated with a shock (CS+) and the other was not (CS−). This recording was then shown to the children (observational learning). Thereafter, both stimuli (CS+ and CS−) were presented to the children without any shock (direct expression test). For both the parent and child, skin conductance activity was recorded throughout the entire procedure. We measured physiological concordance between the parent's phasic skin conductance signal during conditioning and the child's signal during the observational learning stage. Children showing stronger concordance and a less secure relationship with

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their parent exhibited higher levels of fear to the CS+, as indicated by a heightened skin conductance response during the direct expression test. Thus, when children have an insecure relationship with their parent, strong physiological concordance may increase their sensitivity to observational fear learning.

Introduction

Observational fear learning is important during childhood, particularly within the family environment. It is well established that children can learn to fear by observing their parents. Several studies have shown that children express more fear (assessed by behavioral, subjective, and physiological measures) toward stimuli when they had previously observed their mother or father reacting negatively, nervously, or fearfully to the same stimuli (Askew & Field, 2007; de Rosnay et al., 2006; Dubi et al., 2008; Dunne & Askew, 2013; Gerull & Rapee, 2002; Marin et al., 2020). To study this phenomenon in adults and children, some studies have used observational fear conditioning protocols, where an observer watches a demonstrator being exposed to two stimuli—one paired with an aversive stimulus, such as a mild electric shock (conditioned stimulus [CS+]), and one presented alone (nonconditioned stimulus [CS−]). Results have shown that when the observer is in turn exposed to the same two stimuli, the observer exhibits higher fear levels to the CS+ compared with the CS− (Marin et al., 2020; Olsson et al., 2007; Olsson & Phelps, 2007). Given that no shock is given to the observer, the fear association is acquired through the observation of the demonstrator's experience. Because skin conductance activity reflects the activity of the sympathetic nervous system (SNS), it is commonly measured during fear conditioning protocols. Indeed, the skin conductance response (SCR) is the most widely employed index to quantify fear learning (Debiec & Olsson, 2017; Lonsdorf et al., 2017; Marin et al., 2020; Mauss & Robinson, 2009; Olsson et al., 2007; Olsson & Phelps, 2007; Pärnamets et al., 2020). Because the social transmission of fear involves two individuals, certain dyadic factors (e.g., attachment relationship and the biological synchronization between two people) are important to consider in order to understand the variability in different individuals' propensity to socially learn fear.

The attachment and threat detection systems are intertwined. When children face a threat, their attachment system is activated. This activation drives them to get within proximity of their caregiver, who serves as a protector and will help them to regulate their fear (Bowlby, 1973, 1982). From a biological point of view, various studies have shown that parent–child relationship quality is associated with the development of key brain regions involved in the fear circuitry (Gee et al., 2013, 2014; Lebowitz et al., 2018; Lupien et al., 2011; McLaughlin et al., 2016; Mehta et al., 2009; Tottenham et al., 2010, 2011). Moreover, the parent–child attachment relationship has been shown to influence fear reactions in children. Insecure children tend to have higher physiological fear levels when presented with threat-related stimuli (e.g., fearful video clips or images; Gilissen et al., 2007, 2008; Stupica et al., 2019) or in the context of an observational fear learning protocol (Bilodeau-Houle et al., 2020).

Another dyadic factor that has been proposed to be a facilitator of observational fear learning is the synchronization of biological systems between two individuals (Pärnamets et al., 2020). Pärnamets and colleagues (2020) studied the effect of physiological concordance[1] of autonomic system activity between two adult strangers during an observational fear learning protocol. They measured both the demonstrator's and observer's phasic skin conductance signals while the latter watched the demonstrator being exposed to a fear conditioning protocol. The researchers showed that a higher skin conductance concordance between the demonstrator and observer was associated with better discrimination between

[1] In the literature, a variety of terms have been used to refer to the matching of biological systems such as synchrony, concordance, coregulation, covariation, and attunement. To simplify reading, we use the term *physiological concordance* in the current article.

a threat (CS+) and safety (CS−) stimuli when the observer was directly exposed to them. Using a similar protocol, Marin, Bilodeau-Houle, and colleagues (2020) showed that stronger parent–child concordance (also assessed by phasic skin conductance signals) was associated with higher fear levels to the threat stimulus (CS+) when children (observers) were directly exposed to it. These results suggest that physiological concordance between two individuals tends to promote observational fear learning.

That being said, different factors pertaining to the parent–child relationship can influence the concordance of biological systems. For example, Sethre-Hofstad and colleagues (2002) found mother–preschooler adrenocortical response concordance during a challenging task (child beam walk). These results were found for sensitive mother dyads but not for dyads where the mother was less sensitive (maternal sensitivity was coded using the Ainsworth Sensitivity Scale). Another study showed that greater reciprocity during a mother–child interaction task was associated with lower diurnal cortisol concordance between the mother and her school-aged child (Pratt et al., 2017). Ouellette and colleagues (2015) showed that the quality of parenting moderates the hair cortisol concentration (HCC) associations between mothers and their school-aged daughters, such that mother–daughter HCC associations became stronger as parenting quality became lesser. With regard to the parent–child attachment relationship, Smith and colleagues (2016) showed that mother–preschooler respiratory sinus arrhythmia (RSA) concordance during the Strange Situation procedure (SSP) was stronger in dyads where the child had an insecure-resistant attachment compared with dyads where the child had an avoidant, disorganized, or secure attachment style. However, a study found lower dyadic concordance in heart rate changes during the SSP for insecure-resistant toddler–mother dyads compared with secure dyads (Zelenko et al., 2005). Although these studies are somewhat inconsistent, they suggest that parent–child physiological concordance is dependent on children's relationship with their parent.

