Adolescents at risk of anxiety in interaction with their fathers: youth vagal tone and cardiac synchrony

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Master's Thesis

Master's degree in General Health Psychology

at the

Universitat de les Illes Balears

Academic year: 2018 - 2019

Date: July 09th, 2019

UIB Master's Thesis Supervisor: Maria Balle Cabot

Abstract

Background and Objectives. Heart rate variability is considered an indirect measure of vagal function and has found to be diminished in adults with anxiety disorders. However, results regarding adolescents are less conclusive. The synchrony of physiological responsiveness among mother-child interactions is thought to promote child's self-regulatory abilities. Mothers' psychopathology and child internalizing problems have been reported to disturb dyadic physiological synchrony, but less is known about adolescents' risk of anxiety and the role of fathers. Therefore, the aims of this study were to examine the vagal response of adolescents with different risk for anxiety disorders during positive and negative interaction tasks and whether father-adolescent cardiac responses were synchronized during them.

Method. We examined differences in vagal tone (measured by temporal and spectral indices) among 24 adolescents with high risk for anxiety disorders (M_{age} = 14.15, SD_{age} = 0.66), 14 with medium risk (M_{age} = 14.21, SD_{age} = 0.58), and 28 with low risk (M_{age} = 14.14, SD_{age} = 0.73). Interbeat interval series were continuously recorded for both father and adolescent when performing a positive and a negative 10-min discussion task.

Results. No differences in vagal responsiveness were found between anxiety risk groups. Low anxiety risk group had significantly low vagal tone (spectral index) in the negative content interaction task if compared with the positive one. Physiological synchrony was only present a level above chance in the group with medium risk for anxiety in the negative content interaction task.

Conclusions. Adolescents with low risk for anxiety seem to exhibit higher vagal fluctuation than adolescents with medium and high risk for anxiety, which could be a protective factor in the onset of anxiety disorders. Results highlight the complexity and uncertainty of physiological synchrony.

Keywords. Anxiety; adolescents; fathers; heart rate variability; physiological synchrony.

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Introduction

The onset of mental health disorders usually occurs during the transition from childhood to adulthood (Kessler et al., 2007). Anxiety problems are the most prevalent mental health disorders among adolescence with a lifetime prevalence ranging from 15-30% (Essau, Conradt, & Petermann, 2002; Merikangas et al., 2010) and it impacts negatively in the functioning at a social, emotional and academic level. Unfortunately, despite the high prevalence of anxiety disorders and its huge socioeconomics costs, its etiology remains unclear (Beidel & Alfano, 2011).

Recent advances in Developmental Psychology indicate that temperamental features (Rothbart & Bates, 2006) and emotion dysregulation (Hervás & Vásquez, 2003) may be predictors of the onset of anxiety disorders in adolescence.

Over the last decades, a new approach has emerge proposing that parasympathetic control via the vagus nerve is a key factor for the emotion regulation (Porges, 2001; Thayer & Lane, 2000). An indirect measure of the vagal function is the heart rate variability (HRV) which consists in the variations in the length of successive interbeat intervals (IBIs) and it is now widely considered a relevant marker of psychological well-being (Kemp & Quintana, 2013). HRV has been operationalized with a variety of time domain and frequency domain indices. The first type is based on the IBIs or on the differences between successive IBIs, meanwhile the second type gives information about variance or power in the heart rate or heart period time series which is explained by periodic oscillations at various frequencies (Thayer, 2010). The root mean square of the successive differences (RMSSD) and the respiratory sinus arrhythmia (RSA) are two well-known time-domain indices. The first one reflects the variance between successive beat-to-beat intervals (i.e. higher values reflect higher variability) meanwhile RSA considers the change in heart period corresponding with the inspiratory and expiratory phases of the respiratory cycle. On the other hand, the high frequency power band (HF-HRV; 0.15-0.4Hz) is the most commonly used frequency-domain measures since they reflect vagal cardiac vagal tone (Thayer, 2010).

Overall, anxiety in adulthood has been associated with reduced HRV (for a review see Chalmers, Quintana, Abbott, & Kemp, 2014). However, this association remains uncertain in adolescents, since results on this population seem more inconsistent. Few studies are in the line with the results on adulthood. For example, Scott and Weems (2014) examined the differences between youths with high anxiety and youths with low anxiety and found a negative linear association between resting vagal tone indexed by HF-HRV and both child- and caregiver-reported anxiety symptoms. Otherwise, several studies have reported controversial results regarding on the relationship between anxiety or internalising symptomatology in adolescents and their vagal tone. For instance, Greaves-Lord et al. (2007) in a young adolescent sample found that parent-reported anxiety and self-reported anxiety were associated with low RSA in resting supine posture. However, self-reported affective problems were associated with high RSA in standing posture in male adolescents. In a succeeding study (Greaves-Lord et al., 2010), the authors found that RSA predicted anxiety symptoms two years after the first assessment, but only in female adolescents and with a small size effect, not permitting RSA to identify individuals at risk for anxiety. More recently, some studies have reported no differences in HRV from sympathetic nervous system activity among adolescents with different levels of anxiety while performing a stressful cognitive task (de la Torre-Luque, Fiol-Veny, Bornas, Balle, & Llabrés, 2017) or during a standardized speech task (Schmitz, Ruschen-Cafer, Wilhelm, & Blechert, 2013).

Traditionally, adolescent's cardiac functioning has been assessed individually and mostly while performing a stressful task or in resting periods. Nevertheless, over the last decade a growing body of research has examined cardiac patterns during dyadic interactions -normally mother-child or mother-adolescent dyads (e.g., Amole, Cyranowski, Wright, & Swartz, 2017)- and have focused on the congruence between both interactors' cardiac outcomes. Physiological synchrony, which is considered as the matching biological states between caregivers and their children (Feldman, Magori-Cohen, Galili, Singer, & Louzoun, 2011), is thought to be a relevant mechanism that lays the groundwork of child's development of self-regulatory abilities and corresponding difficulties (Calkins, 2011). Such phenomenon has been examined frequently by means of RSA (McKillop & Connell, 2017), HF-HRV (Amole et al., 2017), heart rate (Bornstein and Suess, 2000) and IBIs (Suveg, Shaffer, & Davis, 2016; Woltering, Lishak, Elliott, Ferrao, & Granic, 2015).

