Profiles of Vagal Withdrawal to Challenging Interactions: Links with Preschoolers' Conceptual Shifting Ability

Sara Scrimin [a], Elisabetta Patron [b], Silvia Lanfranchi [a], Ughetta Moscardino [a], Daniela Palomba [b] , Lucia Mason [a]

[a] Department of Developmental Psychology and Socialization, University of Padova, Italy

[b] Department of General Psychology, University of Padova, Italy

RUNNINH HEAD: Vagal Withdrawal to challenging interactions and Conceptual Shifting

Correspondence concerning this article should be addressed to Sara Scrimin, Department of Developmental Psychology and Socialization, University of Padova, via Venezia 8, 35131 Padova, Italy. Phone: +39 049 827 1275 Fax: +39 049 827 6511 E-mail: sara.scrimin@unipd.it

Abstract

The current study investigated profiles of vagal withdrawal in response to a challenging task in preschoolers. Also, the association between those profiles and conceptual shifting ability was assessed. Electrocardiogram of 43 4-year-olds was registered during a sequence of games including a win and a lose phase, while conceptual shifting ability was assessed via a standardized test. Cluster analyses revealed 3 profiles of cardiac vagal response to the task. Children in the first cluster displayed significant vagal withdrawal, children in the second cluster showed non-significant vagal withdrawal, while children in the third group displayed vagal augmentation to the challenge. These profiles differentiated preschoolers' conceptual shifting ability. Specifically, children with vagal withdrawal had the best performance in categorization and flexibility tasks and committed less perseverative errors compared to children who showed blunted vagal withdrawal or vagal augmentation to the challenge. Implications for theory and practice are discussed.

Keywords: Cardiac Vagal Withdrawal, Challenge Task, Conceptual Shifting, Preschoolers.

Introduction

Emotion regulation is of fundamental relevance in children's adaptive functioning across various domains, including social, emotional and cognitive development and the ability to cope with daily living tasks (Cole et al., 2004; Graziano, Reavis, Keane, & Calkins, 2007). It has been commonly defined as the ability to control, evaluate, and modify emotional reactions in response to environmental changes in order to achieve a specific goal (Thompson, 1994). In this context, emotion regulation includes two components: socio-emotional regulation, which refers to the response to social interaction in different emotional contexts; and cognitive regulation, which relates to cognitive processes such as executive functions and problem-solving, necessary to choose and apply the correct emotion regulation strategy (Libermann, Giesbrecht, & Muller, 2007). Both components of emotion regulation start to develop early in preschool, forming a critical foundation that will set the stage for the establishment of higher cognitive processes well into adulthood (Garon, Bryson, & Smith, 2008). For example, preschool children develop emotion regulation skills that are of foremost importance when interacting with others, and especially when such interactions require the ability to deal with a certain amount of challenge and frustration. Also, they progressively learn how to resist to distraction, hold information in mind and manipulate it to focus and re-focus their attention. These abilities are three of the main components of executive functions: inhibition, working memory, and shifting ability (Hofmann, Schmeichel, & Baddeley, 2012; Miyake, Friedman, Emerson, Witzki, Howerter, & Wager, 2000; Monette, Bigras, & Lafrenière, 2015).

Socio-emotional and cognitive correlates of emotion regulation are thought to be subserved by brain structures that are also well-known substrates of executive functions, such as orbitofrontal and dorsolateral regions of the prefrontal cortex (PFC) (Beauchaine et al., 2015). Supporting this hypothesis, reduced top-down control of the PFC over the amygdala and scarce amygdala-orbitofrontal cortex connectivity have been reported as correlates of emotional dysregulation (Churchwell et al., 2009).

Emotion regulation has also been associated with psychophysiological and mostly autonomic modulation of emotional responding to environmental challenges (Porges, Doussard-Roosevelt, & Maiti, 1994; Kreibig 2010). Indeed, the influence of the autonomic nervous system's parasympathetic branch over the heart's sinoatrial node (i.e., cardiac vagal tone) has been extensively reported as a reliable physiological index of emotion regulation. According to the neurovisceral integration theory (Thayer et al., 2009), this index of emotion regulation reflects the activity of the PFC. Indeed, the activation of a brain network that includes different regions of the PFC, namely OPP including OPP such as the insular cortex, the rostral anterior cingulate cortex and the amygdala, determines an increase of vagal nerve input over the sinoatrial node (Thayer & Lane 2000; Wong et al., 2007).

Cardiac vagal tone can be reliably estimated through the square root of the mean squared differences of successive heart periods (rMSSD), a specific Heart Rate Variability (HRV) index (Adrian, Zeman, & Veits, 2011; Li, Snieder, Su, Ding, Thayer, Treiber, & Wang, 2009). Empirical evidence suggests that lower cardiac vagal tone at rest predicts worse performance in tasks assessing cognitive and executive functions (such as working memory, cognitive efficiency, and inhibitory control) in school-age children (Marcovitch, Leigh, Calkins, Leerks, O'Brien, & Blankson, 2009; Staton, El-Sheikh, & Buckhalt, 2009).