Moreover, whereas parent–child physiological concordance is critical for children to learn emotion regulation (Feldman, 2007), the interaction between the concordance of biological systems and family context has been shown to affect a child's self-regulation abilities (Birk et al., 2022; Davis et al., 2018; Saxbe et al., 2017; Suveg et al., 2016). For instance, with a sample of mother–preschooler dyads, Suveg and colleagues (2016) investigated the impact of cardiovascular concordance, positive behavioral concordance (i.e., mutual cooperation, reciprocity, and harmony; Harrist & Waugh, 2002), and family risk on the child's self-regulation abilities during a drawing task. In families with greater risk levels (a measure derived from socioeconomic disadvantage and parental psychopathology), physiological concordance was negatively associated with the child's self-regulation abilities and positive behavioral concordance. These results highlight the importance of investigating the moderating role of family context-related variables in the relationship between parent–child physiological concordance and outcomes observed in children.

Fear reactions and learning are modulated by the parent–child attachment relationship (Bilodeau-Houle et al., 2020; Gilissen et al., 2007, 2008; Stupica et al., 2019). Further, fear learning can also be modulated by physiological concordance (Marin et al., 2020; Pärnamets et al., 2020). Moreover, the latter varies according to the attachment relationship (Smith et al., 2016; Zelenko et al., 2005). Thus, we aimed to study the moderating role of attachment in the association between physiological concordance and fear learning. More specifically, we investigated whether the concordance of biological systems between a child and parent influences the child's fear learning as a function of the parent–child attachment relationship. Given that this study consisted of exploratory analyses of secondary data and that the literature on this topic is scarce and inconsistent, we did not formulate specific hypotheses (Tong, 2019). However, we expected that parent–child physiological concordance would facilitate observational fear learning in children but that the effect would differ based on the attachment relationship.

Method

Participants

A total of 91 biologically related and healthy parent–child dyads participated in the study. Of these, 83 dyads were recruited in the context of a research project that aimed at developing and validating an observational fear learning protocol (Marin et al., 2020). At the time that the secondary analyses were performed for this study, nine dyads had participated in another research project in our laboratory that used the same observational fear protocol (the project was since put on hold due to the COVID-19 pandemic). Given the availability of these data, and to increase our statistical power, we included these dyads in the current study. Because anxiety disorders have a median age of onset of 11 years (Kessler et al., 2005), combined with the knowledge of previous studies that have performed direct fear conditioning (Jovanovic et al., 2014; Neumann et al., 2008; Waters et al., 2009) and observational fear conditioning protocols with children (Askew & Field, 2007; Dunne & Askew, 2013), we recruited children aged 8 to 12 years. Exclusion criteria and sample size determination are presented in the online supplementary material. This project was approved by the ethics committee of the Centre intégré universitaire de santé et de services sociaux (CIUSSS) de l'Est-de-l'Île-de-Montréal. Informed consent and assent were obtained from parents and children, respectively. Parents and children were compensated for their participation.

Procedure

Questionnaires

To assess parent–child relationship security, children completed a validated French version of the Security Scale–Child Self-Report (Bacro, 2011). This 15-item questionnaire was completed twice—once for the mother and once for the father (see supplementary material for details). In the current project, we used the security score pertaining only to the parent who participated in the study.

Observational fear learning protocol

Parents. Parents were exposed to a direct fear conditioning protocol (Marin et al., 2020; adapted from Milad et al., 2007, 2009). Before the procedure, Ag/AgCl electrodes were placed on the palm of their left hand to record skin conductance activity. To deliver shocks, electrical stimulation electrodes were placed on the index and middle fingers of their right hand. Parents were asked to select an electric shock intensity level (0.8–6.0 mA) that was very annoying but not painful. First, they underwent a habituation phase where two colored lamps (e.g., blue and yellow lamps) were presented twice on a computer screen without being reinforced by an electric shock. Parents were then exposed to the conditioning phase, where both lamps were presented again. At this stage, one lamp (e.g., blue lamp) was reinforced with the electric shock (CS+ for the parent [CS+Parent]). The other lamp (e.g., yellow lamp) was never paired with the shock (CS−). There was a total of eight CS+ presentations (five were paired with a shock) and four CS− presentations. The conditioning phase was video-recorded (no audio). Prior to the study, a stranger man and woman were filmed while undergoing a similar procedure, although a different colored lamp was reinforced (e.g., red lamp, CS+ for the stranger [CS+Stranger]). The CS− was the same for the stranger and parent (e.g., yellow lamp; Fig. 1). The lamp colors that were used for the multiple CS+ and CS− were counterbalanced across dyads. Each trial began with a black screen (intertrial interval) lasting 9 to 15 s (with an average of 12 s) followed by the image of an office with a lamp turned off (baseline image) that was presented for 3 s. Thereafter, the lamp was turned on (e.g., blue/red [CS+] or yellow [CS−]) for 6 s. For the parent and stranger, reinforced trials ended with the administration of a 0.5-s shock (unconditioned stimulus [US]) to the fingers on their right hand.