Research in this field has found that parents' psychopathology may interfere in parent-child physiological synchrony, either by debilitating the positive association between parent and child physiological function or by providing divergences in parent-child physiological outcomes (Davis, West, Bilms, Morelen, & Suveg, 2018). For instance, Woody, Feurer, Sosoo, Hastings and Gibb (2016) reported a weakened vagal synchrony in mother-child dyads in which mother had history of a lifetime major depressive disorder (MDD) when compared with control mother-child dyads with no history of MDD. In families with non-depressed mothers, positive RSA synchrony was observed across the negative condition of the Discussion Paradigm meanwhile in families of mothers with histories of depression, higher maternal RSA was related to lower youth RSA. Similarly, McKillop and Connell (2018) evidenced how maternal RSA was positively related to subsequent youth RSA but that its relation was moderated by maternal depression and maternal negative affect. Higher negative affect and higher maternal depression were related with an attenuated relationship between both partners RSA, leading to diminished physiological linkage. Amole et al., (2017) reported a positive correlation in HF-HRV slopes among control mother-adolescent dyads in discussions about shared pleasant events, but not in discussions about conflict topics. During the same positive and negative discussion tasks, both mothers and daughters with history of MDD displayed discordant (negatively associated) moment-to-moment HF-HRV responses.

Recent publications show up how child risk for psychopathology may too interfere the concordance of physiological processes among parents and children. For instance, Lunkenheimer, Tiberio, Skoranski, Buss and Cole (2018) found evidence that child higher externalizing and internalizing problems were associated with weaker concordance of RSA during free play, clean up and teaching tasks with their mothers. In a prior study (Lunkenheimer et al., 2015) also found evidence that the higher were child-externalizing problems, the weaker was the RSA concordance between parents and their children. These results seem to indicate that both maternal and child psychological problems may interfere in parent-child physiological synchrony, suggesting then that studying children externalizing and internalizing problems are equally important as it is parent's psychopathology.

Most research that aimed to study parent-child dyadic interaction has considered only the maternal figure since it has classically been recognized as the primary attachment figure (Bowlby, 1958). However, fathers' role as a relevant linking figure is widely accepted, and is primordial in child's development (Grossmann et al., 2002). Despite this consideration, a substantial body or research have mainly focused on mothers (e.g. Suveg et al., 2016), have excluded fathers from the study (McKillop & Conell, 2018) or have employed a reduced father's sample if compared to mothers (Han et al., 2019). Only one study has examined physiological synchrony considering an adequate sample of fathers (Gordis, Margolin, Spies, Susman, & Granger, 2010) and providing, in fact, evidence of differences in mother-adolescent and father-adolescent physiological synchrony.

The current study

As noted above, results have shown a controversial association between HRV in its different measures and adolescent anxiety problems. Hence, the present work examined differences in the vagal tone of adolescents with different levels of risk for anxiety disorders by analysing the RMSSD and the HF-HRV as indices of vagal tone. Moreover, this study sought to explore the physiological linkage between fathers and their adolescents across different positive and negative content interaction tasks by examining their IBI series data. This measure allows the examination of father-adolescent physiological synchrony within each second across hundreds of data points within a short period of time (Suveg et al., 2016). Positive and negative topics were intentionally selected as research suggests that dyadic social interactions may influence adolescents' vagal tone, which seems to decrease during negative content discussions and increase during the positive ones (Shahrestani, Stewart, Quintana, Hickie, & Guastella, 2015). Those fluctuations are thought to reflect cardiac autonomic flexibility and seem to be reduced in individuals with psychopathology. Moreover, IBI synchrony may be stronger during emotionally charged interaction tasks, at least across early and middle childhood (Suveg et al., 2016; Woltering et al., 2015).

We selected an adolescent sample since most of the work on physiological synchrony has focused on infancy (Davis et al., 2018) remaining less clear if parents and children also coordinate their cardiac response after the first lifetime developmental periods. The lack of studies beyond infancy is due to it is a sensitive period during which the child's neurobiological development is mainly depending on his/her caregivers (Feldman, 2017). Nevertheless, adolescence also represents a vulnerable period for the development of affective disorders. During this period, family relationship processes are relevant sources for both risk and protective factors as they promote the development of interpersonal and emotion regulation skills (Steinberg, 2005).

To sum up, the primary aim of this study was to compare the RMSSD and the HF-HRV of adolescents with high, medium, and low risk for anxiety disorders during a positive and a negative content interaction task. The second aim of this study was to explore if there exist physiological synchrony among adolescents and their fathers across both discussion tasks. Regarding the first aim, we hypothesized that participants in high risk would show less vagal activation compared with participants with low and medium risk in both interactions. Additionally, we hypothesized that participants with low risk for anxiety disorders would show differences in HRV indices between the positive and the negative content interaction task (high flexibility) if compared with those with medium and high-risk. In relation to the second aim, we did no hypothesis as no prior study has explored before if there exist physiological synchrony among father-adolescent dyads by cross-correlating fathers' and adolescents' IBIs.

