Environmental sensitivity and cardiac vagal tone as moderators of the relationship between family support and well-being in low-SES children: An exploratory study

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Abstract

This cross-sectional study explored whether the association between perceived family support and child well-being was moderated by the individual trait of *Environmental Sensitivity* (the ability to register, process, and respond to stimuli) and cardiac vagal tone (CVT, an index of self-regulation) in a sample of children living in socioeconomically disadvantaged families. Participating children (N = 131, M_{age} = 7.20 years, 47% boys) were individually interviewed about the support received within the family as well as their physical and emotional well-being. Children's sensitivity was assessed via a series of behavioral tasks, and CVT was recorded at rest. Hierarchical cluster analysis on the behavioral items yielded three sensitivity groups: 'Low sensitive' (43%), 'Moderately sensitive' (33%), and 'Highly sensitive' (24%). The three groups of children did not differ in baseline CVT. However, linear regression analyses revealed that at low and average levels of family support, highly sensitive children with higher resting CVT reported better well-being than those with low resting CVT, whereas no effect was observed among children in the other two groups. In the context of high family support, children reported high levels of well-being irrespective of their levels of vagal activity or sensitivity. The findings suggest that among low SES families, when children experience a poorly supportive family environment and are highly sensitive to negative experiences, having a higher resting CVT may confer an advantage in terms of well-being. Implications for theory and practice are discussed.

Keywords: Cardiac vagal tone, Children, Environmental sensitivity, Family support, Low SES, Well-being.

To date, almost 1 in 7 children from countries belonging to the Organization for Economic Cooperation and Development (OECD) live in income poverty (i.e., living on a disposable income that is at most 50% of the national median) (OECD, 2018). Although trends vary considerably both within and across societies, recent data indicate that urban areas are often characterized by a range of social inequalities in terms of access to labor market, household income, and utilization of health/social services that contribute to the perpetuation of the cycle of disadvantage for many families with a history of poverty and social exclusion (Eurostat, 2020).

An extensive literature documents associations of early adversity and low socio-economic-status (SES) to children’s subsequent emotional and behavioral problems both in the short and in the long term (Spencer et al., 2013). Living in poor households is a major risk factor for several mental, emotional, and behavioral disorders, as well as other developmental challenges and physical health problems (Pinderhughes et al., 2001). Financial strain tends to undermine positive parental behaviors, such as warmth and consistent discipline, as well as to increase harsh interactions and scarce and inconsistent support within the family (Conger et al., 2010). Furthermore, empirical evidence suggests that low SES in early childhood may impact on autonomic nervous system functioning, increasing the risk of cardiovascular disease and hypertension later in life (Alkon et al., 2012). Thus, identifying the protective processes involved in children’s well-being in low SES families is of utmost importance to minimize the adverse effects of poverty and ensure equal opportunities for health and education among children living in resource-poor environments (Sturge-Apple et al., 2016).

The current study used a socioecological, risk-and resilience oriented framework (Bronfenbrenner & Morris, 1998; Masten, 2018) to explore the unique and interactive contributions of contextual and personal characteristics to the well-being of low-SES children.

This framework is particularly useful to shed light on the risk and protective mechanisms underpinning psychosocial adjustment among vulnerable populations (Masten, 2016). In particular, we considered the role of perceived family support regarding children's subjective well-being, and investigated interactions with the phenotypically observable temperamental trait of Environmental Sensitivity (ES) and/or with individual differences in cardiac vagal tone (CVT) in the prediction of child adjustment. Indeed, empirical evidence from separate lines of research indicates that these individual-level variables substantially influence how environmental conditions shape children's outcomes (Graziano & Derefinko, 2013; Obradović & Boyce, 2009; Pluess, 2015). Given the lack of studies simultaneously considering ES and CVT in children with a low SES background, we also examined the relationship between resting CVT and children's ES.

Family Support and Child Well-being

In this study, we focus on child well-being as a relevant outcome among school-age children. Specifically, we refer to Riley's (2004) broad conceptualization which emphasizes that a child's experienced health status includes perceived well-being, illness, and health together with participation in developmentally appropriate tasks and activities, as well as behaviors that promote or threaten one's health. Within this framework, and following previous research (Scrimin et al., 2018), well-being was assessed in terms of self-reported physical and emotional functioning, since these factors have been shown to substantially impact on children's quality of life in both home and school contexts (Drotar, 2014),

It is widely acknowledged that a supportive family environment providing warmth, responsiveness, and nurturance is linked to a host of positive developmental outcomes, including socio-emotional competence, academic success, and good physical health (Newland, 2015). Across infancy and childhood, family support is particularly important as it prepares children to enter the school system well-equipped and ready to start navigating the world and its social and cognitive requests autonomously, also through the provision of a home environment that supports children's learning (e.g., books, educational toys) (Razza et al., 2010). Research has shown that in impoverished families, family support may be compromised due to the stressful situation resulting from financial strain, joblessness, and limited access to essential goods and opportunities (Bornstein & Bradley, 2014). Indeed, prolonged economic pressure undermines parents' mental health, often leading to depression, anxiety, and sense of inadequacy. In turn, these feelings contribute to more frequent marital conflicts and an overall lower quality of family relationships (Conger et al., 2010). As a consequence, children living in low SES families are more likely to develop a range of maladjustment problems than their peers from high SES families (Neppl et al., 2017).