Children. Children were exposed to an observational fear learning protocol (Marin et al., 2020) including three sequential phases: (1) habituation, (2) observational learning, and (3) direct expression test/extinction learning. Before the start of the procedure, Ag/AgCl electrodes were placed on the palm of the children's left hand to record skin conductance activity. Then, children were exposed to the habituation phase, where three colored lamps (blue, red, and yellow) were each presented twice on a computer screen. Thereafter, children underwent the observational learning stage, during which they watched the video of their parent and the stranger (same sex as the parent) undergoing the fear conditioning protocol described above. High-quality resolution videos allowed the children to distinguish between lamp colors, facial affect, and postural reactions in parents and strangers. The presentation order (parent or stranger first) of the videos was counterbalanced across dyads. To assess their aware-

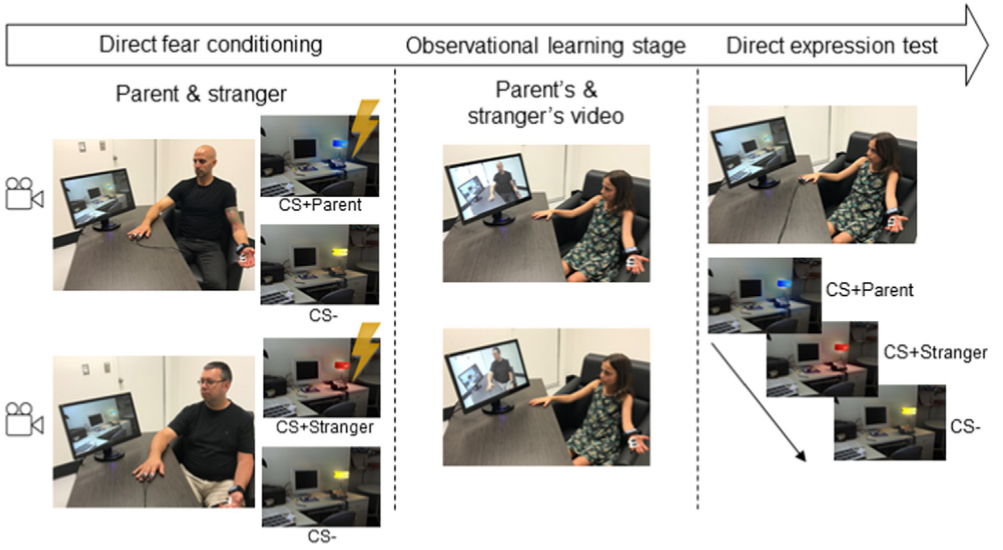

Fig. 1. Observational fear learning protocol. First (left panel), the parent and stranger were exposed to a direct fear conditioning protocol. They were exposed to two colored lamps; one was paired with a mild electric shock (CS+Parent or CS+Stranger), and the other was not (CS−). The colored lamps paired with the shock were different for the parent and stranger (e.g., blue for the parent and red for the stranger). Skin conductance activity was recorded, and both procedures were filmed. Lightning represents the administration of electrical stimulation. Second (middle panel), children underwent the observational fear learning stage, where they watched the videos of their parent and the stranger. Skin conductance activity was recorded. Third (right panel), children were exposed to the direct expression test, where the three stimuli (CS+Parent, CS+Stranger, and CS−) were presented to them. They were instructed that they might receive a shock for some stimuli, although no shock was given to children to test observational learning. Skin conductance activity was recorded.

ness of the CS–US contingency, children were asked to identify which colored lamp was/was not associated with a shock for the parent and stranger. Next, children underwent the direct expression test/extinction learning. Electrical stimulation electrodes were attached to the index and middle fingers of the children's right hand. To test observational fear learning, the experimenter told children that they may receive mild electric shocks for some colored lamps. However, no shock was ever administered to the children. The three colored lamps were then presented on the computer screen (eight intermixed presentations of each colored lamp; Fig. 1). The trial duration was the same as for parents/strangers. Because children were never administered any shocks, we expected that extinction would occur rapidly. Therefore, only the first two presentations of each colored lamp during the direct expression test/extinction learning were used to assess fear acquisition (Marin et al., 2020). Thus, we refer only to the direct expression test in this study.

Physiological recordings

Skin conductance activity was recorded using BioNomadix wireless technology (MP160) and AcqKnowledge software (BIOPAC, Goleta, CA, USA). Phasic skin conductance signals of parents during the conditioning phase and of children during the observational learning stage were used to assess physiological concordance. SCR was used to evaluate children's fear learning during the direct expression test (see below).