While the literature has mainly focused on cardiac vagal tone at rest as an indicator of emotion regulation and self-regulatory abilities, fewer studies have investigated the role of vagal response to challenging situations. Challenges, such as stressful situations, are associated with a phasic suppression of vagal influence (Berntson et al., 1993), which modifies cardiac activity (i.e., heart rate increase) to meet environmental demands. Such a pattern of autonomic response, namely cardiac vagal withdrawal, has been linked to a better performance in the context of both emotional and cognitive environmental challenges. The relationship between vagal withdrawal during challenging states and adaptive functioning has been documented in children as well (Graziano & Derefinko, 2013). Both excessive (Donzella et al., 2000) and blunted (Markovitch et al., 2010) vagal withdrawal during a stressful task have been linked to poor outcomes in children. Excessive vagal withdrawal was found to correlate with greater manifestation of negative affect (sadness and anger) in a social challenge task (Donzella et al., 2000) and to characterize children at risk for behavior problems (Calkins et al., 2007). , Blunted vagal withdrawal, instead, was found to correlate not only with coping difficulties and externalizing behaviors (Porges et al., 1996), but also with poor performance on executive function tasks (Markovitch et al., 2010) in children. Intriguingly, Marcovitch and collaborators, (2010) found that moderate vagal withdrawal (not too high and not too low) during a stressful task was associated with the best executive function performance in preschoolers. Thus, it could be argued that adequate (i.e., moderate) vagal withdrawal to a stressful task is a reliable predictor of children's performance during challenging situations.

A number of studies have reported significant reciprocal associations between emotion regulation and executive functions in children. For example, a link between higher inhibitory control and adaptive socio-emotional responses has been found (Blankson, O'Brien, Leerkes, Marcovitch, Calkins, & Weaver, 2013; Carlson & Wang, 2007). Similarly, working memory appears to be positively related to autonomic regulation in children (Staton, El-Sheikh, & Buckhalt, 2009).

Yet, little is known about the possible relation between children's shifting ability and emotion regulation. The ability to shift attention between different tasks or information involves the disengagement from an irrelevant task, or from information that becomes no longer relevant, and the subsequent active engagement in a newly relevant task. A specific shifting domain is conceptual shifting, which has been defined as the ability to consciously shift from a concept or a cognitive set to another (Ozonoff et al., 2004); more generally, conceptual shifting can be considered an index of cognitive flexibility (e.g., Miyake et al., 2000; Prager, Sera, & Carlson, 2016). One of the most widely used tools to assess conceptual shifting is the Wisconsin Card Sorting Test (WCST, Berg, 1948) and its modified version for children (MCST; Nelson, 1986). The test assesses the ability to categorize a series of stimulus cards and to adjust the criteria according to external feedback given by the experimenter. According to Cianchetti, Corona, Foscoliano, Contu, and Sannio-Fancello (2007), two types of information can be obtained from this test: (a) how many times the child is able to see the presented stimuli from a different perspective, classifying them with a different criterion, which could be considered as a measure of the ability to categorize, and (b) whether the child is able to shift from a previously reinforced categorization rule to a new one without going back to the previous criterion, which could be considered a measure of flexibility.

Despite the pivotal role of emotion regulation and conceptual shifting in children's socio-emotional development, data are lacking on the possible link between autonomic emotion regulation (i.e., vagal withdrawal) and conceptual shifting. The association between vagal withdrawal to a challenging task and the ability to effectively transition between tasks and situations could add some relevant information to the extant literature supporting a common physiological path in charge of self-regulatory skills (Porges, Doussard, Roosevelt, Portales, & Greenspan, 1996; Thayer et al., 2009). This knowledge, in turn, may allow to plan effective interventions supporting children's cognitive and emotional self-regulation.

To study how children respond to a social-emotional competitive challenge, we used the procedure proposed by Donzella et al. (2000). In their work, the authors asked children to participate individually in a competition against the researcher to determine who would win enough games to receive a prize. The competition included one winning (a challenging situation with positive valence) and one losing period (a challenging situation with a negative connotation) before a last winning phase (to restore positive affect in the child) after which they received a prize. While the challenging situation was expected to produce a larger vagal withdrawal during the negative challenge period, when children were clearly at risk of losing (Calkins, 1997), findings indicated a significant vagal withdrawal as the children began to play (positive challenge) against the adult. Moreover, children who experienced the threat of potentially losing the competition also exhibited a negative emotional reaction to the challenge.

In the current study, we sought to explore the relationship between vagal withdrawal during a challenging social interaction and conceptual shifting ability in a group of preschoolers. Vagal withdrawal during the challenge was anticipated to influence children's cognitive performance. Specifically, we hypothesized that:

1) two different profiles of emotion regulation in response to challenge would emerge: A first profile characterized by moderate vagal withdrawal during the challenge (i.e., adequate emotion regulation), and a second profile with blunted (reduced) vagal withdrawal during the challenge (i.e., poor emotional regulation);
2) performance on the shifting task would be predicted by vagal withdrawal to the challenge, such that children with moderate vagal withdrawal would show better performance in a shifting task than children with lower vagal withdrawal.

Method

Participants

Forty-three preschoolers (24 boys, 55.8%) with a mean age of 4.74 years (*SD* = 0.62) took part in the study. All children were attending a public preschool in northeast Italy and were from low- to middle-class families. Parental written permission and children's verbal assent were required for participation; in addition, written informed consent was obtained from the school principal and by the Ethical Committee of the Psychology section of the University of Padova. Children were given the opportunity to decline participation between the two sessions and during the single session. Data reported in this study are part of a larger longitudinal study. Before the beginning of data collection and registration, trained researchers spent three months (at the beginning of the school year) participating in classroom activities and organizing games with children in order to familiarize and obtain preschoolers' total trust. Subsequently, children were tested individually during 6 separate sessions. In the present study, we report on the data collected in two of the six sessions, which took place between January and February 2016.

