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CORRELATION BETWEEN BEHAVIOR AND AUTONOMIC NERVOUS SYSTEM ACTIVATION IN CHILDREN EXPOSED TO A FRUSTRATING STIMULUS

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Abstract

Children who encounter a frustrating stimulus experience both behavioral and physiological responses. The natural response to frustration can be characterized by aggression and panic that is designed to allow the individual to engage in a behavioral response to overcome whatever is frustrating them (Stifter et al., 1993). This is diminished over time as the result of socialization influences and the development of behavioral inhibition and arousal regulation skills. A physiological response to frustration also occurs which typically takes the form of parasympathetic activity suppression and sympathetic activation (Porges, 2001). This is the synchronous autonomic nervous system (ANS) response to a challenging stimulus and is expected to be associated with appropriate inhibition control and arousal regulation skills. The purpose of this thesis was to investigate the correlation between ANS activity and behavior in response to a frustrating stimulus. Children completed a go or no-go task designed to induce frustration and physiological measures of electro-dermal activity (EDA) and respiratory sinus arrhythmia (RSA) were collected throughout the task period. These physiological measures were compared with behavioral data taken from questionnaires completed by the children's teachers and the research assistants administering the test. Results from this study showed a correlation between RSA suppression and EDA activation only in children who had not been previously identified as aggressive. It was also found that synchronous ANS response to a frustrating stimulus was positively correlated with inhibitory control behaviors. These results demonstrate that it is important to study the ANS as a whole and to examine the relationship between parasympathetic and sympathetic activity in response to a frustrating stimulus. The interaction between the two systems appeared to be a better predictor of behavioral response that either system independently. Future research in the area of behavior and ANS responsivity is needed. This future research should examine both the sympathetic and parasympathetic nervous systems concurrently.

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Introduction

Frustration can be operationalized as the feeling that occurs due to un-fulfillment of a goal or omission of an expected reward (Abler, Walter, & Erk, 2005). A major part of emotional development in infancy and early childhood is the acquisition of skills that enable children to cope with difficulties by regulating their own emotions (Calkins & Johnson 1998). As individuals move from infancy into toddlerhood, they must develop the ability to regulate negative emotions such as frustration. This is a particularly important skill set to develop during toddlerhood as the child is gaining an identity separate from their caregiver as well as some degree of control over their own environment (Calkins et al., 1998).

As soon as infants develop the ability to have and work towards a goal, they also develop the potential to be frustrated if that goal cannot be achieved (Stifter & Grant, 1993). They are also able to behaviorally display signs of frustration. The more important the goal or the more enjoyable the reward, the stronger the frustration reaction may be when an expectation goes unfulfilled (Stifter et al., 1993). When an infant is introduced to a reward and then that reward is taken away, he or she may exhibit signs of anger and negative emotion in response to the un-fulfillment of that positive expectation (Lewis, Hitchcock, & Sullivan, 2004). The emotional response activated by a frustrating event is thought to aid in an infant's development because it motivates the infant to conquer any obstacle which blocks a desired reward and signals the caretaker to take action to help the child (Stifter et al., 1993).

Frequently, from early childhood into adulthood, a frustrating event elicits emotional arousal from an individual that can result in a response characterized by anger, aggression or panic. This is a functional response to frustration designed to allow an individual to achieve their goal. Anger is behaviorally motivating and it generally accompanies physiological arousal (in the form of sympathetic nervous system activation), which helps the individual to engage in a behavioral response designed to overcome whatever is frustrating them.

The anger, aggression or panic resulting from emotional arousal is a natural response to frustration that will be dissuaded as an individual experiences active socialization. This angry or aggressive response experiences a developmental peak in preschool aged children. Past this developmental peak, it is likely that even when an individual is aroused by a frustrating event this type of response will not occur because the inclination toward acting out is inhibited. This inhibition is due to the development of adequate emotion regulation skills and/or the appropriate inhibitory control to avoid a behavioral display. This development occurs because individuals are influenced by multiple factors such as societal norms and/or their personal moral code (Berkowitz, 1989).