Parent–child physiological concordance. As per Pärnamets and colleagues (2020), physiological concordance between parents and children was assessed with cross-recurrence quantification analyses (CRQA). This method allowed for the investigation of patterns of recurrence between two nonlinear time series (Wallot & Leonardi, 2018). Recurrence can be defined as the repetition of elements or patterns in a sequence (Wallot & Leonardi, 2018). In the current study, cross-recurrence can be understood as patterns of recurrence in two distinct sequences. Here, cross-recurrence was computed between two time series: parents' phasic skin conductance signal while undergoing direct fear conditioning and children's phasic skin conductance signal during the observational learning stage (Figs. 1 and 2). Both signals were filtered with a .05- to 1-Hz passband, downsampled to 8 Hz, and then z-scored. Cross-recurrence between both signals was computed in R with the *crqa* package (Coco & Dale, 2014, Coco et al., 2021) using 2000 time points. To keep the recurrence rate between 2% and 4% (Pärnamets et al., 2020), the three parameters radius, delay, and embedding dimensions were optimized (with the *optimizeParam* function) for each dyad. The recurrence rate corresponds to the percentage of points forming recurrence among all points in a recurrence plot. Here, recurrence points refer to instances of co-visitation between phasic skin conductance signals of parents and children. In line with the work of Pärnamets and colleagues (2020), we used four CRQA metrics in our analyses: determinism (DET), laminarity (LAM), length of the longest diagonal (maxL), and relative entropy (rENTR). DET and LAM correspond to the percentage of recurrent points forming diagonal and vertical lines, respectively, among all recurrent points in a recurrence plot. Therefore, DET refers to the predictability of the coupling between both signals and represents synchronous periodicity. On the other hand, LAM refers to intervals when both signals share some stability (Curtin et al., 2017). maxL corresponds to the length of the longest diagonal in a recurrence plot. Similar to DET, it is also a measure of the coupling strength between two signals. rENTR refers to the Shannon entropy of diagonal lines in a recurrence plot, normalized by the number of lines. The latter measure reflects the variability in the length of diagonals. Thus, higher rENTR reflects a more complex distribution of diagonal lengths and suggests that both signals are coupled through more variable patterns (Curtin et al., 2017; McCamley et al., 2017).

Children's fear levels. To quantify children's fear learning during the direct expression test for each stimulus presentation, SCR was calculated using the following formula (Marin et al., 2016, 2017, 2020; Milad et al., 2007, 2008, 2009):

$$\sqrt{\begin{array}{c}(\text{maximal skin conductance during the CS presentation})-\\(\text{mean skin conductance during the last 2 s of the context presentation})\end{array}}.$$

No other transformation was applied to the data, nor was a minimum response criterion used (Lonsdorf et al., 2017). Although data were screened for outlier values (±3.29 standard deviations from the mean), none was detected.

Statistical analyses

Principal component analysis

Because DET, LAM, maxL, and rENTR were intercorrelated, we were inspired by previous works to apply a principal component analysis (PCA) on these four metrics and use the resulting first factor (PC1) as the physiological concordance measure in our statistical analyses (Pärnamets et al., 2020). Factor loadings and explained variance are displayed in Table S1 of the supplementary material.

Principal analyses

To evaluate observational fear learning, we used differential SCR. We subtracted SCR to the CS− from SCR to the CS+Parent (CS+Parent$_{\text{diff}}$) and also subtracted SCR to the CS− from SCR to the CS+Stranger (CS+Stranger$_{\text{diff}}$). The resulting two variables were used in the following analyses. To analyze the impact of physiological concordance and parent–child attachment on children's observational fear learning, we conducted a linear mixed-effects model with random intercepts by individuals and stimulus, physiological concordance, parent–child attachment, and their interaction as fixed effects. It is important to note that a few parents participated with more than one child (see below), which violates the assumption of independence. Therefore, we randomly picked one child in each family and reran the analyses to ensure that this did not change the results. The maximum likelihood method was used for estimation. Significant interactions were decomposed using the simple slope approach

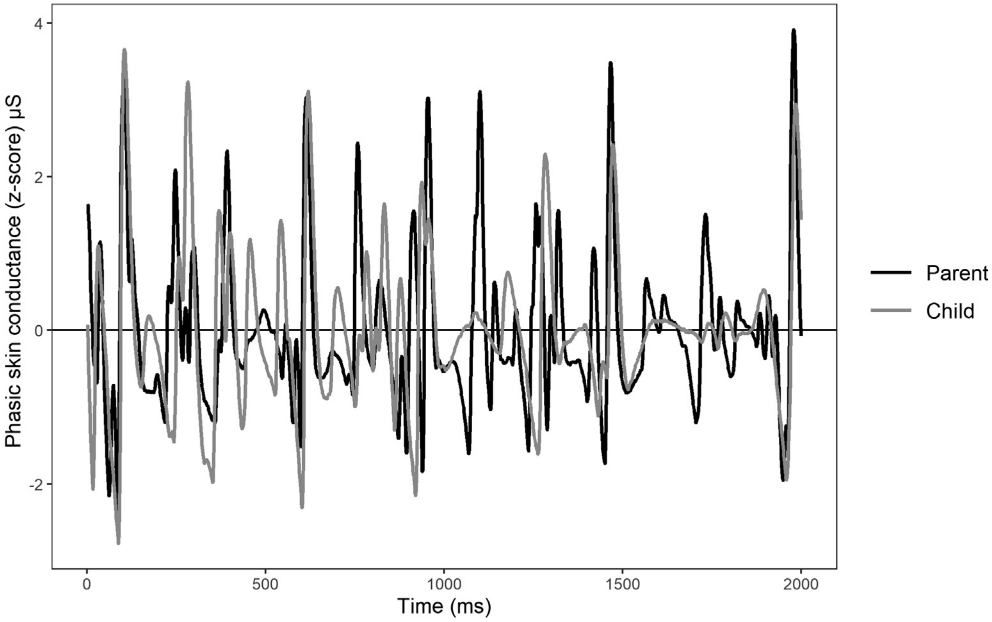

Fig. 2. Parent–child phasic skin conductance time series. The black line depicts phasic skin conductance signal variation over time for one parent while exposed to direct fear conditioning. The gray line depicts phasic skin conductance signal variation over time for one child while exposed to the observational learning stage. The *x*-axis represents time (as measured in milliseconds), and the *y*-axis represents the parent's and child's phasic skin conductance signals (as measured in microsiemens).