Measures

Psychophysiological measures. For the acquisition of the electrocardiography (ECG) signal, a heart rate POLAR sensor was placed on the thorax using a multi-modality physiological monitoring device that encodes biological signals in real-time (ProComp Infiniti encoder, Thought Technology Ltd, Montreal, Canada). ECG signal was recorded continuously via a 12-bit analogue-to-digital converter with a sampling rate of 256 Hz and stored sequentially for analysis. The continuous recording lasted 12 minutes, from which four separate intervals were extracted: 3 minutes of baseline (resting condition, while watching a neutral video clip); 3 minutes in the first winning phase of the competition; 3 minutes while the child lost the three memory games; and the last three minutes to restore positive affect (data from this last phase were not included in subsequent analyses). The ECG signal was then exported in Kubios-HRV 2.2 (Kuopio, Finland) software to estimate the occurrence of each heartbeat and derive the inter-beat intervals, calculated as the difference in msec between successive R-waves. The ECG signal was visually inspected and, to correct for artefacts, a piecewise cubic splines interpolation method that generates missing or corrupted values into the IBI series was performed. Then, heart rate (HR) and the square root of the mean squared differences of successive heart periods (rMSSD) were calculated. Specifically, as an index of variation in inter-beat intervals, rMSSD is sensitive to short-term heart period fluctuations and estimates high-frequency variations in HR (Task Force 1996), thus it is thought to specifically reflect parasympathetic activity through the influence of the vagal nerve on the heart (Berntson et al., 1997).

Competitive Challenge task. The procedure is the same as described in Donzella et al. (2000). In brief, children played with the researcher a sequence of 9 games to gain a final prize. The 9 games were divided in three phases in which scores were controlled for the child to win the first phase (games 1-3), to lose the second (games 4-6), and a final phase in which children would win the total challenge (games 7-9). The general aim of the task was to study two separate situations in which the child was 1) challenged by playing a game, but still winning it, therefore the challenge had a positive connotation (i.e., Win phase); 2) challenged by playing and losing the game, therefore the challenge had a negative connotation for the children (i.e., Lose phase). During the last phase (recovery), positive emotions were restored since the researcher made a great show on assigning a medal and a bag of candies. All children at this point where very happy and proud.

Conceptual shifting. It was assessed by administering the Modified Card Sorting Test (Nelson, 1976), a reduced version of the Wisconsin Card Sorting Test (Berg, 1948). Four stimulus cards depicting a single red triangle, two green stars, three yellow crosses, and four blue circles were presented. Children were required to match each card according to color, shape, or number, with every consecutive card of two sets of 24 response cards portraying all possible combinations of color, shape, or number. Children were informed about accuracy without mentioning the scoring criterion. After they completed six consecutive correct sorts (completion of a "category"), they were informed that the sorting criterion would change. The procedure continued until the child completed the three categories twice, or until all 48 response cards were used.

The following parameters were recorded (see Cianchetti et al., 2007; Lanfranchi, Jerman, Dal Pont, Alberti, & Vianello, 2010): 1) Number of categories completed (minimum score 0, maximum score 6); 2) Percentage of correct responses; 3) Perseverative errors: the child persist with the same incorrect category; 4) Non-perseverative errors: all errors not classified as "perseverative errors". As suggested by Cianchetti et al. (2007), the number of categories completed (and the percentage of correct responses) reflect the "ability to categorize", while the number of perseverative errors reflects cognitive flexibility.

Control Variables

Since inhibitory control and working memory have been shown to be associated with both shifting ability and vagal cardiac activity at rest (Thayer et al., 2009), these variables were controlled for in the analysis.

Inhibitory control. It was assessed via a Stroop like day-night test for children (Gerstatd, Hong, & Diamond, 1994). In this task, children are presented with 16 cards and asked to say "night" if the sun is depicted on the card and "day" when they see moon and stars. Children are also given a control version of the task, in which they are asked to associate two separate abstract drawings with the words "day" and "night". The proportion of correct responses given in the experimental (day-night test) and control trials is an indicator of inhibitory control.

Visual Working Memory. It was assessed with a visuospatial dual task previously used by Lanfranchi et al. (2010). The children were presented with a frog on a 4 x 4 chessboard, the frog moved to reach a cell on the chessboard colored in red. Children had to remember the frog's starting position and to perform the concurrent task of tapping on the table when the frog jumped onto the red square. The task had four levels of difficulty, depending on the number of steps in the pathway: two, three, four, or five steps. For every trial performed correctly, with the child both remembering the frog's starting position and performing the tapping task, 1 point was assigned (minimum score 0, maximum 8).

Procedure

In the first session, the researcher invited the child to play together in a separate and quiet room. After applying the sensor, the researcher explained the rules of the game and then started the first of 9 games included in the challenging task (lasting overall 9 minutes). The procedure of the entire session replicated the work by Donzella and colleagues (2000), with the only difference that winning the final game made the child win a bag of candies and a medal.

Successively, children were tested individually on conceptual shifting, inhibitory control, and working memory. It is important to note that children were familiar with the researcher who collected the data and were happy to join her for the individual sessions.