Researchers speculate that emotional arousal in response to a frustrating event may be more likely to occur when the frustrating event is repeated as well as when the goal or reward is of greater importance to the frustrated individual (Berkowitz, 1989). This emotional arousal can be a functionally useful response, such as when someone is attempting to remove a stubborn lid from a jar. However, emotional arousal can also be a problematic response, such as when a child's toy is stolen by another child and the first child then reacts aggressively

Frustration and Central Nervous System Responsivity

Thus far the behavioral responses to frustration have been highlighted in this paper, but of equal importance is the cascade of physiological responses that may transpire during children's frustration response to challenging events. The behavioral response to frustration is a function of the cortico-limbic system of the brain (Moadab et al., 2010). It is believed that the anterior cingulate cortex (ACC), a region found between the two hemispheres of the brain, is important in determining anxiety and self-control abilities. The ACC is found between the frontal lobe, which is responsible for executive functions, and the limbic system, which addresses motivational functions. The ACC is thought to be involved in the interaction between the processing of emotional stimuli and the cognitive control of attention.

The ACC is split into dorsal and ventral regions. The dorsal region of the ACC is involved in planning and impulse control (Moadab et al., 2010). It is generally activated when an individual is presented with a go or no go task, among other things, as go or no go tasks require inhibitory control. Insufficient mediation of emotional response by the dorsal ACC can lead to poor performance on these types of tasks.

The ventral region of the ACC is involved in the processing of emotional and motivational information, particularly for negative emotions (Moadab et al., 2010). It is also associated with impulse control. Decreased activation of the ventral ACC is associated with a decrease in anxiety while increased ventral ACC activation indicate that greater mental resources are being put towards processing challenging emotions. This leads to the potential development of internalizing behavior problems.

Frustration and Autonomic Nervous System Responsivity

During experiences of frustration, the autonomic nervous system (ANS), a division of the peripheral nervous system, may be activated by the cortico-limbic system of the brain (Moadab et al., 2010). The ANS is the division of the peripheral nervous system that functions involuntarily to either inhibit or excite various tissues and organs within the human body (Arthur & Hoyle, 2001). It is divided into the sympathetic, parasympathetic and enteric nervous systems. The ANS is necessary to maintain the body's resting state as well as to innervate or inhibit the appropriate systems to respond to a challenging or threatening stimulus.

Parasympathetic Nervous System. The parasympathetic nervous system (PNS) is the division of the autonomic nervous system that is responsible for maintaining the body's resting state. It innervates a variety of organs including the heart. The parasympathetic preganglionic fibers, which project onto the heart, originate in the neural cell bodies of the vagal nerve (Porges, 2001). Vagal nerve control of the heart is present at all times at a baseline level. This is referred to as the "vagal brake" as it slows heart rate. The vagus itself is controlled by the nucleus ambiguus. The parasympathetic preganglionic fibers travel to a ganglion in the area of the targeted cardiac tissue from which shorter postganglionic fibers project onto the heart. The neurotransmitter found in both the parasympathetic pre- and post-ganglionic synapses is acetylcholine. Parasympathetic stimulation of the heart, via the vagus-mediated method discussed above, has negative chronotropic (speed of contraction) and inotropic (strength of contraction) effects on cardiac muscle. It also decreases the conduction velocity of cardiac muscle fibers (Arthur & Hoyle, 2001).

Respiratory sinus arrhythmia (RSA) is a physiological marker used to measure parasympathetic nervous system activity, and specifically vagal tone to the heart (Beauchaine, 2001). It measures the relationship between heart rate and the respiratory cycle by measuring the distance between successive R peaks. The trends seen in the cardiac cycle over time are viewed with respect to the respiratory rhythm and overall patterns are identified. Vagal input to the heart is increased during exhalation, decelerating the heart rate, and decreased during inhalation, accelerating the heart rate (Berntson, Quigley, & Lozano, 2007). By indexing heart rate variability (HRV), the differences in the beat-to-beat length of the cardiac cycle over time, a measurement of parasympathetic activity is obtained which is largely free of sympathetic influences (Beauchaine, 2001).