Method

Participants

This sample was part of the second phase of a research project titled: *Complejidad de la Regulación Emocional en Adolescentes en Riesgo de Ansiedad: un Análisis Multimétodo y Multinivel (CREAMM)* conducted at University of Balearic Islands. At the beginning, 1165 adolescents from nine randomly selected high schools of Majorca were collectively assessed and distributed in three anxiety risk groups (see Figure 1. - flow diagram - for a better understanding of the distribution of the subjects between the different groups). We considered participants at "high risk for anxiety" (*n* = 102) those who obtained scores equal or greater than the 75th percentile in two self-reported measures (Sensitivity to Punishment, anxious symptomatology; see Instruments' section). Those adolescents with scores equal to or less than Pc 25 in the same variables were considered at "low risk for anxiety" (*n* = 95). Finally, a third group with average scores between Pc 40 and Pc 60 were considered at "medium risk for anxiety" (*n* = 49). Students who were in one of the three groups were invited to participate and a total of 89 decided to take part in the study.

Both adolescents and their biological and nonbiological fathers participated voluntary and did not meet criteria for psychiatric disorders neither were currently in psychological treatment. Five father-adolescent dyads were excluded for presenting some mental health disorder: one adolescent presented social phobia, two fathers presented generalized anxiety disorder, and one father and one adolescent were on mourning due to a recent loss in their family (*n* = 5 out of *n* = 89, 5.61%). We excluded eighteen father-adolescent dyads due to apparatus failure (*n* = 18 out of *n* = 84, 21.42%; see Data Acquisition and Preprocessing's section).

The final sample in the present study was comprised by 66 fathers (M_{age} = 45.57, SD_{age} = 4.34, mean body mass index [BMI] = 28.20) and 66 high-school-aged adolescents distributed in three groups according to their risk of anxiety: 28 adolescents with low risk (M_{age} = 14.14, SD_{age} = 0.73, range = 13.19 – 16.13 years old; mean BMI = 21.26, 50.0% girls), 14 adolescents with medium risk (M_{age} = 14.21, SD_{age} = 0.58, range = 13.17 – 15.09 years old, mean BMI = 23.79, 50.0% girls), and 24 adolescents with high risk (M_{age} = 14.15, SD_{age} = 0.66, range = 13.30 – 15.42 years old, mean BMI = 21.83, 62.5% girls).

The study was approved by the University's Bioethics Committee, and all participants and their parents/legal guardians provided written consent.