Although associations between levels of family support and child well-being are well-documented, empirical evidence suggests that these associations may vary as a function of children's individual characteristics. In this study, we consider two important aspects which have been shown to moderate the effects of the family environment on children's adjustment, namely sensitivity to environmental stimuli and CVT. In separate studies, these individual characteristics have been shown to serve as potential risk/protective factors for psychological adjustment in samples from both high and low-SES backgrounds (Hopp et al., 2013; Lionetti et al., 2019a; Scrimin et al., 2018; Slagt, Dubas, van Aken, Ellis, & Deković, 2018).

Environmental Sensitivity

ES is defined as "the ability to register, process, and respond to external factors" (Pluess, 2015, p. 138) and profoundly influences how people adapt to social environments. Specifically, this trait-like characteristic refers to the depth of cognitive processing and reactivity to both positive and negative environments. Although it correlates with common personality and temperamental traits, meta-analytic evidence suggests that sensitivity constitutes a unique, individual characteristic (Lionetti et al., 2019b). According to empirical studies (Belsky & Pluess, 2009; Greven et al., 2019), a significant minority of individuals is characterized by heightened sensitivity, therefore benefitting more from positive environments, but also being more prone to maladaptation in adverse conditions. Thus far, theories have proposed that biologically based factors such as genetic variation, early temperament, and physiology are markers of this innate tendency (Assary et al., 2020; Boyce, 2016; Slagt et al., 2016).

In developmental research, sensitivity can be assessed with a recently developed questionnaire, namely the self-report *Highly Sensitive Child* scale (HSC; Pluess et al., 2018), and the observational *Highly Sensitive Child Rating System* for preschoolers (Lionetti et al., 2019a). These measures operationalize increased sensitivity through a series of items (or observational scales) assessing the extent to which an individual recognizes and processes negative and positive environmental stimuli. Despite being conceptualized as a continuous trait, data-driven analyses on child and adult samples in the UK and the US suggest the existence of a three-group classification, with around 25 to 30% of the population being highly sensitive, 25 to 30% low sensitive, and around 40% medium sensitive (Lionetti et al., 2018; Pluess et al., 2018).

Intervention studies where the environmental variable was manipulated provide evidence that highly sensitive children benefit more from positive environmental stimuli than their low sensitive peers (Kibe et al., 2020; Nocentini et al., 2018; Pluess & Boniwell, 2015). In terms of moderation, a recent correlational study in which the HSC scale was adapted to an interview format revealed that ES exacerbated the negative effects of a stressful environment on children's physical and social functioning, and magnified the positive effect of a supportive environment on their social performance (Scrimin et al., 2018).

Albeit informative, the few available studies on children's ES largely focused on middle-class samples, leaving the question open of whether the results may generalize to children living in more disadvantaged family contexts. Thus, in the current research we explored the presence of sensitivity groups among primary school children living in low SES families in Italy, and examined the role of individual differences in sensitivity as moderating variable regarding the impact of the family environment on children's well-being. To investigate sensitivity, we used an ad-hoc developed procedure by asking children to perform six tasks reflecting item content of the HSC (Pluess et al., 2018). This assessment method was preferred over available questionnaires due to the characteristics of our low-SES sample (e.g., unavailability of parents, low literacy rates), which could have negatively affected the completion of measures, as well as the young age of participants and their possible difficulty to understand questionnaire items.

Cardiac Vagal Tone

Abundant research has shown that the extent to which children are affected by the environment is influenced by the way they physiologically self-regulate in response to different stimuli encountered in their daily lives. Self-regulation is a biologically based, multi-dimensional aspect that is partly shaped by contextual influences; it involves the ability to regulate one's thoughts, behaviors, and emotions in order to adapt to different situations and environments (Park & Thayer, 2014). A key physiological correlate of self-regulatory skills (Porges, 2007) is CVT (Thayer & Lane, 2000), which is indexed by heart rate variability and is associated with the tonic inhibitory control of the parasympathetic system on the heart via the vagal nerve (Berntson et al., 2008; Thayer et al., 2009). CVT is a fairly stable individual trait (Calkins & Keane, 2004) that steadily grows across development in terms of inter-beat intervals. Importantly, it is responsible for maintaining homeostasis and serves to calm and decrease heart rate after the experience of a stressor. Greater CVT influence on the heart, which results from higher parasympathetic activity, implies that the cardiac system is slowed down and prevented from becoming overexcited (Berntson et al., 2008; Thayer et al., 2009).

Resting CVT is thought to index the amount of regulatory resources individuals can draw upon during times of challenge (Porges, 2007). Specifically, higher vagal tone at rest can be considered as an indicator of more cardiac flexibility and ability of the system to respond, since it helps the child to self-regulate and better adapt to the ever-changing environment.

Studies examining relations among CVT and different developmental outcomes indicate that greater resting vagal tone is related to increased sociability, better cognitive and emotional competence, and lower levels of problem behavior (Calkins, & Keane 2004; Patriquin et al., 2013). For instance, higher baseline vagal tone has been linked to fewer externalizing and internalizing problems, more positive and less negative emotionality, and greater social connectedness and social competence (Beauchaine, 2015; Calkins, 1997; Kok & Fredrickson, 2010). A positive effect of high CVT has also been documented among children living in poverty or at-risk environments, for example in the context of low family support or parental conflict (Propper, 2012). In these studies, higher resting CVT served as a buffer against adverse psychosocial outcomes for children living in low-supportive family contexts.