High RSA at baseline shows strong parasympathetic activity, which generally corresponds with good emotion regulation capabilities. A decrease in RSA levels is anticipated as an individual moves from a baseline measurement to a frustrating task (Roosevelt, Montgomery & Porges, 2003). This decrease reflects the withdrawal of the vagal brake that occurs as an individual responds to a new challenge.

The parasympathetic nervous system plays an important part in mediating an individual's response to a frustrating stimulus. When a child encounters a challenging stimulus, they must first orient to the conditions indicated by the new stimulus. They may then attempt to engage with the frustrating stimulus to understand and adapt to it (Roosevelt, Montgomery & Porges, 2003). This engaging behavior requires that the child be calm. For example, a child who is playing a game which s/he is unable to succeed at will attempt to focus more on the game and engage more fully with it in hopes that this increased attention will lead to a greater possibility of winning. This response is mediated by the PNS because that system is responsible for maintaining the body's resting state and returning the body to a resting state following any sudden activation (Arthur & Hoyle, 2001). Parasympathetic activity is believed to promote social engagement and allows a child to exhibit the sustained attention necessary to fully evaluate and respond to a frustrating stimulus (Beauchaine, 2001). If a child has low parasympathetic activity levels under normal conditions, they will be less likely to effectively regulate emotions or focus sustained attention when presented with a challenging stimulus. This is because high parasympathetic activation shows a high level of control over heart rate and therefore a temperamental inclination to exhibit low reactivity in the face of a stimulus.

When a challenging stimulus occurs, the parasympathetic vagal brake may be withdrawn slightly to allow for the orienting and engaging behaviors necessary to deal with the stimulus. This slight withdrawal of parasympathetic stimulation is an appropriate tool to deal with a challenging stimulus. The activation created by withdrawal of the vagal brake is helpful because it is a type of activation that can be regulated relatively easily.

The ability to appropriately use and withdraw the vagal brake is indicative of an individual's ability to regulate their behavior and emotional arousal and thus act appropriately in social situations. An individual who can appropriately apply the "vagal brake" and regulate vagal input to the heart is able to make changes in heart rate that allow for appropriate levels of engagement and disengagement with the environment. Vagal tone to the heart is high under baseline conditions. When an individual experiences a challenging stimulus, the vagal brake is released slightly and vagal tone to the heart is lessened. This decrease in vagal tone allows for a slight activation that allows an individual to focus and concentrate on the stimulus which created the activation.

Sympathetic Nervous System. The sympathetic nervous system (SNS) is the division of the autonomic nervous system that is tasked with responding to challenging stimuli. The sympathetic nervous system acts on smooth and cardiac muscle as well as glandular tissue and is generally responsible for increased metabolic and activity rates in the tissue that it innervates (Arthur & Hoyle, 2001). Sympathetic pre-ganglionic nerve fibers originate in the thoracic and lumbar spinal nerves and then, in most cases, synapse with sympathetic ganglia which lie adjacent to the spine on either side from the neck to the sacrum. The sympathetic postganglionic fibers must then travel to whichever target tissue they are intended for, generally over relatively long distances as compared to the preganglionic fibers. Acetylcholine is the neurotransmitter most commonly used at the preganglionic synapse, and epinephrine is generally found at postganglionic synapse. One exception to this rule is sweat glands, which utilize acetylcholine at both synapses and are the only end organ solely innervated by the SNS.

Electrodermal activity (EDA) is one of the primary ways of assessing sympathetic nervous system activity. Eccrine sweat glands are controlled by the sympathetic nervous system and can be activated by both physical and emotional stimuli (Robertshaw, 1977). Their activity is increased in coordination with sympathetic activation. Eccrine sweat glands are under the control of the sympathetic nervous system alone; not under combined control by both the parasympathetic and sympathetic systems. This control originates in the cortical and basal ganglion areas of the brain and is activated as part of the sympathetic response to a challenging event (Dawson, Schell & Filion, 2007). The eccrine sweat glands found on the palms are thought to be mainly responsible for "gripping" behavior rather than temperature regulation. For this reason, they are more responsive to psychological stimuli.