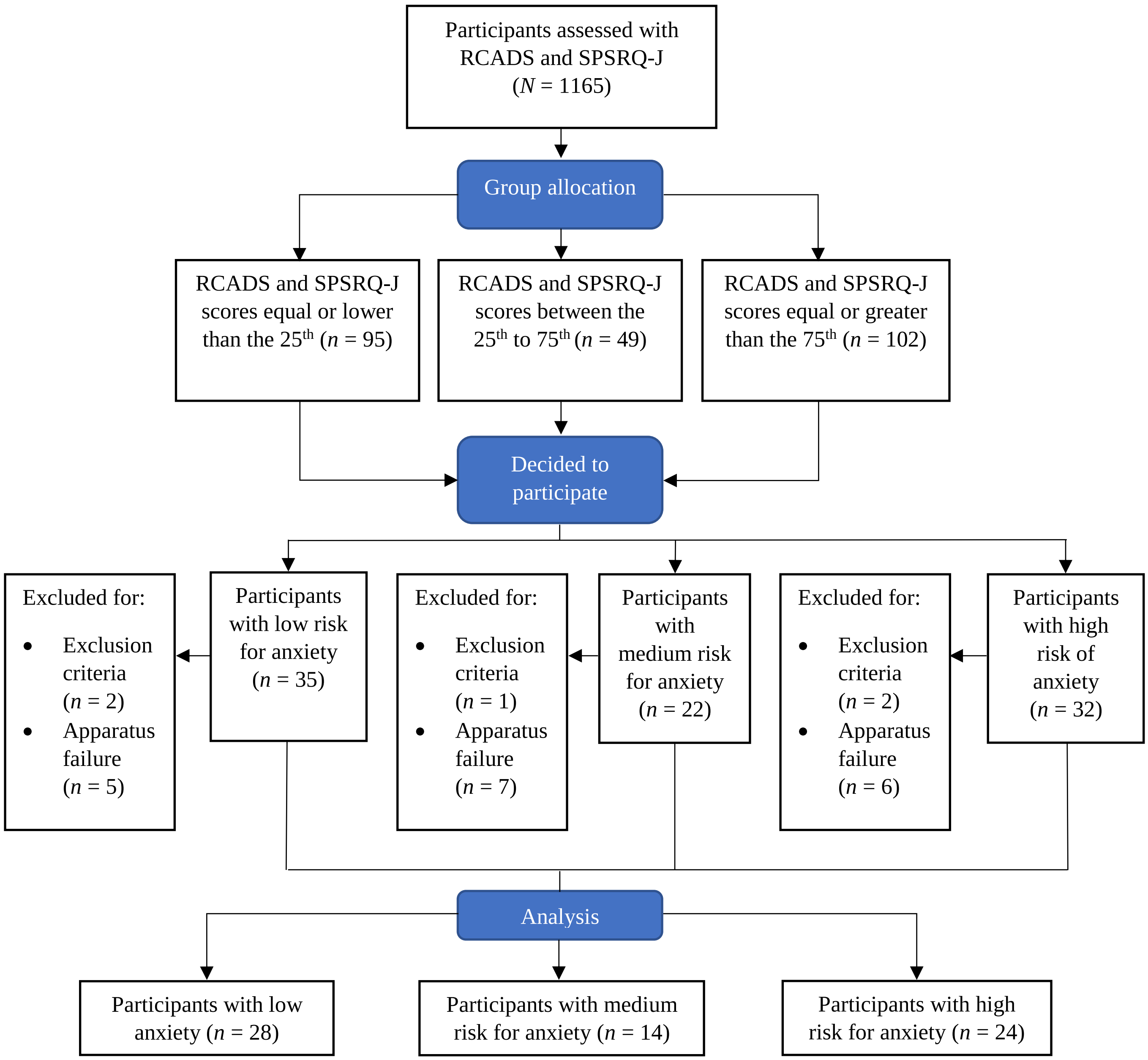

Figure 1: Flow diagram of sample recruitments

Instruments

Adolescent Psychological Assessment

The *Sensitivity to Punishment and Sensitivity to Reward Questionnaire-Junior* (*SPSRQ*-J; Torrubia, García-Carrillo, Àvila, Caseras & Grande, 2008) is a self-report questionnaire adapted for children and adolescents of the adult version developed by Torrubia, Àvila, Moltó & Homemade (2001). It consists in 30 items of dichotomous response (yes-no) formed by two scales of 15 items. One scale assess sensitivity to punishment and the other sensitivity to reward. The scores for each scale are obtained by adding all the affirmative answers. Both scales take part from the Gray's Theory of Sensitivity to Reinforcement in which the Sensitivity to Punishment Scale is related to Behavioural Inhibition System (BIS), and the Sensitivity to Reward Scale is related to the Behavioural Activation System. In this study we used only the Sensitivity to Punish Scale with a Cronbach $\alpha = .77$.

The *Revised Child Anxiety and Depression Scale* (*RCADS*; Chorpita, Yim, Moffitt, Umemoto & Francis, 2000) is a self-reported questionnaire of 47 items designed to assess the DSM-IV (American Psychiatric Association, 2002) symptoms of self-reported anxiety disorders and depression. The scale includes the subscales: (1) separation anxiety disorder, (2) social phobia, (3) generalized anxiety disorder, (4) panic disorder, (5) obsessive-compulsive disorder and (6) major depressive disorder. The adolescent must answer the items according to a frequency scale of 0-3 points (0 = "never", 1 = "sometimes ", 2 =" often ", 3 =" always ") accordingly with their own situation. We used the adapted and Spanish translated version of Sandín, Valiente & Cohort (2009) and considered only anxiety items with a Cronbach's $\alpha = .91$.

Tthe *Kiddie-Schedule for Affective Disorders and Schizophrenia, Present and Lifetime Version* (*K-SADS-PL*; Kaufman et al., 1997) is a semi-structured clinical interview designed to identify current and past psychiatric diagnoses included in the DSM-IV Axis I. We used the Spanish version of the interview developed by Ulloa et al. (2006) which enables to collect information from both the adolescent and their parents. The diagnoses can be labelled as definitive, probable (equal or greater compliance 75% of the diagnostic criteria), or absent.

Fathers Psychological Assessment

The *Overall Anxiety Severity and Impairment Scale* (*OASIS*; Norman, Hami-Cissell, Means-Christensen & Stein, 2006) measures the frequency and severity of anxiety, as well as the level of avoidance, interference between work / school / home, and social interference due to anxiety. Specifically, it asks for the experiences of anxiety and fear that have taken place during the last week. The responses to the items are coded from 0 = "no anxiety" to 4 = "extreme anxiety" and are added together to obtain a total score (Norman et al., 2006). For our sample, we had a Cronbach $\alpha = .86$.

The three-item version (Craske et al., 2009) of the *Patient Health Questionnaire-9* (PHQ-9; Kroenke, Spitzer & Williams, 2001) was used. Respondents were asked to rate each item (two depression and one fatigue items) on a 4-point Likert- type scale (1 *Not at all*; 4 *Nearly every day*). Our sample had a Cronbach $\alpha = .69$.

The *Anxiety and Related Disorders Interview Schedule for DSM-5 Adult Version (ADIS-5*; Brown & Barlow, 2014) is a structured interview based on the criteria of DSM-5 that allows the detection and diagnosis of anxiety disorder, mood disorder (MMD and dysthymia), bipolar disorder, obsessive-compulsive disorder, body dysmorphic disorder, post-traumatic stress disorder, somatic symptom disorder, anxiety disorder by disease and abuse of alcohol and other substances, psychotic disorder and eating disorder. The ADIS-5 provides for each answer a scale of 8 points in which four points are considered a clinical level for the problem for which the adult is responding. Thus, the scores may help to decide which are the main disorders and also if there are additional disorders (Brown & Barlow, 2014).

Cardiac Measures

For the cardiac adolescent response, the square root of the mean of the squares of the successive differences between adjacent N-N peaks (RMSSD), and the high-frequency band (HF-HRV; 0.15–0.40 Hz) spectral power (both of them in log-linear scale) were calculated (see Data Acquisition and Preprocessing).

The quantification of physiological synchrony between fathers and adolescents was based on cross-correlations of participants IBIs.

Procedure

Fathers accompanied their adolescents to a Balearic Islands University laboratory for a 120-min visit during which consent forms were explained, and informed consent was obtained by adolescents and their fathers. In order to detect current adolescent psychopathological episodes, trained evaluators performed structured interviews using the K-SADS-PL with fathers and their adolescents. Fathers were also interviewed using ADIS-5 if they scored a minim of 4 points in the PHQ-3 or 5 points in the OASIS, considered the threshold in the screening tests that indicates presence of depression and anxiety respectively.

After that, fathers and adolescents were invited to choose between different topics to talk about within a positive and a negative interaction task. Topics took part from the Issue Checklist (Robin & Weiss, 1980) and included negative themes such as school activities (homework and exams) discussing with siblings, partying with friends, housework, failed subjects, and an opened option. It also included positive topics such as holidays, a pleasant family trip and free time-shared activities among others. Once the topics were chosen, cardiac activity was recorded for 2 min under resting conditions (participants should be sitting and relaxed) to acclimate them to the laboratory equipment (i.e., electrodes), the laboratory environment and the experimenter. Once finished the baseline period, each father-adolescent dyad participated in two 10-min interaction tasks separated by another 2-min baseline condition. The valence of the interactions (i.e. positive or negative) was counterbalanced to avoid a sequential effect. For the interaction tasks, fathers and adolescents were seated across from each other and separated by two meters approximately.