(Aiken et al., 1991). The analyses were carried out in R with the *nlme* package (Pinheiro et al., 2021) and *reghelper* package (Hughes & Beiner, 2022).

Results

Sample characteristics

Of the 91 parent–child dyads, six dyads were excluded due to technical difficulties related to skin conductance activity recording and one dyad was excluded because the child terminated participation in the study before the direct expression test. Therefore, analyses were conducted on 84 parent–child dyads, which consisted of 75 parents and 84 children (nine parents came to the lab with two children). Dyads were distributed as follows: 35 father–child (18 father–son and 17 father–daughter) and 49 mother–child (20 mother–son and 29 mother–daughter). Parent–child relationship security did not differ between father–child and mother–child dyads (t = 1.42, p =.160). However, physiological concordance values were higher in mother–child dyads compared with father–child dyads (t = −2.19, p =.031). For both mother–child and father–child dyads, the parent–child physiological concordance was not associated with relationship security (father–child dyads: r = −.04, p =.810; mother–child dyads: r =.16, p =.270). Given that physiological concordance differed between father–child and mother–child dyads, the type of dyad (father–child or mother–child) was controlled for in our principal analyses. Sample characteristics details are described in Table 1.

Main analyses

Our analyses revealed a significant three-way interaction among stimulus, physiological concordance, and parent–child attachment (Table 2). Results indicated that the Physiological

Table 1
Sample demographics.

Children	
Sex (%)	
Boys	38 (45,24)
Girls	46 (54,76)
Caucasians (%)	68 (80,95)
Age in years (SD)	9.76 (1.56)
Parents	
Sex (%)	
Male	32 (42,67)
Female	43 (57,33)
Caucasians (%)	68 (90.67)
Age in years (*SD*)	41.28 (4.69)
Education years (*SD*)	15.60 (2.67)
Shock level (*SD*)	
Male	2.51 (1.63)
Female	1.96 (1.17)
Dyads	
Parent–child relationship security (*SD*)	
Father–child	3.25 (0.35)
Mother–child	3.14 (0.41)
Physiological concordance (*SD*)	
Father–child	−0.27 (0.91)
Mother–child	0.19 (1.02)

Note. SD, Standard deviations.

Table 2
Comparison of all models.

	AIC	BIC	logLik	Test	L.Ratio	*p*
Baseline	177.46	186.84	−85.73	–	–	–
Stimulus*	174.37	186.86	−83.18	1 vs 2	5.10	.024
Dyad	175.93	191.55	−82.96	2 vs 3	0.44	.507
Concordance	177.78	196.53	−82.89	3 vs 4	0.14	.706
Attachment	179.78	201.65	−82.89	4 vs 5	0.00	.966
Stimulus × Concordance	181.65	206.65	−82.83	5 vs 6	0.13	.721
Stimulus × Attachment	181.90	210.02	−81.95	6 vs 7	1.75	.185
Concordance × Attachment	182.12	213.36	−81.06	7 vs 8	1.78	.182
Stimulus × Concordance × Attachment**	174.73	209.09	−76.36	8 vs 9	9.39	.002

Note. AIC, Akaike information criterion; BIC, Bayesian information criterion; logLik, log-likelihood; L.Ratio, likelihood-ratio test.
* $p \leq .05$.
** $p \leq .01$.

Concordance × Parent–Child Attachment interaction was significant for the CS+Parent$_{diff}$ but not for the CS+Stranger$_{diff}$ (Table 3). The interaction was then decomposed using the simple slopes approach and revealed that parent–child attachment moderated the association between physiological concordance and children's fear levels to the CS+Parent$_{diff}$. Increased physiological concordance was associated with increased differential fear levels in children with a less secure parent–child attachment (−1 standard deviation; B = 0.13, SE = 0.06, p =.037) but not in those with a moderate (mean; B = 0.01, SE = 0.05, p =.870) or more secure attachment (+1 standard deviation; B = −0.12, SE = 0.07, p =.112) (Fig. 3). The observed effect on the SCR differential score may be attributable to higher fear levels to the CS+ Parent or lower fear levels to the CS−. Indeed, upon inspection of Fig. 4, children with a less secure attachment seem to have higher SCR to the CS+Parent when they are strongly concordant with their parent. We verified this assumption by testing each stimulus separately (see Tables S2 and S3 in supplementary material).

Table 3
Change in child fear levels (SCR) during the direct expression test as a function of stimulus (CS+Parent$_{diff}$, CS+Stranger$_{diff}$), parent–child concordance and parent–child attachment.

	Estimate	*SE*	*t*	*p*	95% CI
Intercept	0.08	0.16	0.49	.628	−0.23, 0.38
Stimulus – CS+Parent$_{diff}$ vs CS+Stranger$_{diff}$*	0.09	0.04	2.18	.033	0.01, 0.17
Dyad	0.07	0.09	0.71	.479	−0.12, 0.25
Concordance	0.01	0.05	0.12	.906	−0.09, 0.10
Attachment	0.01	0.13	0.08	.936	−0.24, 0.26
Stimulus – CS+Parent$_{diff}$ vs CS+Stranger$_{diff}$ × Concordance	0.00	0.04	0.08	.935	−0.08, 0.08
Stimulus – CS+Parent$_{diff}$ vs CS+Stranger$_{diff}$ × Attachment	−0.07	0.11	−0.66	.511	−0.28, 0.14
Stimulus – CS+Parent$_{diff}$ × Concordance × Attachment*	−0.33	0.13	−2.48	.015	−0.59, −0.07
Stimulus – CS+Stranger$_{diff}$ × Concordance × Attachment	0.02	0.13	0.11	.909	−0.24, 0.27

Note. SCR, skin conductance response; CS, conditioned (shock) stimulus; CI, confidence interval.
* $p \leq .05$.