EDA is measured by passing a small electric current between two separate electrodes placed on the palmar surface of the hand (Dawson, Schell & Filion, 2007). This measures the skin's ability to conduct an electric potential. The skin conductance potential changes depending on the amount of sweat on the skin and, therefore, changes in response to eccrine sweat gland activity. The sweat glands found on the palmar surface of the hand are under the control of the sympathetic nervous system and therefore EDA serves as an indicator of sympathetic nervous system activity. When sweat levels increase due to increased sympathetic innervation of the eccrine sweat glands, an increase in skin conductance is expected.

When a child is unable to deal with a frustrating stimulus through sustained attention and withdrawal of the vagal brake, they may activate the "fight or flight" response, which is mediated by the sympathetic nervous system. Sympathetic nervous system activity occurs in response to any unfamiliar or cognitively demanding stimulus (Kagan, Reznik & Snidman, 1987). It can also be seen in response to unfamiliar, stressful and challenging events. Frustrating events can be characterized as fitting all three of these categories and therefore will likely result in activation of the sympathetic nervous system.

Sympathetic nervous system activation can result from high emotional arousal and can be associated with a response characterized by anger, aggression or panic. This response allows an individual to direct their full and strongest efforts towards solving or avoiding the challenge at hand. This type of activation can be useful in some situations but can also be problematic because it is very difficult to regulate.

Sympathetic activation will be present in different levels based on an individual child's temperament. It has been found that low sympathetic activation in response to a frustrating or challenging event can be associated with conduct disorders as well as the temperamental qualities of low fear responses and poor inhibitory control (Fowles, Kochanska & Murray, 2000).

Parasympathetic and Sympathetic Coordination. Behavior is mediated by the interaction of the parasympathetic and sympathetic branches of the autonomic nervous system (Beauchaine, 2001). The parasympathetic system, specifically vagal tone and vagal reactivity, reflects regulatory functioning in the body. The sympathetic system, however, reflects an individual's motivational predispositions. Both the sympathetic and parasympathetic systems may influence an individual's behavioral tendencies and emotional inclinations. The systems work together, but are theoretically independent, so they can either cooperate or compete in influencing behavior.

When an individual is confronted by a challenging stimulus, the nucleus ambiguus of the vagus nerve, a part of the parasympathetic nervous system, will decrease input to the heart thereby increasing the frequency of cardiac contractions (Porges, 2001). In some cases, parasympathetic system response may be enough to allow an individual to cope with a challenging stimulus. However, if the challenge is demanding enough, the sympathetic nervous system will be activated, by the cortico-limbic system of the brain, and can work with the PNS to manage the challenge. Sympathetic activation triggers the "fight or flight" response, which results in an even greater increase in the strength and frequency of cardiac contractions along with a variety of other effects. These effects are designed to allow large amounts of blood and oxygen to reach brain and muscle tissue where they are needed in order to fuel acting out behaviors.

A great deal more research is needed in the area of correlation between the two branches of the autonomic nervous system as inconsistencies have been found between previous studies. This paper will take a multi-system approach to studying the physiological response to frustration. The branches of the autonomic nervous system are integrated within the body, so it is necessary to study the ANS as an integrated system to get an accurate understanding of the body's response to a frustrating stimulus.

Loose Coupling of Behavior and Physiological Reactivity Associated with Frustration

After discussing both the behavioral and physiological responses associated with frustration, the next logical step is to ask how behavior and physiology interact with one another. Due to the fact that the sympathetic and parasympathetic branches of the autonomic nervous system are responsible for mediating multiple stages of physiological and behavioral responses, it is reasonable to assume that changes in physiology and behavior would mirror each other (Quas, Hong, Alkon & Boyce, 2000). The link between the physiological reaction to a challenging stimulus and the behavioral reaction is strongest in infancy and decreases as an individual enters childhood and then toddlerhood (Stifter et al., 1993). This is likely because the transition into childhood includes development of the skills necessary to control obvious behavioral displays in response to an external stressor, such as frustration.