For the participation in the study, families were compensated with 50 euros.

Data Acquisition and Preprocessing

We used the Firstbeat Bodyguard 2© (Firstbeat Technologies Ltd., Jyväskylä, Finland) devise which continuously records beat-to-beat HR with a sampling frequency of 1,000 Hz. This tool is adhered to the skin using two disposable electrodes that are adhered under the right collarbone (at the top of the right-side chest) and under the left chest area, following Schiller's (2011) recommended procedure. The recordings lasted a total of 24 minutes that were distributed in two periods of two-minutes baseline (not analysed), and two 10-minutes interaction periods. Thus, for each father and each adolescent, two 10-minute time series were analysed and the number of IBIs in each time series depended on the participant's HR. As did in Fiol-Veny, De La Torre-Luque, Balle & Bornas (2018), we visually inspected each recording to exclude distorted signals due to apparatus failure (n = 18 out of n = 84, 21.42%). The time series was filtered with the Physionet (Goldberger et al., 2000) HRV toolkit (http://www.physionet.org/tutorials/hrv-toolkit/). Any IBI less than 400 ms or greater than 1100 ms was excluded. Using a window of 11 intervals (5 intervals on either side of the central interval) but excluding the central interval, the average over the window was calculated. If the central interval laid outside 20% (0.20) of the window average, this interval was excluded and the window was advanced to the next interval, resulting in the mean of excluded IBIs (*n* = 229 out of n = 11808, 1.94%). Finally, the RMSSD was calculated on these time series and the lnHF-HRV was extracted with ranges from 0.15-0.40 Hz by using the fast Fourier transform. All HRV measures were calculated using the Physionet (Goldberger et al., 2000) HRV toolkit.

The quantification of physiological synchrony was based on cross-correlations of participants IBIs. To do so, we used a novel but validated algorithm called *Surrogate Synchrony* (*SUSY*; Tschacher & Haken, 2019) which computes synchrony based on windowed cross-correlations of two simultaneously occurring processes. For this purpose, time series of both participants were cross-correlated (Boker et al., 2002) within window segments of 30s duration without overlap. For each window, cross-correlations were computed for positive and negative time lags up to five seconds in steps of 0.1s. All cross-correlations were then aggregated by transforming correlations to Fisher's Z and using absolute values only (both positive and negative cross-correlations contributed positively to the 10-min synchrony measure) then, computing the mean Z in a segment. Finally, the mean Z of all segments was aggregated, yielding the overall mean Z of the time series.

In order to control for coincidental synchrony, *SUSY* allows to generate surrogate time series by segment-wise permutation of the time-series of adolescent and his/her father. Thus, if one 10min time series contains 20 segments of 30s, a total of 380 different surrogates can be generated. In doing so, adolescents' cardiac response in the fourth 30s segment may be paired with father's second one, creating then artificial time series that never took place. We accounted for a total of n = 100 shuffled combinations in order to arrive at a large sample of pseudointeractions. Then, synchrony in each surrogate was identically calculated to the synchrony of the original time series as described above, and a global parameter for physiological synchrony was also provided. For the statistical comparison of synchrony vs pseudoshynchrony, *SUSY* compares these two mean values employing a dependent t-test, providing then an Effect size value calculated by using Cohen's d for each father-adolescent dyad.

Analytic approach

HF-HRV and RMSSD values were *ln* transformed to accomplish normal distribution criteria before any statistical procedure was performed. Differences in vagal tone were analysed by general linear model repeated-measures MANOVA with "anxiety risk group" (at three levels: high, medium and low) as between-participants factor and "interaction valence" (at two levels: positive interaction and negative interaction) as within-participants factor. Secondly, exploratory analysis evaluated whether synchrony and pseudosynchrony values were significantly different in each anxiety risk group by a dependent *t*-test. Effect sizes were calculated using Cohen's *d*.

IBM SPSS v. 22 was used for analyses.

Results

Descriptive statistics of the demographic and self-reported variables are presented in Table 1. No significant differences in age, BMI or sex were found between groups of anxiety. High anxiety risk group showed significantly more anxiety symptomatology and sensitivity to punishment scores than medium and low anxiety risk groups. Participants with medium risk for anxiety showed significantly higher anxiety symptomatology and sensitivity to punishment scores than low anxious group.

Table 1

Comparison on demographic and psychological variables between groups of risk for anxiety

	Low Risk (n = 28)	Medium Risk (n = 14)	High Risk (n = 24)	χ^2 / H (3)	p
	N (%) /M (SD)	*N (%) /M (SD)*	*N (%) /M (SD)*		
Female	14 (50)	7 (50)	15 (62.5)	0.96	.61
Age	14.14 (0.73)	14.21 (0.58)	14.15 (0.66)	0.21	.90
BMI	21.26 (3.97)	23.79 (4.97)	21.83 (3.55)	3.11	.21
Anxiety	13.89 (6.34)	21.00 (8.77)	36.16 (14.56)	33.54	< .01
Sensitivity to punishment	2.82 (2.16)	6.07 (216)	8.54 (3.02)	33.25	< .01

Note: BMI = Body Mass Index.

No differences were found between anxiety risk groups in lnRMSSD and lnHF-HRV in none of the interaction tasks. Participants with low risk for anxiety showed significantly lower lnHF-HRV in the negative content interaction task than in the positive one (p = .02) if compared with the other groups (see Table 2). This difference was maintained after Bonferroni corrections with a p value of < .05.