CS–US contingency awareness (i.e., being able to identify which colored lamp was associated with a shock for the parent and stranger) was reported by 77% (65 children) of the sample. To increase our statistical power, we decided to include the data from all children in our analyses. But to ensure that the contingency awareness did not change the results, our analyses were again conducted without children who were unaware of the CS–US contingency, and similar results were obtained (see Tables S4–S7 in supplementary material).

Of note, our results remained unchanged when only the 83 dyads from the original project were considered and when we randomly selected one child for each parent who had two participating children.

Discussion

The objective of this study was to investigate whether the effect of parent–child physiological concordance on observational fear learning in children varied according to the attachment relationship. We found that parent–child physiological concordance predicted differential SCR between the CS+Parent and CS− for children who had a more insecure relationship with their parent. For children with a more secure relationship with their parent, physiological concordance had no impact on differential SCR between the CS+Parent and CS−. Importantly, for more insecure children, the impact of physiological concordance on differential SCR seemed to be mainly driven by higher SCR to the CS+Parent. Parent–child physiological concordance was unrelated to differential SCR between the CS+Stranger and CS−.

Our results act in conjunction with those found by Pärnamets and colleagues (2020), who observed that the physiological concordance between an adult demonstrator and an adult observer predicted the observer's differential SCR during the direct expression test. Given that we tested our research objective using parent–child dyads, we were unable to explore the same question using stranger–child dyads (because no attachment to the stranger could be measured). Extending beyond the findings of Pärnamets and colleagues (2020), our results suggest that the association between physiological concordance and observational fear learning observed in strangers differs as a function of relationship quality when tested in familiar dyads. In favor of this hypothesis, some studies in healthy parent–child dyads have shown that parent–child biological concordance is modulated by family context variables such as the parent's sensitivity (Sethre-Hofstad et al., 2002), reciprocity between the parent and child (Pratt et al., 2017; Saxbe et al., 2017), parenting quality (Ouellette et al., 2015), presence of maltreatment within the family (Creaven et al., 2014), and attachment relationship (Donovan & Leavitt, 1985; Smith et al., 2016; Zelenko et al., 2005). These studies suggest that the impact of physiological concordance on observational fear learning depends on the child's relationship with the parent and family context.

Observational fear learning is an adaptive mechanism but can also contribute to the development of fear-related psychopathologies such as anxiety disorders and posttraumatic stress disorder

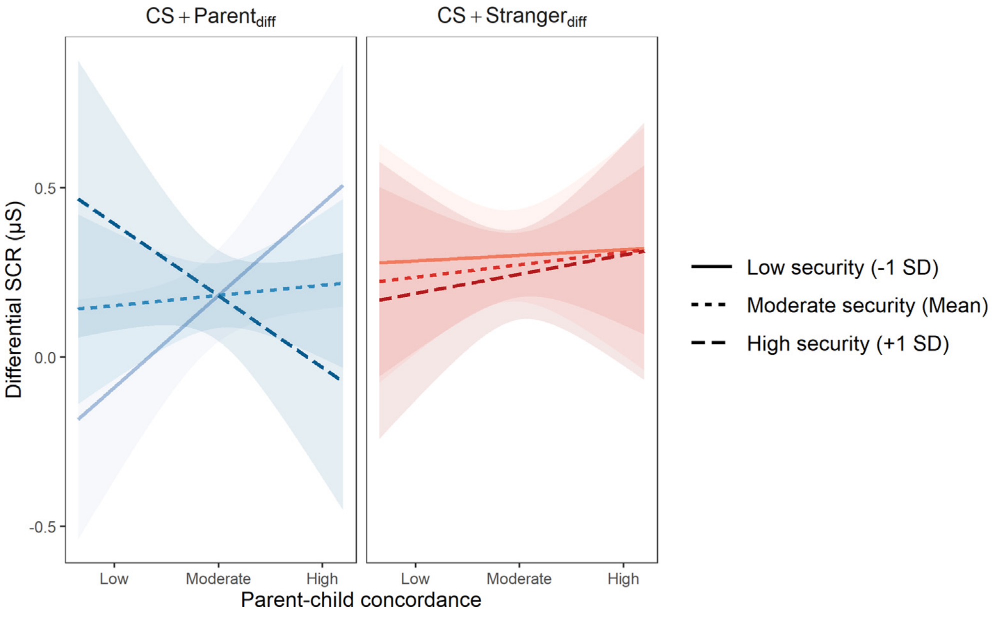

Fig. 3. The effect of parent–child relationship security on the association between parent–child physiological concordance and children's differential fear levels as a function of the stimulus. The *x*-axis represents parent–child physiological concordance, and the *y*-axis represents children's differential SCR (CS+Parent minus CS− and CS+Stranger minus CS−, as measured in microsiemens). The moderating variable (parent–child attachment) represents the score on the Security Scale–Child Self-Report. Left panel: Parent–child relationship security moderated the association between parent–child physiological concordance and children's physiological fear levels for the CS+Parent$_{diff}$. For children presenting lower security levels, stronger concordance with their parent was associated with higher differential SCR. Right panel: Parent–child attachment did not moderate the effect of parent–child physiological concordance on children's physiological fear levels for the CS+Stranger$_{diff}$. The 95% confidence intervals are illustrated by the shadow around the lines.