Results

Preliminary Analyses

To examine how cardiac activity varied during the competitive challenge task (Baseline, Win, and Lose), repeated measures ANOVAs for HR and rMSSD of HRV were performed (see Figure 1 panel a and b). ANOVAs on HR yielded a significant effect of phase ($F_{(2, 42)} = 10.10$; $p < .001$; $\eta_p^2 = 0.19$). Post-hoc pairwise comparisons revealed that HR significantly increased from baseline (*M* = 98.31, *SE* = 1.53) to Win phase (*M* = 104.80, *SE* = 1.91), but no significant changes emerged in the Lose phase (*M* = 105.81, *SE* = 1.74). Analysis on rMSSD yielded no significant main phase effect ($F_{(2, 42)} = 2.78$; $p = .07$; $\eta_p^2 = 0.06$). A non-significant vagal reduction emerged from baseline (*M* = 51.02, *SE* = 3.26) to Win (*M* = 48.24, *SE* = 3.86) and Lose (*M* = 43.64, *SE* = 3.10)

[Insert Figure 1 about here]

Vagal Withdrawal in response to the Competitive Challenge Task

To address the first research question, we performed hierarchical cluster analysis using Ward's method to examine whether there were subgroups of children who exhibited the same pattern of vagal withdrawal to the competitive challenge (i.e., change in rMSSD from baseline to Win and Lose phases, calculated as the differential value between rMSSD recorded at Win and Lose phases from baseline values). Specifically, we sought to identify whether there were reliably distinct groups of children who showed the same pattern of vagal withdrawal during the two phases of the competitive challenge. We 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). Two of such gaps emerged in the dendrogram. To further corroborate this finding, an additional method (i.e., centroid) was used. This analysis confirmed the results obtained applying Ward's method.

Overall, the findings revealed three profiles of vagal withdrawal to the competitive challenge. Descriptive statistics and group comparisons are presented in Table 1. As can be seen in Figure 1, panel c, the first cluster of children (*n* = 14) showed high vagal withdrawal (negative change in rMSSD) during both Win and Lose phases. A one sample t-test revealed that rMSSD change from baseline was significant in both Win ($t = -10.88$; $p < .0001$) and Lose ($t = -9.41$; $p < .0001$) phases. Therefore, this group was named Vagal Withdrawal (VW). Children in the second cluster (*n* = 17) displayed a small vagal withdrawal from baseline to the Win and Lose phases, which was non-significant (Win: $t = -1.11$; $p = .28$; Lose: $t = -2.05$; $p = .06$); therefore, this cluster was labeled Blunted Vagal Withdrawal (BVW).

Finally, children in the third cluster (*n* = 12) showed a significant positive change in rMSSD from baseline to both the Win ($t = 7.99$; $p < .0001$) and Lose (t = 3.92; $p < .01$) phases; thus, this group was named Vagal Augmentation (VA).

To first reconfirm cluster analysis and to better characterize the response of each group to the challenging task, a mixed ANOVA was conducted to compare rMSSD changes in the three groups of children. Specifically, an ANOVA with Cluster (VW, BVW and VA) as a between-subject factor, and Phase (Win vs Lose) as within-subject variable was performed. The analysis yielded a significant main effect of Cluster ($F_{(2, 38)} = 87.99$; $p < .0001$; $\eta_p^2 = 0.81$). Post hoc comparison showed that VW had a significant vagal withdrawal (i.e., reduction in rMSSD from baseline to challenge phases) compared to BWV and VA ($p < .0001$). BVW showed a change in rMSSD that was lower compared to VW and greater compared to VA cluster (all *p*s < .0001). Also, a main effect of Phase emerged ($F_{(2, 38)} = 5.49$; $p = .02$; $\eta_p^2 = 0.12$). Post hoc comparison revealed a significant greater vagal withdrawal to Lose challenge compared to Win ($p < .05$). Finally, a significant interaction of Cluster x Phase emerged ($F_{(2, 38)} = 4.10$; $p = .02$; $\eta_p^2 = 0.17$). Post hoc comparison showed that VW and BWV yielded no differences between Win and Lose Phases, while children in the VA cluster had a significantly higher vagal augmentation in response to Win challenge compared to the Lose challenge (*p* < .05) phase (see Figure 1, panel c).

[Insert Table 1 around here]

Cardiac Vagal Response and Conceptual Shifting

To address the second research question, a multivariate analysis of variance was performed to compare scores in conceptual shifting between the three clusters while controlling for inhibitory control and working memory (Thayer et al., 2009. Results indicated that inhibitory control and working memory were not associated with any of the shifting measures, all *F*s > 1. Yet, as shown in Table 1, children in the VA cluster performed significantly worse than VW on both parameters (number of categories completed and the percentage of correct responses) of the Conceptual shifting task (*p* < .05). Finally, children in the VW committed less perseverative errors than children in the VA (*p* < .01) and BVW (*p* < .05) clusters.

Discussion

To the best of our knowledge, this is the first study to investigate emotion regulation (as indexed by cardiac vagal withdrawal) during a competitive challenge task and its association with preschoolers' conceptual shifting abilities. Two key findings emerged: first, differently from the study hypotheses, three groups of children who showed different patterns of vagal response during the competitive challenge were identified; second, children's vagal patterns of response were significantly and differentially related to their performance in a conceptual shifting task.

Preliminary analysis indicated that children's cardiac response to the game was congruent with the one reported by Donzella et al. (2000) in their study. The game was specifically designed to elicit negative emotions linked to the threat of potentially losing the competition. In line with the authors, we found a pattern of cardiac response characterized by a significant increase in HR at the beginning of the game, and no significant changes in cardiac vagal tone. Importantly, data from

Donzella et al. (2000) showed that higher vagal withdrawal was associated with greater manifestation of either sad or tense/angry affect, thus confirming the association between vagal control and emotion regulation in children.

Successively, a cluster analysis was performed to assess whether distinct profiles of children could be identified based on changes in rMSSD from baseline to Win and Lose phase of the competitive challenge task. This analysis yielded a three-group solution: vagal withdrawal, blunted vagal withdrawal, and vagal augmentation.