Table 2

Comparison between interactions' valence and anxiety risk groups (MANOVA) in cardiac vagal tone

		Positive Interaction	Negative Interaction	*F*	*p*	η^2
	Anxiety risk group	*M (SD)*	*M (SD)*			
lnRMSSD	Low	3.65 (0.46)	3.63 (0.44)	Interaction: $F(2,63) = 0.32$	.72	.01
	Medium	3.41 (0.52)	3.41 (0.51)	Anxiety risk group: $F(2,63) = 1.71$	.18	.05
	High	3.70 (0.53)	3.72 (0.51)	Valence content: $F(1,63) = 0.01$	.91	.00
lnHF-HRV	Low	6.57 (0.92)	6.46 (0.99)	Interaction: $F(2,63) = 0.40$	.66	.01
	Medium	6.05 (1.09)	5.94 (1.17)	Anxiety risk group: $F(2,63) = 1.51$	.22	.04
	High	6.59 (1.08)	6.54 (1.09)	Valence content: $F(1,63) = 5.75$	.02	.08

Note: lnRMSSD = logarithmic transformation of square root of the mean of the squares of differences between adjacent N-N intervals (ms); lnHF = logarithmic transformation of high frequency power.

The comparison of genuine and fabricated interactions revealed that physiological synchrony was marginally present a level above chance but only in the medium anxiety risk group during the negative interaction. For a visual example, see Figure 2. Among father-adolescent dyads with low and high risk of anxiety, physiological synchrony was not significantly higher than pseudosychrony, neither in positive nor in negative interaction task (see Table 3). For a visual example, see Figure 3.

Table 3

Values of physiological synchrony within father-adolescent dyads in positive and negative episodes and separated by groups of anxiety

		Physiological Synchrony	Physiological Pseudosynchrony	*t* (gl)	*p*	Cohen's *d*
Interaction task	Anxiety risk group	*M (SD)*	*M (SD)*			
Positive	Low	.265 (.044)	.264 (.035)	0.21 (27)	.83	0.02
	Medium	.275 (.038)	.277 (.035)	-0.42 (13)	.68	-0.04
	High	.251 (.043)	.253 (.039)	-0.40 (23)	.69	-0.00
Negative	Low	.274 (.043)	.272 (.037)	0.54 (27)	.59	0.04
	Medium	.292 (.036)	.281 (.033)	2.14 (13)	.05	0.28
	High	.245 (0.38)	.246 (.034)	-0.23 (23)	.81	-0.03

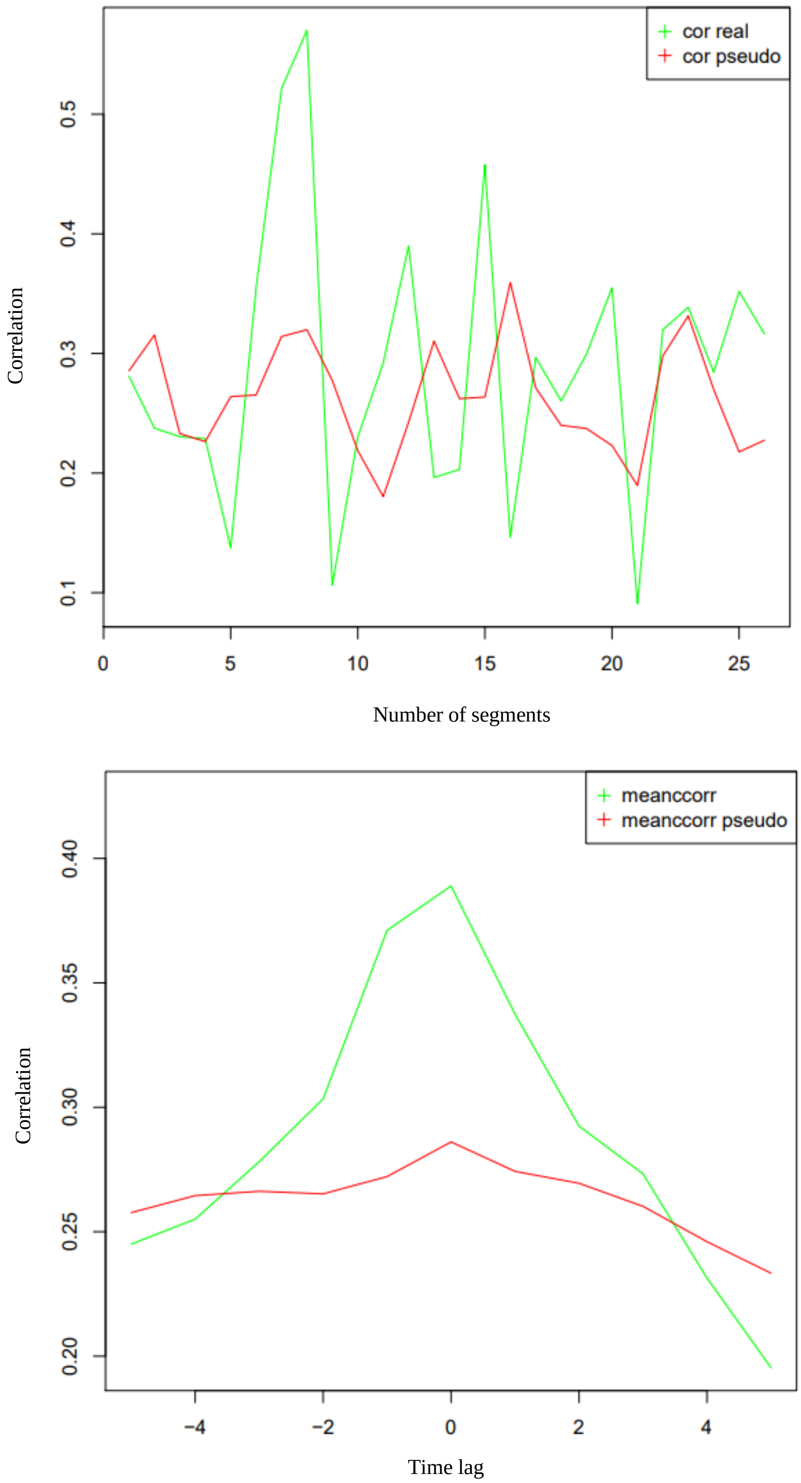

Figure 2: Example of a dyad with high physiological synchrony. The upper figure shows genuine synchrony (r = 0.31) and pseudosynchrony (r = 0.28) fluctuations across the 30sec segments of the 10min interactions. The lower figure shows genuine synchrony and pseudosynchrony values depending on the lag (±5sec).