Prior Aggression and Physiological and Behavioral Responsivity

Children who exhibit indicators of aggression in their school and home lives may respond differently when presented with a stimulus designed to induce frustration. Behaviorally, these high-risk individuals are more likely to show an outward reaction to the stimulus that is not mediated by arousal regulation or inhibitory control. Their tendency towards aggressive behaviors indicates that these individuals are potentially lacking in these regulatory abilities.

These high-risk individuals may also experience differences in physiological reactivity when compared with low risk individuals who are not identified as particularly aggressive. The ANS response to frustration may differ from the expected synchronous of RSA suppression in coordination with EDA activation. An asynchronous response to frustration (RSA suppression with low corresponding EDA activation) can be associated with qualities such as low fear responses and poor inhibitory control (Fowles, Kochanska & Murray, 2000).

Present Study

Hypothesis 1a. The parasympathetic and sympathetic nervous systems work concurrently to appropriately evaluate and respond to challenging situations (Beauchaine, 2001). These systems are theoretically independent of one another and therefore can either cooperate or compete in determining an individual's responses and behaviors. *A synchronous response, characterized by an increase in sympathetic activation and a suppression of parasympathetic influence, is expected in response to the frustration task.*

Hypothesis 1b. Children in this study have been divided into high risk and low risk groups based on their prior levels of aggressive behavior. *Significant differences in SNS and PNS synchrony will be seen between high and low risk groups.*

Hypothesis 2. Although an asynchronous response is possible, synchronous response by the ANS is expected in response to a frustrating stimulus. Coordination between the branches of the autonomic nervous system allows for a child to react appropriately when confronted with a frustrating stimulus. *Children who exhibit sympathetic reactivity in coordination with parasympathetic withdrawal will exhibit better arousal regulation and behavioral inhibition skills.*

Method

This study utilizes data from a high-risk group of kindergarten students participating in the PATHS to Success Project.

Participants. There were 1400 students who entered kindergarten in the Harrisburg, PA area during the Fall of 2008 and Fall of 2009. This study will utilize data from only the students who entered school in the fall of 2009. The highest 20% of these students identified by the aggression screening questionnaire were recruited to participate in this study. Fifty-six children who did not exhibit aggressive behaviors were also recruited into the comparison (low-risk) group. The high-risk (aggressive) children were randomly assigned to an intervention or non-intervention conditions, however, the current study is restricted to data collected at the pre-intervention assessment for all children.

Procedures

Screening and Recruitment. Teachers in the Harrisburg School District were asked to fill out the Teacher Observation of Child Adaptation- Revised (TOCA-R) survey, which was used to identify which children had the highest rates of aggressive behavior. Teachers rated a variety of behaviors (including harming others, fighting and yelling at others) on a six-point frequency scale (*almost never*=1 to *almost always*= 6).

Parents completed consent forms providing permission for an annual assessment of the children. Later, youth provided verbal assent for individual assessments. Each of the consent forms described the general purpose of the study and indicated that participants can refuse to participate or withdraw at any time without ramification. In all cases, a research assistant answered any questions about the consent letter and study to give participants a clear and accurate understanding of the project. The signed consent forms are retained in the files of the Research Office. These consent procedures were approved by the Penn State IRB.

Neurobiological Assessments. Assessments were done in an RV that was fitted with physiological equipment and driven to the various schools where the tests were conducted. The autonomic data was collected and analyzed using Mindware software. To collect skin conductance level (SCL) data, electrodes were placed on the thenar and hypothenar eminences of the child's non-dominant hand. Seven cardiac electrodes were also placed on the child's torso to collect electrocardiograph (ECG) and cardiac impedance data. As part of the assessment, children were asked to sit still and quietly and watch a computer screen of moving stars while baseline data measurements were recorded.