(PTSD; Craske et al., 2017). Accordingly, an insecure relationship combined with high physiological concordance may make children more susceptible to learning fear through observation. For example, Motsan and colleagues (2021) found that trauma-exposed children who developed PTSD exhibited higher RSA concordance and lower behavioral concordance with their mother compared with children who were exposed to trauma but did not develop PTSD (resilient children). These results suggest that lower physiological concordance may be optimal in certain circumstances (e.g., when a member of the dyad has a fear-related psychopathology).

However, another study reported that RSA concordance was higher among dyads where the child was trauma-exposed but did not develop PTSD, suggesting that higher concordance could be protective (Gray et al., 2018). That being said, children in the latter study were younger (3–6 years) than those in our study and in Motsan and colleagues' study (2021). Therefore, a heightened concordance might not be protective in some circumstances (e.g., fear-related psychopathology in the dyad or low attachment), although it remains crucial to consider the impact of the developmental period. Given that parents play an important role in helping with a child's regulation, physiological concordance is necessary during early childhood (Feldman, 2007; Gray et al., 2018; Motsan et al., 2021). However, there is emerging literature suggesting that less synchronization with the mother is likely to be protective when a child grows older. Indeed, studies have found that an elevated synchronization may contribute to stress during middle and late childhood or adolescence (Motsan et al., 2021; Papp et al., 2009; Pratt et al., 2017; Williams et al., 2013).

The studies cited above measured concordance using RSA, whereas we used skin conductance activity. Whereas RSA results from the activation of the parasympathetic system and also reflects the individual's ability to maintain homeostasis and to adaptively respond to external stimuli, skin

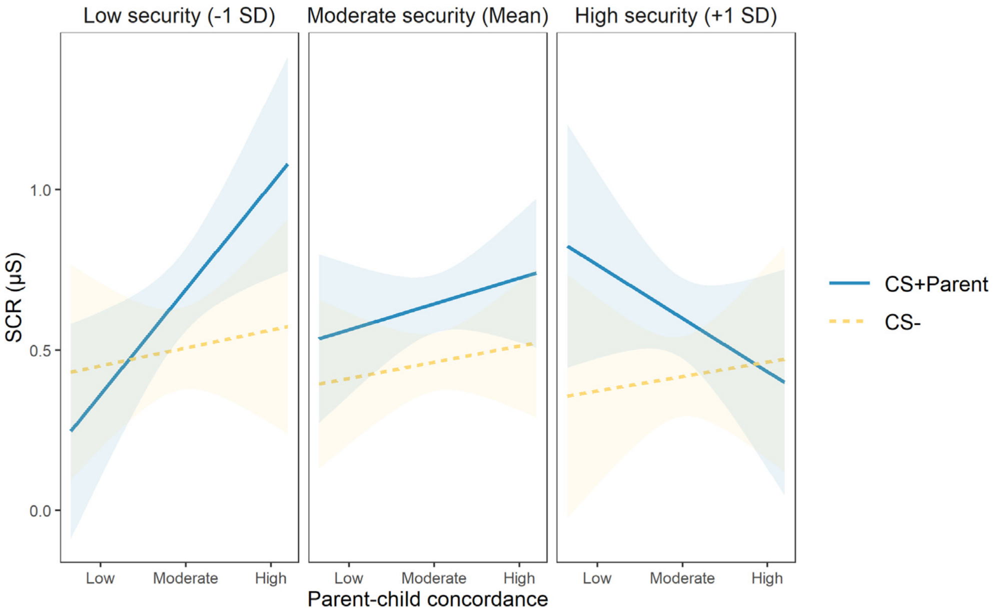

Fig. 4. The effect of parent–child relationship security on the association between parent–child physiological concordance and children's fear levels for the CS+Parent and CS −. The *x*-axis represents parent–child concordance, and the *y*-axis represents children's physiological fear levels (as measured in microsiemens). The solid line represents the CS+Parent, and the dotted line represents the CS −. The left panel includes children with lower relationship security, the middle panel includes children with moderate relationship security, and the right panel includes children with higher relationship security. Children with lower attachment security have higher fear levels to the CS+Parent when concordance with the parent is strong. The 95% confidence intervals are illustrated by the shadow around the lines.

conductance activity results from the activation of the sympathetic system, which is activated in fearful or stressful contexts. To date, it is premature to conclude whether concordance of a system that is linked to self-regulation may be more adaptive than concordance of a system that is associated with fear and stress reactivity (e.g., the sympathetic system). Of note, other sympathetic nervous system markers, such as salivary alpha-amylase (sAA) and finger-pulse amplitude (FPA), were used to show increased physiological concordance in conflictual dyads (Ghafar-Tabrizi, 2008; Gordis et al., 2010). Such concordance may reflect the experience of shared negative emotions. This echoes our findings where the experience of fear learning may lead to negative emotions that are more likely to be shared in highly synchronized (but with poor attachment) dyads. Taken together, these results suggest that higher concordance of the SNS is not always beneficial. However, as mentioned earlier, there appear to be certain developmental effects that are associated with physiological concordance. Therefore, this calls for further investigation into the longitudinal aspects of physiological concordance.