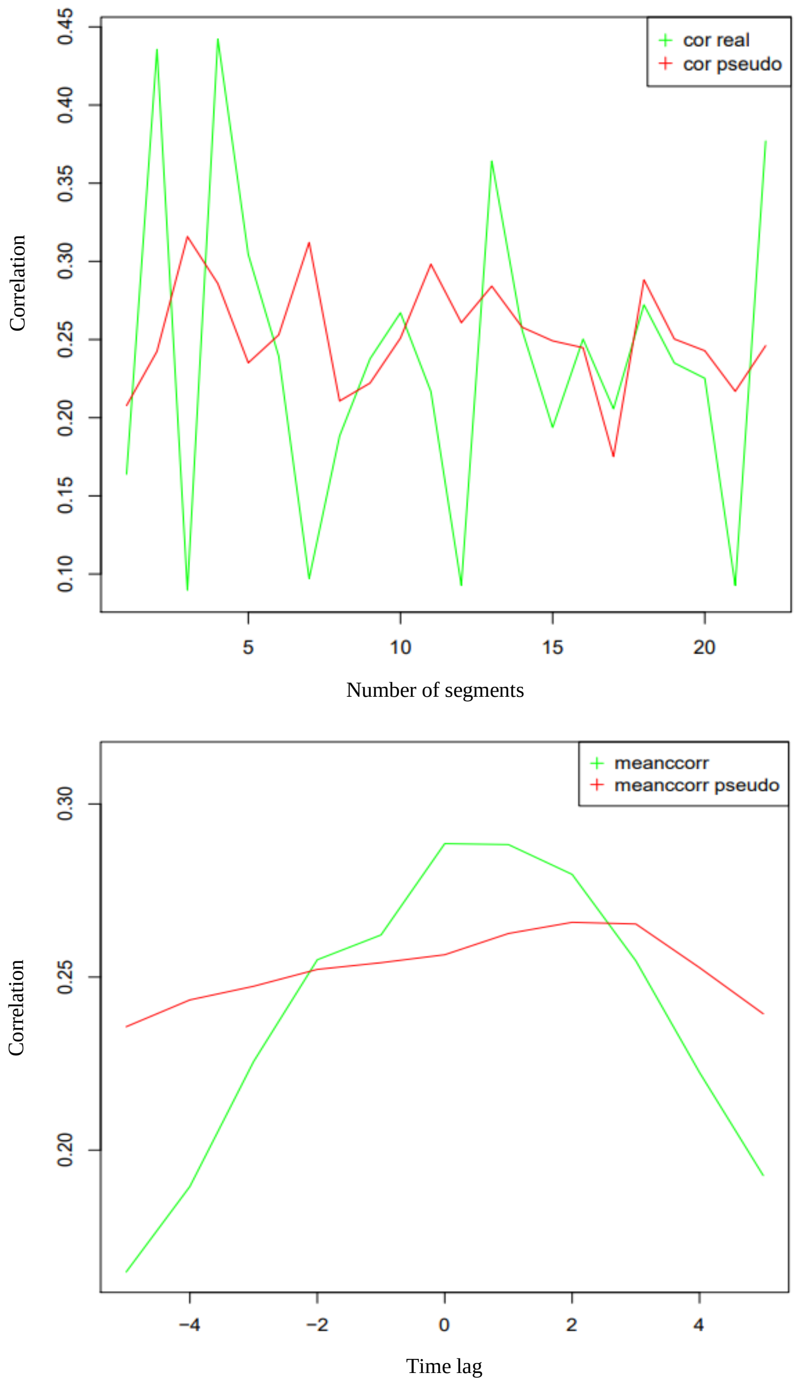

Figure 3: Example of a dyad with no physiological synchrony. The upper figure shows genuine synchrony (r = 0.25) and pseudosynchrony (r = 0.26) fluctuations across the 30sec segments of the 10min interactions. The lower figure shows genuine synchrony and pseudosynchrony values depending on the lag (±5sec).

Discussion

To our knowledge, this is the first work to study vagal responsiveness of adolescents with different risk for anxiety during father-adolescent dyads. The main purpose of this study was to examine whether there were differences in the vagal response (i.e. lnRMSSD and lnHF-HRV) of adolescents with different risk levels for anxiety in positive and negative interaction tasks with their fathers. Further, we analysed how lnRMSSD and lnHF-HRV of each anxiety risk group varied depending on the valence of the interaction task. Secondly, we aimed to determine if moment-to-moment physiological synchrony could be detected across simulated negative and positive content interactions that might typically occur among fathers and their adolescents during their daily life.

Overall, research has shown that anxiety is generally related with decreased levels of vagal responsiveness in adults (Chalmers et al., 2014) and in adolescents (Balle, Tortella-Feliu, & Bornas, 2013). Nevertheless, and contrary to our hypothesis, our findings showed no significant differences in cardiac vagal measures among groups neither in positive nor in negative interactions. These results could be since the conflict topics chosen (e.g., family arguments, failed subjects) in the interaction tasks may have been less threatening if compared with tasks specifically designed to elicit stress (e.g., Trier Social Stress Test for Children; Buske-Kirschbaum et al., 1997). Other studies neither reported differences in adolescents' cardiac patterns across stressful tasks in subclinical samples (e.g., de la Torre-Luque et al., 2017), suggesting that significant diminished cardiac vagal tone might be more noticeable once the disorder is well-established.