It has been suggested that in both positive and negative environments, high baseline CVT may be viewed as a potential physiological marker of sensitivity (for a review see Belsky & Pluess, 2009), especially in the first months of life (Conradt et al., 2013) and even during gestation (Peltola et al., 2016). At this young age, vagal influence on the heart appears to be a marker of the degree to which infants are attuned to their environment (Beauchaine, 2001; Conradt et al., 2013; Propper, 2012). However, another recent study found low (vs. high) baseline CVT to be a susceptibility factor in the association between early experiences of insensitive caregiving and children's later effortful control and regulation of negative emotions (Skibo et al., 2020). Thus, more research is warranted to shed light on the role of children's vagal regulatory capacity as a putative susceptibility factor which may lead to negative or positive developmental outcomes depending on the quality of the environment (Beauchaine, 2001).

The Present Study

This cross-sectional study had two main aims. First, we investigated behaviorally observed ES in low SES children exploring the existence of sensitivity groups with a cluster-analytic approach, and assessed whether the emerging groups differed in terms of physiological self-regulation as indexed by resting CVT. Based on extant research, we expected to find three sensitivity groups reflecting low, medium, and high levels of this individual characteristic (Lionetti et al., 2018; Pluess et al., 2018). Due to the lack of studies investigating the association between ES and CVT, and given the mixed evidence concerning high vs. low resting CVT as a susceptibility factor, no hypothesis was formulated concerning possible differences in resting CVT as a function of children's sensitivity.

Second, we examined the moderating role of ES and CVT in the association between family support and children's well-being. Following previous research (Newland, 2015; Razza et al., 2010), we anticipated a main effect so that children reporting higher family support would show overall higher levels of well-being. In terms of ES, because individuals high in sensitivity are overall more reactive to stimuli (Pluess, 2015), we expected that highly sensitive children would report greater well-being in the presence of a supportive family environment, and lower levels of well-being in the context of an unsupportive family environment compared to their less sensitive peers. With regard to psychophysiological self-regulation, we anticipated that higher resting CVT would serve as a protective factor in the context of poor family support, and that lower resting CVT would be a risk factor for low child well-being (Blair & Peters, 2003; Propper, 2012). Furthermore, despite the absence of prior research in this area, it was reasonable to expect that the moderating effect of high resting CVT would be more pronounced among highly sensitive children due to their tendency to process internal and external stimuli more deeply.

Method

Participants

A total of 131 first, second, and third-graders (65 boys, 47.4 %) with a mean age of 7.20 years (*SD* = .95) took part in the study. Students attended public primary schools located in disadvantaged urban neighborhoods in Northern Italy and came from low-SES families. Specifically, all families involved in this study had a yearly income of less than 12.000 €, which is consistent with relative poverty status in Italy (ISTAT, 2020); furthermore, 75% of families had just one working parent. Parental written permission and students' verbal assent were required for participation; in addition, written informed consent was obtained from school principals. The study was approved by the Ethics Committee of the University of Padova (protocol n. 3415).

Procedure

Data reported in this study were collected as part of a larger study aimed at investigating the links between self-regulation and psychological functioning in primary school students (see Scrimin et al., 2018, 2020). To establish a friendly relationship with the participants, researchers joined the classroom and interacted with children weekly over three months, and by organizing several short lessons and games. Children were then individually tested in a quiet room at school. All assessments took place in the morning (between 9 a.m. and 12 p.m.). Once the child entered the room, s/he was asked to perform a number of tasks to assess ES (see Measures section for a detailed description). Next, the sensors for measuring CVT were attached and the researcher invited the child to sit comfortably and watch an 8-minute long relaxing video during which the electrocardiogram (ECG) was recorded. After registration was over, the sensors were removed. Children were subsequently interviewed about their perception of the support received at home from their parents and their own emotional and physical well-being. Of importance, all children were happy to take part in the study and joined the researchers for all the assessment sessions. At the end of the assessment, children were thanked for their participation and received a certificate attesting their role as a "Assistant scientists" together with a golden star-sticker.

Measures

Child Well-Being. The Child Health and Illness Profile – Child Edition (CHIP–CE) (Riley et al., 2004) is a 45-item questionnaire that can be administered as an interview to the child. It is designed to evaluate the well-being of children ages 6 through 11 years, and examines aspects of health and well-being that can be influenced by health systems, school systems, and health promotion efforts. The CHIP–CE targets health-related quality of life aspects that are of special interest to the school-aged group. In the present study, we interviewed children using the Emotional and Physical comfort subscales. Frequency of symptoms in the past four weeks (e.g., "how often did you …feel really worried?" or "have a bad stomach ache?") was assessed by asking children to orally report and indicate their response on a 5-point illustrated Likert scale. Next, the mean of the two subscales was calculated, and an overall mean was computed to obtain and index of children's well-being, with higher scores indicating higher well-being. The measure has excellent psychometric properties (Riley et al., 2004) and has previously been used in Italy (Scrimin et al., 2018). In the current study, Cronbach's Alpha was .79 for the total scale.