As discussed, our results align with the possibility that children with a less secure parent–child relationship and heightened physiological concordance display a greater susceptibility to learning fears through observing their parent and, consequently, may contribute to the development of fear-related psychopathologies. However, it is important to note that the heightened SCR to the CS+Parent at the direct expression test is not necessarily evidence of dysregulated fear learning. Thus, more studies are needed to test this hypothesis. Indeed, one may argue that these children show better differential learning (greater discrimination between the CS+Parent and the CS−), which may be perceived as adaptive. Failing to discriminate between safe and dangerous stimuli characterizes many fear-related psychopathologies such as PTSD (Grasser & Jovanovic, 2021). Given that children in our study were free of psychopathologies, our results could also mean that a heightened parent–child physiological concordance within the context of a less secure parent–child relationship leads to better discrimination. If so, parent–child concordance would be a protective factor. A longitudinal design could provide insight into this question given that it would be possible to investigate whether the children with a less secure parent–child relationship and a greater concordance in our study would be more likely to develop fear-related psychopathologies in the future compared with other children. Moreover, the mixed results in the literature (Birk et al., 2022; Davis et al., 2018) suggest that physiological concordance is not inherently adaptive or maladaptive and that it depends on many context-related and psychological variables (e.g., type of the task, psychopathology of the parent or child; Birk et al., 2022; Davis et al., 2018).

Limitations and future directions

Our study has some limitations. First, the study was cross-sectional, making it impossible to assess developmental effects, as well as the stability of physiological concordance, across time. Second, testing for sex and gender effects would have been important given that (a) previous studies have mainly focused on mother–child dyads and (b) in the rare studies where the father–child dyads were included, some differences were found between mother–child and father–child physiological concordance. That being said, the investigation of the impact of dyad type on physiological concordance was not among the objectives of our study due to a lack of statistical power (supplementary exploratory analyses were performed nonetheless; see Table S8 in supplementary material). Third, fear learning was assessed only with SCR data. Although studies have demonstrated that physiological and subjective measures of fear are correlated (Fanselow & Pennington, 2018; Taschereau-Dumouchel et al., 2020), there is an ongoing debate in the literature as to whether the emotional experience of fear and the physiological and behavioral responses to threat, such as SCR, emerge from a central neuronal circuit or two distinct neuronal systems (Fanselow & Pennington, 2018; LeDoux & Pine, 2016; Taschereau-Dumouchel et al., 2020). Therefore, physiological measures of fear should not be mistaken for being representative of all the relevant mechanisms involved in fear and anxiety disorders. Moreover, fear conditioning results are not always stable across different physiological fear measures (e.g., fear-potentiated startle, heart rate; Bach & Melinscak, 2020; Glover et al., 2011; Ojala & Bach, 2020). Therefore, future research should replicate this study using other physiological fear measures as well as behavioral and subjective fear measures. On a related note, both physiological concordance and fear learning were measured with skin conductance activity. However, physiological concordance and fear learning were not assessed during the same phase of the protocol. Fourth, this study was originally designed to develop an observational fear conditioning protocol in parent–child dyads that has since been published (Marin et al., 2020). Therefore, our research design did not allow us to measure parent–child concordance during a live mutual interaction, which could have affected the results of this study. Although physiological concordance can efficiently be assessed in noninteractive contexts (Birk et al., 2022; Borelli et al., 2019; Cosgrove et al., 2019; Gray et al., 2018; Lee et al., 2018), it is generally stronger in interactive contexts (Davis et al., 2018). Finally, it is important to consider the possibility that parent–child concordance could be attributable to similar familial physiological reactions to the fear conditioning protocol rather than the observation of the parent. More studies are needed to rule out this hypothesis.

Conclusion and clinical implications

This exploratory study in healthy parent–child dyads has allowed us to identify a joint impact of attachment and physiological concordance on observational fear learning. These data are an important first step to better understanding the mechanisms by which some children are more susceptible to learning fear from the familial environment and, in turn, could have clinical implications. If parent–child physiological concordance contributes to vicarious fear learning, this may be unfavorable for children in certain family contexts such as those who have an insecure relationship with their parent or who are living with a parent suffering from fear-related psychopathologies (e.g., PTSD, specific phobia). Thus, therapists could focus on the following important potential intervention targets during psychotherapy sessions: teach parents suffering from these types of psychopathologies to modulate their observable fear responses and promote their children's self-regulation strategies. Moreover, if parent–child concordance can facilitate the vicarious acquisition of fear, it may also favor vicarious fear extinction learning (George et al., 2022) and, consequently, could be used as a potential treatment to diminish certain fears in children.

CRediT authorship contribution statement

Alexe Bilodeau-Houle: Conceptualization, Formal analysis, Investigation, Writing – original draft, Visualization, Project administration. **Simon Morand-Beaulieu:** Conceptualization, Formal analysis, Writing – original draft, Writing – review & editing. **Valérie Bouchard:** Investigation. **Marie-France Marin:** Conceptualization, Funding acquisition, Methodology, Resources, Supervision, Writing – review & editing.

Data availability

Data will be made available on request.

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Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jecp.2022.105553.

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