In line of the second hypothesis, our findings suggest that the valence of the dyadic interactions displayed a relevant role in adolescents' vagal responsiveness. According to the recent literature, HRV changes during social interactions. Negative dyadic tasks are associated with reduced HRV meanwhile positive and neutral content interactions do not seem to increase HRV significantly (Shahrestani et al., 2015). Our results are in the line of the previous studies as participants with low risk for anxiety exhibited significantly lower values of lnHF-HRV in the conflict dyadic task if compared with the positive content discussion. These findings suggest that, as seen in depressed individuals (Rottenberg, Clift, Bolden, & Salomon, 2007), adolescents with medium and high risk for anxiety may exhibit less vagal fluctuation than those with lower scores of anxiety risk, which may reflect difficulties to flexibly adjust physiological arousal to changing interpersonal context.

Regarding the second objective, by means of a novel but validated statistic algorithm that enabled us to perform cross-correlation analysis for each member's IBI series, we observed moment-to-moment physiological synchrony in father-adolescent dyads with medium risk for anxiety, but only in the negative content interaction task.

Biobehavioural synchrony model (Feldman, 2012) proposes that healthy parent-child dyadic interactions imply the synchronization of both interactors' physiological responses, and that physiological concordance seems to play a role in the development of attachment bonds and child self-regulatory abilities. Nevertheless, literature in this field is only beginning to arise and, for the moment, the available findings do not allow a firm response. Several studies suggest that, since their early life, healthy children and their mothers tend to synchronize their physiological outcomes during a variety of interactive tasks (Lunkenheimer et al., 2015) and that those shared physiological patterns seem also to occur in adolescence (Amole et al., 2017). However, some emerging findings are not in the line of the previous. For instance, in a recent study Ostlund, Measelle, Laurent, Conradt and Ablow (2017) assessed the physiological linkage between 5-

month-old infants and their mothers during a 2-min-play task and a 60-s reunion episode. Examining RSA, mothers' vagal responsiveness was not associated with infants' vagal response neither during the free play task nor in the second half of the reunion episode. Only during the first part of the reunion episode, mother RSA was associated with lower concurrent infant RSA. Moreover, Woody et al. (2016) observed in never-depressed mother-child dyads that higher average mother RSA during both positive and negative discussion task was associated with higher average child RSA. However, the previous authors found no association in HF-HRV between never-depressed mothers and their offspring during the positive content interaction task.

Simultaneously, most findings seem to suggest that mother or child emotional problems may disrupt physiological synchrony, which could reflect difficulties in social interactions that are typically observed in depressed or anxious individuals (Dadds & Barret, 2001). However, these findings are not unanimous since there is several data that points in the opposite direction. In some cases, physiological synchrony has found to be higher in dyads with parents with a lifetime history of depression and children with high negative emotionality (Merwin, Smith, Kushner, Lemay, & Dougherty, 2017). The phenomenon has also been reported in insecurely attached parent-infant dyads (Smith, Woodhouse, Clark, & Skowron, 2016), in highly negative parent-adolescent dyads (Papp, Pendry, & Adam, 2009), in context of interparental aggression (Gordis et al., 2010), and even in families at high levels of risk determined by single parent status, economic disadvantage, low educational attainment and maternal psychological distress (Suveg et al., 2016). The last authors not only determined the presence of physiological synchrony in families with high risk, but also that it was associated with poorer child self-regulation. In our case, only those adolescents with medium risk for anxiety showed physiological synchrony with their fathers but only in the negative content discussion task. We speculate that those participants with high risk for anxiety may display discordant cardiac activity with their fathers, as seen in other studies when child had internalizing problems (Lunkenheimer et al., 2018). Moreover, as suggested by Suveg et al. (2016), a mismatch of physiological states in the context of risk may also be adaptive as it may prevent an increase of negative emotional experience, meaning that one partner is able to block the negative effects of anxiety risk by adjusting their physiological functioning. Otherwise, adolescents with medium and low risk for anxiety would be expected to synchronize their physiological outcomes with their fathers, reflecting then a healthy relationship that may contribute to the development of adolescent's self-regulatory abilities. Surprisingly, only the firsts exhibited congruent dynamic changes in IBIs and only in the negative content discussion. Thus, our results, in combination with the findings of the previous authors, highlight the uncertainty of this phenomenon and question its implications and utility as a scientific construct, and its relationship with more adaptive behavioural profiles.

Although the initial contributions of this study, there were certain limitations. First, our study might be weakened by the small sample size, especially in the group of medium risk for anxiety, which could have an impact on our results. We experienced data loss due to apparatus failure during some of the interactions, thus having to discard the data of the entire dyad. Moreover, fathers' emotional problems were not considered when designing groups, since group selection was made according to adolescents' risk for anxiety disorders. In addition, every father was assessed in order to control for clinical conditions, but fathers' subclinical features were not considered, which could have influenced in our analysis. In relation to these latter, the literature provides a variety of physiological indices and statistical approaches that have been used to quantify physiological synchrony, which might explain the heterogeneity and inconsistency, not only of our results, but also of the overall findings in this field. Finally, anxiety risk groups included both male and female adolescents and analysis did not differentiate adolescents' gender, even though matching-gender dyads seem to experience more synchrony than mismatching-gender dyads (Feldman, 2003). For the future research would be important to address these limitations.

Despite these limitations, the present study demonstrates several strengths and represents an effort to examine adolescent's individual vagal responsiveness in dyadic contexts and to assess moment-to-moment father-adolescent interaction using physiological measures to detect the existence of physiological synchrony. Overall, our findings may indicate that the relationship between anxiety and HRV in adolescents is not as clear as it seems. Moreover, the novel results of this study emphasise that physiological synchrony is not a straightforward phenomenon and demand more attention on father-child or father-adolescent dyads in order to better explicate how physiological synchrony operates at various developmental periods but also with different attachment figures.

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