Inhibition Control Task. In this task, children participated in a Go/No-go task that would require motivated responding. In this task, children were shown cartoon "critters" and told to respond by pressing a button. During Go trials, which comprised 80% of the total trials, the critters were presented and children were supposed to press the button. The other 20% of trials (the no-go trials) consisted of the children being told not to press the button for critters that had just appeared in the previous trial. The task was simple but also interesting enough that it was possible for most children to complete it. Children were given an opportunity to practice and then told that their responses would be scored and, if they did well, they would win a prize bag of toys. When children responded correctly (by pressing quickly on the go trials and not pressing on the no-go trials), they did not receive any error feedback. When they responded incorrectly (not pressing quickly enough during a go trail or pressing during a no-go trial), error feedback in the form of a large red square appeared on the screen.

The child's performance on the practice trial dictated how quickly the critters were presented in subsequent trials. A speed was chosen which would allow a child to be successful on 40 to 60% of trials. This was to allow an approximately equal number of successful inhibitions and errors. Speed increased when children exhibited better than average inhibitory control and decreased when children exhibiter poorer than average inhibitory control.

There were three blocks in the task, each lasting approximately three minutes. Feedback on their success was given approximately every five trials. Feedback was presented visually rather than numerically due to the age of the participants. Two types of feedback were used. The first was a face which was smiling when the child got more points than the previous incidence of feedback and frowning when the child got less points compared to the previous feedback incidence. The overall point value was displayed as a thermometer graphic including a bar that raised and lowered in accordance with points gained or lost. The first block was ensured to be rewarding to every child by using an algorithm that excessively rewarded correct trials.

The second block, or frustration block, utilized an algorithm that excessively punished children's incorrect responses. By using these algorithms, it was ensured that rewards changed regardless of how children performed. The third and final block reverted to the original algorithm ensuring that all children ended with a successful performance and achieved the prize. After every block, a 30 second baseline period was conducted to give children time to rest and to provide new baseline physiological data. The entire task lasted approximately 11 minutes. The baseline values minus the average physiological data collected across the first block of the inhibition control task were used to assess SNS and PNS reactivity.

This paper utilizes data collected during the baselines and second block of the task only. The second block is the frustration block and therefore will provide information about children's SNS and PNS reactivity in response to a frustrating stimulus.

Physiological Assessments

Electrodermal Activity. Electrodermal activity (EDA) data was collected using Biolab acquisition software throughout the baseline period as well as when the children were participating in the inhibition control task. Mindware's EDA 3.0 program measured the electrodermal activity with the gain set at 10 μS/ Volt, 16-bit A/D resolution and a sampling frequency of 500 Hz. The low pass filter was set at 10 Hz and the high pass filter was set at .05 Hz. The tonic skin conductance levels, or time in which the wave changes were less than .05 μS, were recorded along with the galvanic skin responses, or number of changes in wave amplitude .05 μS or higher. Trained research assistants edited the data to identify movement artifacts and any misidentified responses. The average of tonic skin conductance and the total number of galvanic skin responses are calculated for baselines as well as for the three blocks of the inhibitory control task.

Respiratory Sinus Arrhythmia. Electrocardiograph (ECG data) was collected throughout the baselines and inhibition control task using the Biolab acquisition system. Three active leads were placed on the child's chest (distal right clavicle, inferior left rib and inferior right rib) to collect ECG data. The ECG signals were passed through a microcomputer with a 16 bit A/D converter and the ECG was collected at 500 Hz. Artificial heart periods were interpolated in order to maintain the time series and the date was edited by trained research assistants to remove movement artifact.

The R-wave time series data taken from the electrocardiogram was decomposed into heart rate variability (HRV) frequencies using a fast-Fourier transformation to evaluate respiratory sinus arrhythmia (RSA). The components are then expressed as the amount of spectral power within a given frequency band (spectral density function). Spectral power is then divided into high frequency variability (greater than .15 Hz) and low-to-mid frequency variability (greater than or equal to .15 Hz). Mean RSA across the baseline periods indexes the baseline RSA. The change score in RSA between baseline and the inhibition control task is the RSA suppression. The RSA average was calculated for the 3 blocks of the inhibition control task as well as the baseline periods.