Specifically, children in the first cluster displayed a cardiac response characterized by a significant vagal withdrawal both during the positive and negative challenge phase of the game. Children in the BVW cluster displayed a lower, non-significant cardiac vagal withdrawal from the beginning of the game when facing the positive and negative challenge. Finally, children in the VA cluster displayed no vagal withdrawal, but an increase in cardiac vagal activity during the win phase, and a smaller vagal augmentation during the lose phase.

The ability to suppress vagal tone during a challenging situation indexes an adaptive psychophysiological response (Calkins, 1997; Calkins & Dedmon, 2000; Porges et al., 1996). Blunted vagal withdrawal was found to correlate not only with coping difficulties and externalizing behaviors (Porges et al., 1996) but also with poor performance on executive function tasks (Markovitch et al., 2010) in children. It could be speculated that children in the VW have a better emotion regulation ability that allows them to better face the challenge. Children in the BVW cluster showed a non-significant vagal withdrawal to the challenge, and therefore may be less capable of regulating their emotional response. Finally, children in the VA cluster showed a pattern of response to the task characterized by no vagal withdrawal. Indeed, while both VW and BVW clusters showed a reduction in vagal input on the heart at some point, VA showed a vagal augmentation. According to Porges (1995), enhanced parasympathetic activation mediates cardiac activity when environmental demands require coping. Vagal augmentation during challenging situations may reflect increased engagement and attentiveness to elements in the environment, which is a coping mechanism that helps to focus attention and to resist distracting information. While this mechanism could support emotion regulation processes in order to manage the challenge (Wilson & Gottman, 1996), when excessive it may reflect hypervigilance to environmental events. Katz et al. (2007) found that vagal augmentation during an interpersonal challenge was associated with more severe symptoms in conduct-problem children. More importantly, Hinnant and El Sheikh (2009) reported that the combination of low resting vagal tone and vagal augmentation to a challenge were predictive of externalizing symptoms in children.

The identification of subgroups of preschoolers who responded in different ways to the competitive challenge task underlines the importance of studying individual differences in patterns of psychophysiological response to a socio-emotional event. Indeed, different response patterns may characterize different levels of abilities in emotion regulation and adaptive skills to face requests from the environment. More importantly, vagal augmentation to a task has been associated with internalizing and externalizing disorders, as well as to an increased risk of psychopathology (Beauchaine et al., 2015; Beauchaine & Thayer, 2015) and conduct-related problems (Katz, 2007).

With the second research question, we explored whether children's profiles of cardiac response were associated with their performance in the conceptual shifting task while controlling for inhibitory control and working memory. Findings revealed that children in the VW cluster performed significantly better than those with a VA profile on all conceptual shifting scores. Following Cianchetti et al. (2007), the number of correct categories completed can be conceptualized as a measure of categorization and the number of perseverative errors as a measure of flexibility. Therefore, children with higher levels of emotion regulation (i.e., higher vagal withdrawal during challenging situations) had better performances in terms of both categorization and flexibility. On the contrary, children who showed vagal augmentation during the challenge yielded a lower performance in terms of categorization and flexibility. Also, children in the VW cluster committed less perseverative errors as compared to those in the BVW and VA clusters, while the latter committed more perseverative errors than both children in the VW and the BVW groups. Hence, vagal withdrawal during emotionally challenging situations (both positive and negative), which has been found to be an adaptive and appropriate response that facilitates the mobilization of metabolic resources and helps to generate coping strategies to control behavioral and emotional reactions (e.g., Calkins and Kane, 2004), also appears to facilitate the ability to shift from a cognitive strategy to another. Vagal withdrawal during emotionally challenging situations is indeed linked to adaptation in social, emotional, and cognitive contexts (Calkins et al., 2007; Marcovitch et al, 2010).

The present data support the idea that this psychophysiological mechanism allows for a better performance not only in inhibitory control (Mathewson et al., 2010) and working memory (Gillie et al., 2014), but also in other pre-frontal functions. Specifically, conceptual shifting abilities might as well be mediated by the activity of the parasympathetic nervous system, suggesting that both emotional and cognitive self-regulation abilities are related to a common physiological path (Porges et al., 1996; Thayer et al., 2009). Yet, this aspect should be further investigated.

One last consideration concerns those children who exhibited vagal augmentation to the challenge, as they performed poorly in both conceptual shifting components. This finding is in line with previous studies reporting a positive relation between basal cardiac vagal tone and several cognitive abilities (Thayer et al., 2009), including executive functioning (Marcovitch et al., 2010).

The present findings should be interpreted with caution due to study limitations. The main issue is related to sample size. The small number of children assessed prevents from generalizing these findings. More participants are needed to better understand the characteristics of children in each of the three identified clusters, as well as to control for a number of other variables that may influence the link between resting cardiac vagal tone and vagal withdrawal during a competitive challenge and conceptual shifting (e.g., task self-efficacy or motivation, as well as sustained attention and temperament). Moreover, an additional physiological measure assessing sympathetic activity (e.g., cardiac pre-ejection period or skin conductance) might give more detailed information about children’s response to the challenging task.

Despite these caveats, the present study adds to the literature by providing some important theoretical hints on individual differences in preschoolers' psychophysiological response while interacting with others in a challenging competition. Also, preliminary findings linking parasympathetic response during a challenging socio-emotional event and performance in an exclusively cognitive task involving conceptual shifting were reported.

The present results have potential implications for both educational and clinical practice. Specifically, interventions considering individual differences in children's vagal response and targeting the improvement of emotion regulation skills are recommended. Since a growing number of empirical studies have documented the effectiveness of bio-behavioural techniques (such as biofeedback, Prinsloo, Rauch, Lambert, Muench, Noakes, & Derman, 2011) to self-regulate individuals' psychophysiological activity, these practices could be usefully implemented at an early age.