Family Support. A standardized set of five questions derived from the Child Health and Illness Profile – Child Edition (CHIP–CE) (Riley et al., 2004) described above was administered as an interview to the child. Examples of questions of the Family Support subscale are "How often in the last four weeks did your parents or someone in your family…

take time to talk with you about your plans for the next day?" or "…listen to your concerns or ideas?". The frequency of family behaviors in the past four weeks was assessed using a 5-point Likert scale ranging from 0 = never to 4 = every day; scores were averaged to yield a total family support score, with higher values reflecting higher levels of family support. The measure has excellent psychometric properties in terms of reliability and validity (Riley et al., 2004). In the present study, Cronbach's Alpha of this subscale was .81.

Environmental Sensitivity. ES was investigated at the phenotypic level using a series of ad-hoc laboratory procedures specifically designed to be child-friendly and easily applicable in the early years of primary school[1]. Each task was derived from items included in the HSC scale (Pluess et al., 2018) in order to assess sensitivity to a variety of contexts, including: 1) Response to loud and unpleasant noises (loud sound of a needle scratching a blackboard, items 4 and 10 of the HSC short form), 2) response to pleasant classical and relaxing music (item 2 of the HSC), 3) response to a nice smell (chocolate, items 3 and 8 of the HSC); 4) response to a bad and strong smell (vinegar, items 3 and 8 of the HSC), 5) response when asked to do a lot of things all at once (copy a drawing while counting backward from 20, items 1, 5 and 7 of the HSC short form); 6) response when someone is observing the child while s/he is asked to perform a task (item 12 of the HSC). For tasks 1-2-3-4 (i.e., sounds and smells), the child was asked to listen or smell, and subsequently interviewed by the experimenter about his/her reaction in terms of valence and arousal via the Self-Assessment Manikin (SAM, Bradley & Lang, 1994), a pictorial rating scale designed to measure an emotional response where higher scores reflect higher arousal (1= calm and 5= highly aroused) and negative valence (1=positive emotionality and 5= negative emotionality). Similarly, the child was asked to describe his/her response in terms of valence and arousal when asked to simultaneously perform two different tasks and when being observed by the two researchers in the room using the verbally administered SAM. Thus, we obtained 6 scores for arousal and 6 scores for valence. Next, given that the correlation between noises and between smells was high (all *r*s > .72), we calculated an average score for responses to sounds and responses to smells in terms of valence and arousal, yielding four valence scores (i.e., valence emotionality experienced in response to noises, sounds, doing multiple things together and being looked at) and four arousal scores (i.e., arousal experienced in response to noises, sounds, doing multiple things together and being looked at).

Cardiac Vagal Tone. For the acquisition of the electrocardiogram signal, a POLAR sensor was placed on the child's chest using a monitoring device that encodes biological signals (ProComp Infiniti, Thought Technology, Montreal, Canada). The ECG signal was recorded continuously for 8 minutes via a 12-bit analog-to-digital converter with a sampling rate of 256 Hz and stored sequentially for analysis. The raw ECG signal was then exported in Kubios-HRV 2.2 (Kuopio, Finland) software to estimate the occurrence of each heartbeat and derive the series of normal inter-beat intervals (IBIs), calculated as the difference in ms between successive R-waves. To identify and correct artifacts, the raw signal was visually inspected and a piecewise cubic splines interpolation method was performed when necessary. Then, the square root of the mean squared differences (rMSSD) of successive IBIs was calculated. rMSSD is an index of short-term heart period fluctuations and specifically reflects vagally mediated influence of the parasympathetic activity on the sinoatrial node (Berntson et al., 1997).

Analytic Plan

Statistical analyses were conducted using SPSS and R software (R Core Team, 2016). First, we computed descriptive statistics and correlational analyses between study variables using Pearson's *r* correlation. Second, we run a series of preliminary analyses on the ES scores to reduce the number of components and to identify sensitivity groups using a data-driven approach. Specifically, we performed hierarchical cluster analysis using Ward's method to examine whether there were subgroups of children who displayed similar levels of ES. This method was selected because it ensures higher accuracy of results, minimizes the variance between elements, and performs significantly better than other hierarchical methods (Hands & Everitt, 1987). To corroborate the results of this analysis, we used the centroid method as an additional linkage method. Ward and centroid methods represent different algorithms through which observations are linked to form clusters that are increasingly cohesive and separated from each other. Specifically, in Ward's method the proximity between two clusters is defined as the increase in the squared error that results when two clusters are merged, whereas the centroid method calculates the proximity between two clusters by calculating the distance between the centroids of clusters (i.e., the mean values of the observation on the variables of the cluster). We then inspected the resulting dendrogram to identify the largest gaps or distances between cluster groups and determine the appropriate number of meaningful clusters that agglomerated the data (Olson & Biolsi, 1991). Moreover, we used the Silhouette function in the R cluster package to calculate the silhouette coefficient as an internal evaluation measure of different cluster solutions (Kaufman & Rousseeuw, 1990). This coefficient is calculated for each object and indicates the appropriateness of its cluster membership by measuring cohesion and separation by taking into account the participants who lie within their clusters, and also the ones who are somewhere in between clusters. The values of this coefficient vary between -1 and 1, with a coefficient closer to 1 indicating that the groups are more distinct from each other (Bergman et al., 2003). Third, we used univariate analysis of variance (ANOVA) to explore the association between CVT and detected sensitivity groups. In addition, we computed bivariate correlations between average scores of valence and arousal and CVT. Finally, we performed linear regression analysis to examine the associations of family support, ES, and resting CVT with children's well-being.