Child Behavioral Outcomes

Trained research assistants conducted the above procedures and carefully observed the children throughout the baseline periods as well as the 3 blocks of the inhibition control task. At the end of the child's time in the RV, the research assistants filled out a questionnaire known as the "Kindergarten Child Assessment Interviewer Checklist." This questionnaire contained 13 questions gauging the child's behavior throughout entire the assessment period. Each question was followed by 4 multiple-choice responses from which the research assistant was able to choose.

Items in this questionnaire assessed things such as the child's attention and concentration, carefulness, patience, cooperation and defiance. An example item, question 5, stated, "Can wait during and between tasks." The options given from the interviewer to choose from were as follows: "1- Child is impulsive throughout assessment, needing lots of boundary setting; transitions between tasks made difficult because of child's activity level/impulsivity, 2- Child is often impulsive across multiple tasks or highly impulsive during one activity; child needs multiple prompts to wait while assessor gathers materials for new task, 3- A few instances of impulsive behavior; child sometimes shows anticipation for interesting task materials but rarely needs reminder and 4- Child waits before pointing to materials, reaching for blocks, etc., and waits patiently for new tasks to begin; no ambiguous or impulsive behaviors." All 13 items followed this general format. The answers given by the assessors served as indicators of the child's outwardly displayed behavior throughout the assessment period- both at baseline and during the inhibition control task. The item given as an example above, question 5, was used as a measure of inhibitory control throughout the analyses.

Behavioral data was also taken from "The Strengths and Difficulties Questionnaire" (Goodman, 1997). This questionnaire was filled out by the child's teacher in regards to their overall behavior in school settings. Twenty items were included on the survey such as "Often, unhappy, depressed or tearful" and "Many fears, easily scared". Teachers were asked to rate each of these statements as "not true", "somewhat true" or "certainly true". Five of these measures were averaged together in order to create a composite score of the child's overall emotional symptoms. This score was used throughout our analyses as a measure of internalizing behaviors.

Results

Demographics

Table 1. Demographic Statistics

Total Number of Participants= 182				
Race/Gender	**African American**	**Caucasian**	**Male**	**Female**
Number of High Risk Participants	108	10	79	39
Number of Low Risk Participants	56	8	61	3

Table 1 shows the number of males and females in the high-risk group and low risk group. It also shows how many members of the high risk and low risk groups are of African American ethnicity and how many are of Caucasian ethnicity.

Preliminary Analyses

Preliminary analyses were conducted to examine whether there were any significant correlations between the sex and race of respondents and the scores on any of the physiological or behavioral measures. There were significant differences between African American and Caucasian ethnicity groups on the physiological measure of skin conductance responses during the frustration task ($F = 3.85$, $p < .05$). Racial differences were not identified on any other physiological or behavioral measures. Subsequent analyses using these variables co-varied for sex, ethnic differences and low risk or high-risk group assignment.

Table 2. Means and Standard Deviations

	High Risk Group (N= 97) *Mean (Standard Deviation)*	**Low Risk Group (N= 55)** *Mean (Standard Deviation)*
RSA Baseline	6.64 (1.12)	6.64 (1.16)
EDA Baseline	18.29 (5.60)	18.72 (7.66)
RSA Reactivity*	6.03 (1.08)	6.06 (1.09)
EDA Reactivity*	0.32 (2.00)	0.56 (1.72)

* Reactivity (average over frustration task - baseline)

Table 2 shows the means and standard deviations for variables that will be used in the following analyses. Out of the total number of participants recruited, this data was able to be collected from 97 high-risk participants and 55 low risk participants.

Hypothesis 1a. A synchronous ANS response, characterized by an increase in sympathetic activation and a suppression of parasympathetic influence, is expected in response to the frustration task.

A partial correlation, which controlled for sex, ethnicity and baseline values, was done to assess the relationship between EDA and RSA levels at baseline. No significant correlation was found.

Another partial correlation, which also controlled for sex, ethnicity and baseline values, was done to assess the relationship between EDA and RSA reactivity (change from the baseline levels to levels during the frustration block). For the overall sample, there was a trend towards a positive significant correlation ($r = .17$, $p < .10$), which indicates RSA suppression in correlation with EDA activation.