References

Adrian, M., Zeman, J., & Veits, G. (2011). Methodological implications of the affect revolution: A 35-year review of emotion regulation assessment in children. *Journal of Experimental Child Psychology*, *110*, 171-197.

Beauchaine, T. P., & Thayer, J. F. (2015). Heart rate variability as a transdiagnostic biomarker of psychopathology. *International Journal of Psychophysiology*, 98(2), 338-350.

Beauchaine, T. P. (2015). Future directions in emotion dysregulation and youth psychopathology. *Journal of Clinical Child & Adolescent Psychology*, 44(5), 875-896.

Berg E. A. (1948) A simple objective technique for measuring flexibility in thinking. *Journal of General Psychology,* 39, 15–22.

Berntson, G. G., Cacioppo, J. T., & Quigley, K. S. (1993). Cardiac psychophysiology and autonomic space in humans: empirical perspectives and conceptual implications. *Psychological bulletin*, *114*(2), 296.

Berntson, G. G, Bigger, J. T. Jr., Eckberg, D. L, Grossman, P., Kaufmann, P. G., Malik, M., … & van der Molen, M. W. (1997). Heart rate variability: Origins, methods, and interpretive caveats. *Psychophysiology, 34*(6), 623-648.

Blankson, A. N., O'Brien, M., Leerkes, E. M., Marcovitch, S., Calkins, S. D., & Weaver, J. M. (2013). Developmental dynamics of emotion and cognition processes in preschoolers. *Child Development*, *84*(1), 346-360.

Brosschot, J. F., Van Dijk, E., & Thayer, J. F. (2007). Daily worry is related to low heart rate variability during waking and the subsequent nocturnal sleep period. *International Journal of Psychophysiology*, *63*(1), 39-47.

Calkins, S. D. (1997). Cardiac vagal tone indices of temperamental reactivity and behavioral regulation in young children. *Developmental Psychobiology*, *31*(2), 125-135.

Calkins, S.D., Dedmon, S.E., 2000. Physiological and behavioral regulation in two-year-old children with aggressive/destructive behavior problems. *Journal of Abnormal Child Psychology 28*, 103–118.

Calkins, S. D., & Keane, S. P. (2004). Cardiac vagal regulation across the preschool period: Stability, continuity, and implications for childhood adjustment. *Developmental Psychobiology*, *45*(3), 101-112.

Calkins, S. D., Graziano, P. A., & Keane, S. P. (2007). Cardiac vagal regulation differentiates among children at risk for behavior problems. *Biological Psychology*, *74*(2), 144-153.

Carlson, S. M., & Wang, T. S. (2007). Inhibitory control and emotion regulation in preschool children. *Cognitive Development*, *22*(4), 489-510.

Churchwell, J. C., Morris, A. M., Heurtelou, N. M., & Kesner, R. P. (2009). Interactions between the prefrontal cortex and amygdala during delay discounting and reversal. *Behavioral Neuroscience, 123(6)*, 1185.

Cianchetti, C., Corona, S., Foscoliano, M., Contu, D., & Sannio-Fancello, G. (2007) Modified Wisconsin Card Sorting Test (MCST, MWCST): normative data in children 4–13 years old, according to classical and new types of scoring. *The Clinical Neuropsychologist*, 21, 456– 78.

Cole, P. M., Martin, S. E., & Dennis, T. A. (2004). Emotion regulation as a scientific construct: Methodological challenges and directions for child development research. *Child Development*, 75(2), 317-333.

Donzella, B., Gunnar, M. R., Krueger, W. K., & Alwin, J. (2000). Cortisol e vagal tone responses to competitive challenge in preschoolers: Associations with temperament. *Developmental Psychobiology*, *37*(4), 209-220.

Garon, N., Bryson, S. E., & Smith, I. M. (2008). Executive function in preschoolers: A review using an integrative framework. *Psychological Bulletin*, *134*(1), 31.

Gerstadt C., Hong Y. J. & Diamond, A. (1994). The relationship between cognition and action: performance of children 3 1/2–7 years old on a Stroop-like day-night test. *Cognition*, *5*, 129-53.

Gillie, B. L., Vasey, M. W., & Thayer, J. F. (2014). Heart rate variability predicts control over memory retrieval. *Psychological Science*, *25*(2), 458-465.

Graziano, P. A., Reavis, R. D., Keane, S. P., & Calkins, S. D. (2007). The role of emotion regulation in children's early academic success. *Journal of School Psychology*, *45*(1), 3-19.

Graziano, P., & Derefinko, K. (2013). Cardiac vagal control and children's adaptive functioning: A meta-analysis. *Biological Psychology, 94*(1), 22-37.

Hinnant, J. B., & El-Sheikh, M. (2009). Children's externalizing and internalizing symptoms over time: the role of individual differences in patterns of RSA responding. *Journal of Abnormal Child Psychology, 37(8)*, 1049.

Hofmann, W., Schmeichel, B. J., & Baddeley, A. D. (2012). Executive functions and self-regulation. *Trends in Cognitive Sciences*, *16*(3), 174-180.

Katz, L. F. (2007). Domestic violence and vagal reactivity to peer provocation. *Biological Psychology, 74(2)*, 154-164.

Kreibig, S. D. (2010). Autonomic nervous system activity in emotion: A review. *Biological Psychology, 84,* 394-421.

Lanfranchi, S., Jerman, O., Dal Pont, E., Alberti, A., & Vianello, R. (2010). Executive function in adolescents with Down syndrome. *Journal of Intellectual Disability Research, 54*(4), 308-319.