In this analysis, we included all main effects as well as the two- and three way interactions between family support, sensitivity groups, and CVT. To explore interaction effects, we performed tests of the simple slopes (Bauer & Curran, 2005) using the interactions package in R (Long, 2019).

Results

Descriptive Statistics

Descriptive statistics and correlations between study variables are reported in Table 1. Age was not related to any of the study variables, while gender was only associated with sensitivity to smells in terms of valence, with girls reporting smells as generally causing a less negative response. As expected, both family support and CVT (as indexed by rMSSD) were positively associated with child well-being. The only significant association between CVT and ES tasks was found for sensitivity to smells in terms of arousal: children with higher resting CVT reported to be more aroused in response to such stimuli, and vice-versa. Furthermore, family support was negatively related to ES. Specifically, children who reported more family support experienced less arousal when having to do a lot of things together, and when being looked at while doing these things. A number of associations also emerged among the ES items. For example, response to noises and smells in terms of valence were positively intercorrelated. Similarly, doing many things at a time and being looked at were positively related in terms of both valence and arousal (see Table 1).

Identification of Sensitivity Groups

We then performed hierarchical cluster analysis to examine whether there were subgroups of children who displayed similar levels of ES. The eight scores on which the analysis was conducted included responses given in terms of arousal and valence to sounds, smells, to having to do more than one thing at the same time, and having to do it while being watched. Visual inspection and analysis of the resulting dendrogram revealed the presence of two large gaps or distances between cluster groups, supporting a three-cluster solution. A similar pattern emerged after applying the centroid method, which yielded three clusters with similar sample size. To further validate our results, we tested three different clustering solutions (from $k = 2$ to $k = 4$) by calculating the respective silhouette coefficients. The average silhouette coefficient of the three-cluster solution was considered as suitable (M = .45) when compared to the two- (M = .17) and four-cluster solutions (M = .21). Hence, given its appropriateness and interpretability, we retained the three-cluster solution for further investigation.

Descriptive statistics and group comparisons are presented in Table 2. The three clusters differed in all sensitivity domains: children in the first cluster (n = 56) showed a neutral response in terms of valence and low arousal in response to all the presented stimuli, and thus were labeled “Low sensitive”; children in the second cluster (n = 43) responded to the stimuli with an overall positive valence and an average arousal, displaying moderate sensitivity; therefore, this cluster was labeled “Moderately sensitive”; children in the third cluster (n = 32) responded to the stimuli with a negative valence and a high arousal, and hence the cluster was labeled “Highly sensitive”.

Relationship Between Sensitivity Groups and CVT

To examine whether the three sensitivity groups differed in their CVT levels, a univariate analysis of variance was performed. Findings revealed no differences in CVT across the three groups, $F(2, 112) = .48$, $p = .62$, $\eta_p^2 = .02$. Furthermore, no significant correlation was found between CVT and the total valence and arousal scores (obtained by averaging the four items pertaining to each score) derived from the sensitivity tasks, $r = .03$, $p = .76$ and $r = .09$, $p = .54$, respectively.

Moderating Role of ES and CVT in the Family Support-Child Well-Being Association

To investigate the direct and interactive effects of family support, CVT, and ES on child well-being we performed a linear regression analysis. The resulting model explained 28% of the variance. As can be seen in Table 3, family support was significantly and positively associated with children's well-being. No two-way interactions between family support and sensitivity groups or CVT were found. However, a significant three-way interaction between family support, ES groups, and CVT emerged.

As depicted in Figure 1, follow-up simple slope analysis indicated that in the presence of low family support (- 1SD below the mean), highly sensitive children with higher resting CVT reported better well-being than those with low resting CVT ($B = .44$, $SE = .01$, $t = 2.14$, $p = .02$), whereas no effect was observed among children in the other two sensitivity groups. Hence, for highly sensitive children, higher resting CVT served as a protective factor against adjustment problems when family support was low. Similarly, in the presence of an 'average' supportive family environment, highly sensitive children with higher resting CVT reported significantly more well-being compared to those with lower resting CVT ($B = .14$, $SE = .09$, $t = 1.79$, $p = .05$); no significant effect was found for the other two sensitivity groups. Finally, in the context of high family support, all children reported high levels of well-being irrespective of their levels of environmental sensitivity or resting CVT.

Discussion

To our knowledge, the present study is the first to simultaneously explore the moderating role of children's individual differences in *Environmental Sensitivity* (ES) and CVT in the association between family support and children's well-being in the context of socioeconomic disadvantage. Our findings revealed the presence of three sensitivity groups based on children's responses to a series of age-appropriate experiential tasks reflecting item content of the HSC scale: low, medium, and highly sensitive. The three groups did not differ in baseline CVT. However, the positive association between family support and child well-being varied as a function of both sensitivity group and CVT. More specifically, in an unsupportive family environment, highly sensitive children with high resting CVT fared better than their peers in the other two ES groups, and the same pattern was observed in the presence of an 'average' supportive family context. However, when children perceived their families as being highly supportive, their levels of well-being were high irrespective of the two individual characteristics.

Our first aim was to explore ES groups in low SES children. The results highlighted the presence of three groups of children characterized by low (43%), medium (33%), and high (24%) levels of sensitivity. This pattern resembles the distributions reported in previous questionnaire-based research on ES in large samples of children and adolescents, though with a higher percentage of low sensitive children (see Pluess et al., 2018), and suggests that individuals manifest different degrees of sensitivity to their environment. Although further research is needed to replicate this finding, it seems that the categorization is also applicable to children living in socioeconomically disadvantaged families. Furthermore, it should be noted that the sensitivity groups were derived from children's responses to a series of tasks involving reactions to smells, sounds, and performance under pressure, thereby minimizing desirability effects. Albeit exploratory, our results indicate that this procedure might be a promising tool to assess ES in low SES school-age children who may be less comfortable with responding to a self-report questionnaire (especially those attending the lower grades of primary school) and whose parents are unavailable or reluctant to provide reports on their children's behavior.

We also assessed whether the three sensitivity groups differed in their levels of resting CVT. Our analysis failed to detect such differences, indicating that there is no direct relationship between these two individual characteristics (at least in the current sample). A possible explanation is that CVT was measured as a resting state (i.e., trait), whereas ES was assessed in response to activities (i.e. state), rendering the two constructs somewhat less comparable. From a theoretical perspective, this result might mirror the distinct conceptualization of ES and CVT, since the former refers to the depth of processing in relation to both internal and external stimuli (Pluess, 2015), whereas the latter is an index of physiological self-regulation which is fundamental for adaptation to different situations and environments (Porges, 2007). As such, sensitivity entails a more 'reactive' component which does not necessarily overlap with an individual's ability to regulate his/her constant interactions with more or less challenging environments. Future research is warranted to ascertain the extent to which ES and CVT might represent distinct traits with separate neurobiological substrates, or rather two facets of a common underlying function.

The second purpose of this study was to explore the moderating role of ES and/or CVT in the association between perceived family support and children's physical and emotional well-being. As expected, family support was directly and positively related to better child well-being, confirming the importance of this proximal variable also in low SES samples (Scrimin et al., 2018). In terms of two-way interactions between family support and each individual characteristic, no significant results were recorded. However, a three-way interaction among family support, ES, and CVT emerged. In particular, we found that at low and average levels of family support, children in the highly sensitive group reported greater well-being when resting CVT was high, whereas this pattern was not found among the other sensitivity groups. Thus, albeit preliminary, our findings suggest that high resting CVT might have a buffering effect on the potentially negative impact of an unsupportive (or moderately supportive) family environment on children's well-being, a pattern that has been reported in previous research also among low SES samples (Sturge-Apple et al., 2016). However, our study shows that this effect is evident only among highly sensitive children, who seem to benefit more from a good self-regulatory ability than their low and moderately sensitive counterparts. The latter groups, on the contrary, were not influenced by individual variations in CVT, which is in line with the theoretical assumption that only a small proportion of the population, namely highly sensitive individuals, is exceptionally sensitive to stimuli.

To summarize, although further studies are needed to corroborate these findings, our data seem to support the notion that among individuals who are exposed to chronic stressors, those with higher levels of sensitivity show better outcomes than less sensitive individuals when they can count on better physiological self-regulatory skills (Obradović & Boyce, 2009). Thus, it is useful to consider the combined effect of sensitivity to environmental influences and the ability to self-regulate when evaluating the potentially adverse effects of family support on low SES children's well-being. Future research may compare samples of different SES backgrounds within a single study to examine similarities and/or differences in these interactional patterns, and focus on specific variables related to financial strain (e.g., authoritarian parenting style, depressive symptoms, alcohol use) in order to address which specific factors influence such associations.

Of note, our results also revealed that when perceived family support was high, all children reported high levels of well-being irrespective of their ES or CVT. Hence, despite growing up in a socioeconomically disadvantaged household, children who experience a high-quality family environment in which parents express their support through emotional availability, closeness, and involvement in their children's activities seem to equally benefit from such a nurturing environment. In this context, the role of individual differences in environmental sensitivity and physiological self-regulation might be 'overshadowed' by the positive influence of parental support, which has been shown to boost mental and physical health in both children and adolescents through its effect on attachment relationships and family cohesion (Chen, Brody, & Miller, 2017). Future studies may longitudinally address the interrelations among these factors in childhood to shed further light on the mechanisms involved in the long-term development of both physical and mental health, especially among children and families living in low SES environments.

Several limitations need to be acknowledged when interpreting the results. First, the cross-sectional design does not allow to draw any conclusions about causality. Future research may longitudinally assess low SES children over the primary school years to analyze transactional processes among family background, ES, and self-regulatory skills, possibly identifying relevant developmental trajectories. Second, the absence of one or more comparison groups of children from middle- or high income families prevented us from assessing whether the moderating effects of ES and CVT showed a similar pattern across groups. Studies involving larger and more representative samples are needed to replicate this research and increase the generalizability of findings, evaluating whether the investigated mechanisms are specific to a low SES condition or can be generalized irrespective of children's socio-economic background. Third, although our analyses revealed meaningful relationships among study variables, more research is needed to validate the procedure used to assess ES in children. Specifically, researchers might include additional measures (e.g., self-reports, semi-structured interviews) to establish concurrent and predictive validity as well as internal reliability.