Li, Z., Snieder, H., Su, S., Ding, X., Thayer, J. F., Treiber, F. A., & Wang, X. (2009). A longitudinal study in youth of heart rate variability at rest and in response to stress. *International Journal of Psychophysiology*, *73*(3), 212-217.

Liebermann, D., Giesbrecht, G. F., & Müller, U. (2007). Cognitive and emotional aspects of self-regulation in preschoolers. *Cognitive Development*, 22(4), 511-529.

Marcovitch, S., Leigh, J., Calkins, S. D., Leerks, E. M., O'Brien, M., & Blankson, A. N. (2010). Moderate vagal withdrawal in 3.5 ‐ year ‐ old children is associated with optimal performance on executive function tasks. *Developmental Psychobiology*, *52*(6), 603-608.

Mathewson, K. J., Jetha, M. K., Drmic, I. E., Bryson, S. E., Goldberg, J. O., Hall, G. B., ... & Schmidt, L. A. (2010). Autonomic predictors of Stroop performance in young and middle-aged adults. *International Journal of Psychophysiology*, *76*(3), 123-129.

Michels, N., Clays, E., De Buyzere, M., Huybrechts, I., Marild, S., Vanaelst, B., ... & Sioen, I. (2013). Determinants and reference values of short-term heart rate variability in children. *European Journal of Applied Physiology*, 113(6), 1477-1488.

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex "frontal lobe" tasks: A latent variable analysis. *Cognitive Psychology*, *41*(1), 49-100.

Monette, S., Bigras, M., & Lafrenière, M-A. (2015). Structure of executive functions in typically developing kindergarteners. *Journal of Experimental Child Psychology*, *140*, 120-139.

Nelson H. E. (1976) A modified card sorting test sensitive to frontal lobe defects. *Cortex*, 12**,** 313–24.

Olson, J. R., & Biolsi, K. J. (1991). Techniques for representing expert knowledge. In K. A. Ericsson & J. Smith (Eds.), *Toward a general theory of expertise: Prospects and limits* (pp. 240–285). Cambridge, UK: Cambridge University Press.

Ozonoff, S., Cook, I., Coon, H., Dawson, G., Joseph, R. M., Klin, A., ... & Rogers, S. J. (2004). Performance on Cambridge Neuropsychological Test Automated Battery subtests sensitive to frontal lobe function in people with autistic disorder: evidence from the Collaborative Programs of Excellence in Autism network. *Journal of Autism and DevelopmentalDisorders*, 34(2), 139-150.

Prager, E. O., Sera, M. D., & Carlson, S. M. (2016). Executive function and magnitude skills in preschool children. *Journal of Experimental Child Psychology*, *147*, 126-139.

Prinsloo, G. E., Rauch, H. G., Lambert, M. I., Muench, F., Noakes, T. D., & Derman, W. E. (2011). The effect of short duration heart rate variability (HRV) biofeedback on cognitive performance during laboratory induced cognitive stress. *Applied Cognitive Psychology*, *25*(5), 792-801.

Porges, S. W., Doussard-Roosevelt, J. A., & Maiti, A. K. (1994). Vagal tone and the physiological regulation of emotion. *Monographs of the Society for Research in Child Development, 59(2-3),* 167.

Porges, S.W., 1995. Orienting in a defensive world: mammalian modifications of our evolutionary heritage—a Polyvagal Theory. *Psychophysiology, 32*, 301–318.

Porges, S. W., Doussard‐Roosevelt, J. A., Portales, A. L., & Greenspan, S. I. (1996). Infant regulation of the vagal "brake" predicts child behavior problems: A psychobiological model of social behavior. *Developmental Psychobiology*, *29*(8), 697-712.

Staton, L., El‐Sheikh, M., & Buckhalt, J. A. (2009). Respiratory sinus arrhythmia and cognitive functioning in children. *Developmental Psychobiology*, *51*(3), 249-258.

Task force of the European society of cardiology and the north American society of pacing and electrophysiology. Heart rate variability. Standards of measurement, physiological interpretation, and clinical use. (1996) *European Heart Journal, 17,* 354-381.

Thayer, J. F., Hansen, A. L., Saus-Rose, E., & Johnsen, B. H. (2009). Heart rate variability, prefrontal neural function, and cognitive performance: the neurovisceral integration perspective on self-regulation, adaptation, and health. *Annals of Behavioral Medicine*, *37*(2), 141-153.

Thayer JF, Lane RD. (2000) A model of neurovisceral integration in emotion regulation and dysregulation. *Journal of Affective Disorders*, *61(3),* 201-216.

Thayer JF, Lane RD. (2009) Claude Bernard and the heart-brain connection: further elaboration of a model of neurovisceral integration. *Neuroscience Biobehavioural Review*. 33(2):81-88.

Thompson, R. A. (1994). Emotion regulation: A theme in search of definition. *Monographs of the Society for Research in Child Development, 59(2 ‐ 3)*, 25-52.

Wilson, B.J., Gottman, J.M., 1996. Attention—the shuttle between emotion and cognition: risk, resiliency and physiological bases. In: Hetherington, E.M., Blechman, E.A. (Eds.), *Stress, Coping and Resiliency in Children and Families* (pp. 189–228). Lawrence Erlbaum Associates, Hillsdale, NJ,.

Wong SW, Massé N, Kimmerly DS, Menon RS, Shoemaker JK. (2007). Ventral medial prefrontal cortex and cardiovagal control in conscious humans. *Neuroimage, 35(2),* 698-708.