Despite these limitations, our study provides an innovative contribution to the existing literature on the dynamics underpinning the relation between family support and children's physical and emotional adjustment in the context of socioeconomic disadvantage. From a theoretical perspective, the results pave the way for further investigations addressing the extent to which ES and CVT interact or distinctively contribute to children's outcomes in order to expand current theories of person-environment interplay and associated neurobehavioral correlates (Aron et al., 2012; Belsky & Pluess, 2009; Boyce, 2016; Masten, 2016). From an applied perspective, it might be worth promoting interventions to improve children's self-regulatory abilities (e.g., mindfulness; Kaunhoven & Dorjee, 2017) and increase CVT (e.g., heart rate variability biofeedback, Takacs & Kassai, 2019). Furthermore, our data emphasize the importance of promoting a positive and supportive family environment and suggest that, especially for highly sensitive children living in suboptimal environments, learning to regulate physiological activation might be of particular importance to pave the way for long-term physical and emotional well-being.

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Footnote

We conducted a pilot study with 30 children who were not part of the current study to select the most suitable tasks. This pilot testing was carried out in two phases. The first phase started with the selection of a number of possible tasks that could directly measure the domains described in the short form of the HSC scale (Pluess et al., 2018). This resulted in the creation of 15 tasks, comprising three different unpleasant sounds and three different pleasant sounds, three different pleasant smells and three unpleasant smells, two tasks related to doing multiple things together, and one in which children were observed while doing them. The 15 tasks were then administered (second phase) to the 30 children, who rated their responses to the tasks in terms of valence and arousal. This allowed to choose the most reliable smells and sounds (perceived by children as “bad” or “good” in more than 80% of the sample) as well as to delete one task related to the perception of changes in the environment that was not informative (no variability was found).

Table 1

Descriptive statistics and correlations among study variables

	2	3	4	5	6	7	8	9	10	11	12	13	*M* (*SD*)	*Range*
1. Age	-.09	-.16	.09	-.08	.04	.04	-.07	.02	-.22	.09	.01	-.02	7.20 (.95)	6-9
2. Gender (% male)		.08	-.10	-.04	.02	-.22*	.05	-.05	.08	-.02	-.05	.07	65 (47.4%)	
3. Well-being			.28**	.37**	-.09	-.05	-.04	-.04	.03	.02	-.09	-.02	.3.10(.67)	1-4
4. CVT				-.02	-.07	.03	-.05	-.08	.15	.28**	.13	.05	78.91(31.77)	17.70-217.80
5. Family support					-.12	-.08	.18	.01	.11	-.01	-.28**	-.27**	2.97 (.68)	1-4
ES behavioral categories														
Valence														
6.Responding to noises						.25**	.06	.08	.12	.05	.12	.04	2.12 (1.05)	0-4
7. Responding to smells							-.06	.02	.06	.09	.28**	.12	1.16(.98)	0-4
8. Doing a lot of things together								.39**	.23*	.24**	-.30**	-.33**	2.36 (1.33)	0-4
9. Responding to being looked at									.21	.23*	-.30**	-.42**	2.00 (1.27)	0-4

Arousal					
10. Responding to noises	.38**	-.03	-.03	2.76 (.93)	1-4
11. Responding to smells		.06	.06	2.97 (.88)	1-4
12. Doing a lot of things together			.47**	2.17 (1.48)	0-4
13. Responding to being looked at				1.96 (1.27)	0-4

Note. *N* = 131. CVT = cardiac vagal tone as indexed by the square root of the mean squared differences of successive heart periods (rMSSD); ES = environmental sensitivity.

*$p < .01$; **$p < .001$.

Table 2

Descriptive statistics for the three Environmental Sensitivity groups (N = 131)

	Low sensitive children *n* = 56	Moderately sensitive children *n* = 43	Highly sensitive children *n* = 32
	M(SD)	*M(SD)*	*M(SD)*
Valence			
Responding to noises	2.22 (1.20)	2.82 (1.43)	1.68 (.72)
Responding to smells	3.12 (1.11)	3.00 (1.74)	2.59 (1.20)
Doing a lot of things together	2.44 (1.03)	3.22 (1.21)	1.79 (.87)
Responding to being looked at	1.46 (.78)	3.36 (.94)	0.22 (.42)
Arousal			
Responding to noises	1.15 (.65)	2.18 (1.13)	3.22 (1.33)
Responding to smells	0.87 (.71)	1.77 (.89)	1.83 (1.10)
Doing a lot of things together	2.25 (1.20)	2.69 (1.12)	3.94 (.08)
Responding to being looked at	1.77 (.79)	2.28 (.94)	3.78 (.74)