Table 1

Conceptual shifting parameters of the three clusters (*N* = 43)

	Vagal Withdrawal (*n* = 14) M (SD)	Blunted Vagal Withdrawal (*n* = 17) M (SD)	Vagal Augmentation (*n* = 12) M (SD)	Group Comparison
CC	3.64 (1.15)[a]	2.65 (1.46)	2.25 (1.14)[a]	$F_{(2,42)}$ = 3,10; p = .027; η_p^2 =.25
PC	54.76 (10.35)[a]	46.08 (15.41)	42.19 (9.36)[a]	$F_{(2,42)}$ = 3,95; p = .009; η_p^2 =.30
NPE	5.14 (2.25)	8.41 (4.56)	9.25 (5.82)	$F_{(2,42)}$ = 1,83; p = .14; η_p^2 =.16
PE	14.36 (4.03)[a,b]	20.53 (6.96)[a]	21.42 (5.99)[b]	$F_{(2,42)}$ = 4,07; p = .008; η_p^2 =.31

Note: CC =Categories completed, PC = Percentage of correct responses, NPE = Non-perseverative errors, PE = Perseverative errors.

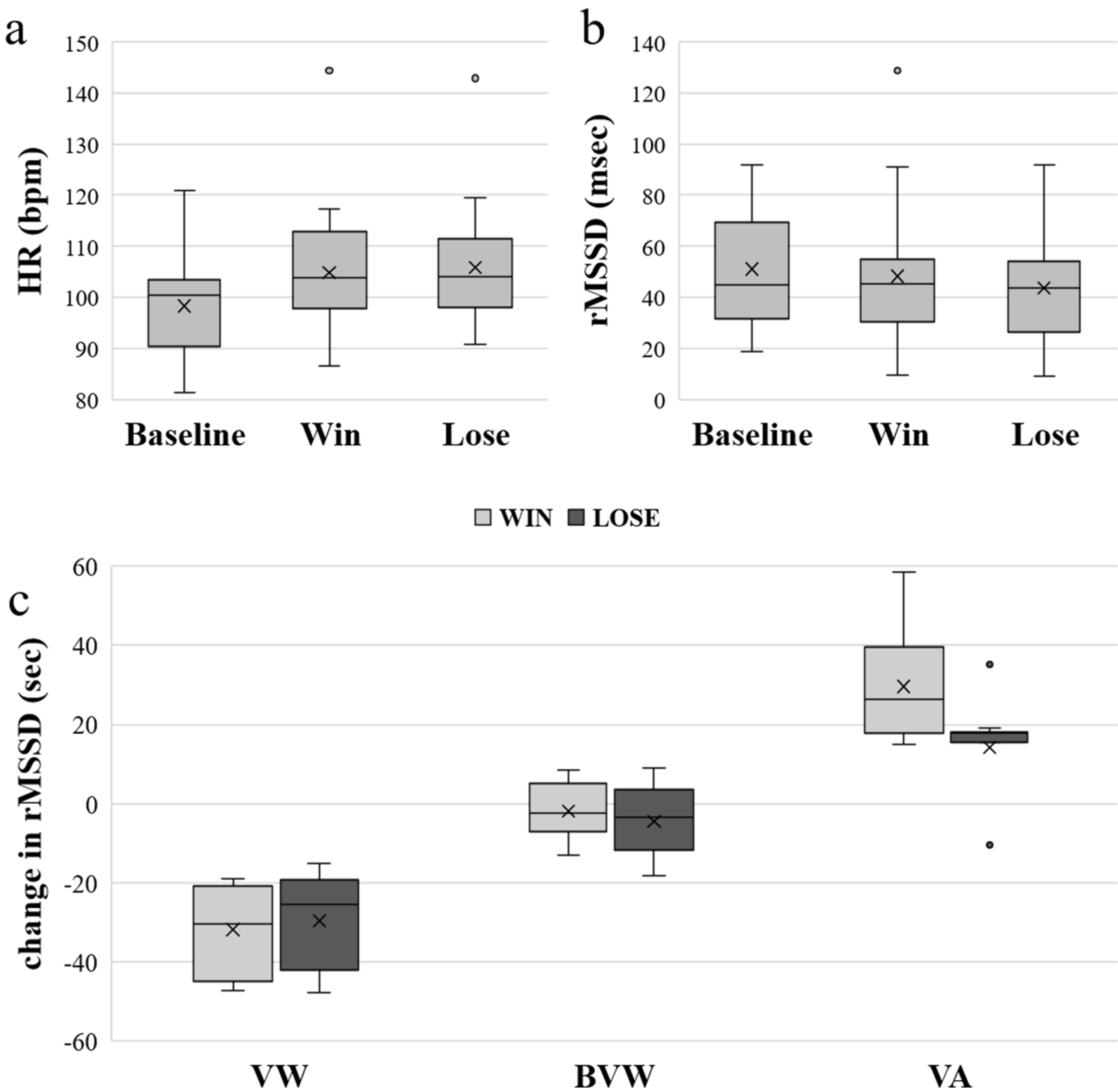
[a] $p < .05$; [b] $p < .01$

Figure 1

Panel a: HR of children during the competitive challenge task.

Panel b: rMSSD of children during the competitive challenge task.

Panel c: Vagal response (as measured by changes in rMSSD from baseline to Win and Lose phases) of the three clusters.



Note: Crosses represent the mean value; central bands represent the median; bottom and top of the boxes represent the first and third quartile, respectively; whiskers reflect the minimum and maximum of all the data. VW = Vagal Withdrawal, BVW = Blunted Vagal Withdrawal, VA = vagal augmentation, HR = Heart Rate, rMSSD = square root of the mean squared differences of successive heart periods.