Table 3

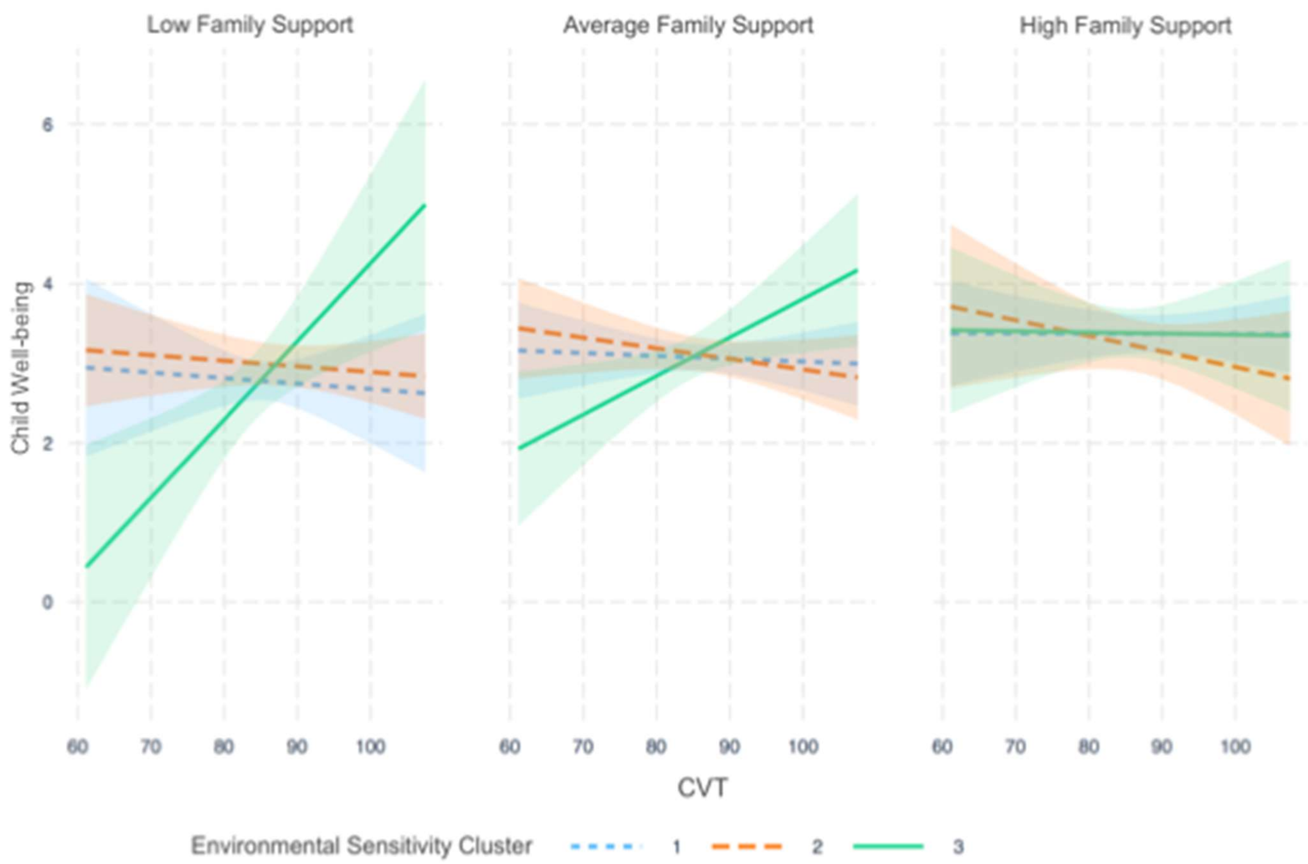
Linear regression analysis predicting children's well-being

Variable	*B (SE)*[a]	*T*	*p*	*95% CI [LL-UL]*	*F*	*p*	η^2_p
CVT	1.06 (.36)	1.53	.04	[-.05-04]	2.31 (1,115)	.07	.01
Family support	1.30 (.44)	2.55	.01	[.25-1.99]	2.92 (1,115)	.05	.03
ES group							
Moderately sensitive	-1.62(1.67)	-.97	.33	[-.06-6.61]	1.98 (2.115)	.15	.04
Highly sensitive	-3.32 (1.67)	-1.98	.05	[-1.95-5.04]			
CVT x Family support	.02 (.02)	1.35	.17	[-.02-.01]	.89 (1,115)	.36	.01
Family support x ES group							
Family support x Moderately sensitive	.44 (2.24)	1.05	.29	[-2.29--.10]	2.36 (2,115)	.10	.04
Family support x Highly sensitive	7.48 (2.78)	2.96	.01	[-1.93-.49]			
CVT x ES group							
CVT x Moderately sensitive	.08 (.02)	1.59	.11	[-.08--.01]	2.15 (2,115)	.12	.04
CVT x Highly sensitive	.04 (.02)	2.05	.04	[-.04-.03]			
CVT x Family support x ES group							
CVT x Family support x Moderately sensitive	-.03(.02)	-1.53	.12	[.01-.03]	3.64 (2,115)	.04	.06
CVT x Family support x Highly sensitive	-.10(.03)	-2.82	.02	[-.01-.02]			

Note. *N* = 131. CVT = cardiac vagal tone as indexed by the square root of the mean squared differences of successive heart periods (rMSSD). ES = Environmental Sensitivity. Baseline category for ES group was low sensitive. R^2 = 28%.

Figure 1

Three-way interaction effect of family support, environmental sensitivity and CVT (indexed by rMSSD) on child well-being



Note. CVT = Cardiac vagal tone as indexed by the square root of the mean squared differences of successive heart periods (rMSSD). Environmental Sensitivity groups: 1 = Low sensitive children (*n* = 56), 2 = Moderately sensitive children (*n* = 43), 3 = Highly sensitive children (*n* = 32).