Hypothesis 1b. Significant differences in SNS and PNS synchrony will be seen between high and low risk groups.

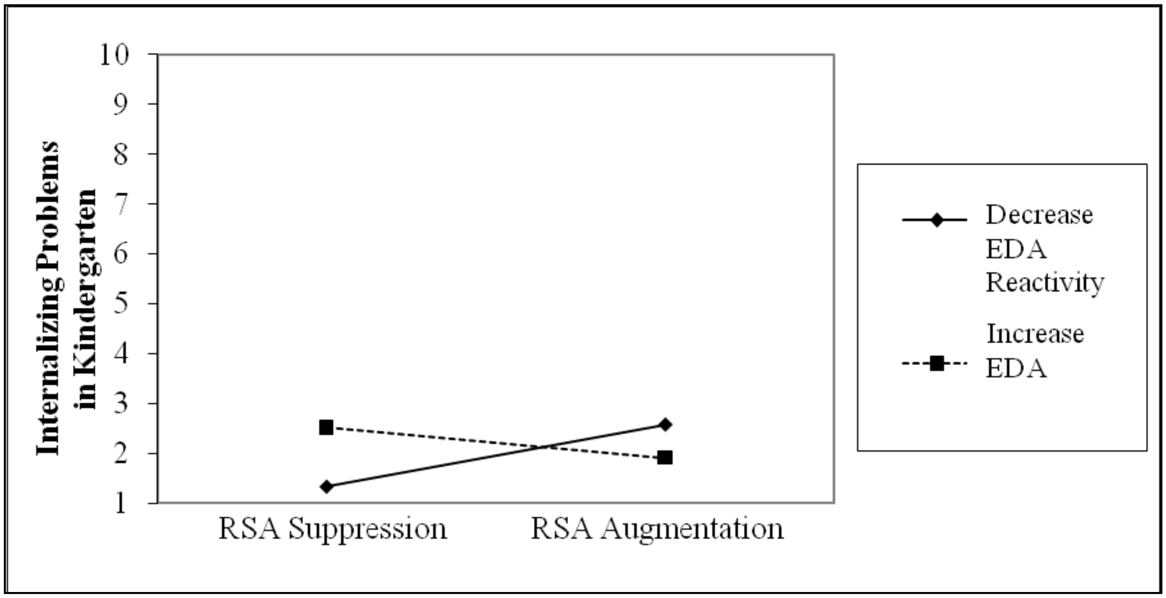
The sample was split into high and low risk groups and another partial correlation, which controlled for sex, ethnicity and baseline values, was done to assess the relationship between EDA and RSA levels at baseline. No significant correlation was found.

The sample remained split and another partial correlation, which also controlled for sex, ethnicity and baseline values, was done to assess the relationship between EDA and RSA reactivity. For the high-risk group, no significant correlation was found between RSA and EDA reactivity (r = .07, p = n.s.). In contrast, a significant positive correlation was found for the low risk group (r = .32, p < .05). This correlation was more significant than that of the group as a whole.

Hypothesis 2. Children who exhibit sympathetic reactivity in coordination with parasympathetic withdrawal will exhibit better arousal regulation and behavioral inhibition skills.

All analyses controlled for gender and race. An ANOVA was run to test how EDA and RDA reactivity influence internalizing behaviors. The interaction between EDA and RSA reactivity were the predictors and internalizing behaviors was set as the dependent variable. Overall F(5,92) ANOVA had a significant fit. The interaction between EDA and RSA reactivity had a significant effect on internalizing problems (F(5,92) = 2.93, p < .05). Children who scored higher on the emotional symptoms questionnaires (indicating strong emotional symptoms) showed disconnect in the interaction between RSA and tonic period reactivity. These individuals showed high RSA suppression with low corresponding EDA activity. Interestingly, the interaction between EDA and RSA reactivity was associated with inhibitory control behaviors, β = -0.08, t(96) = 2.31, p < .05, accounting for 13.7% of the variance. As recommended by Aiken and West (1991), the interaction was plotted (see Fig. 1).

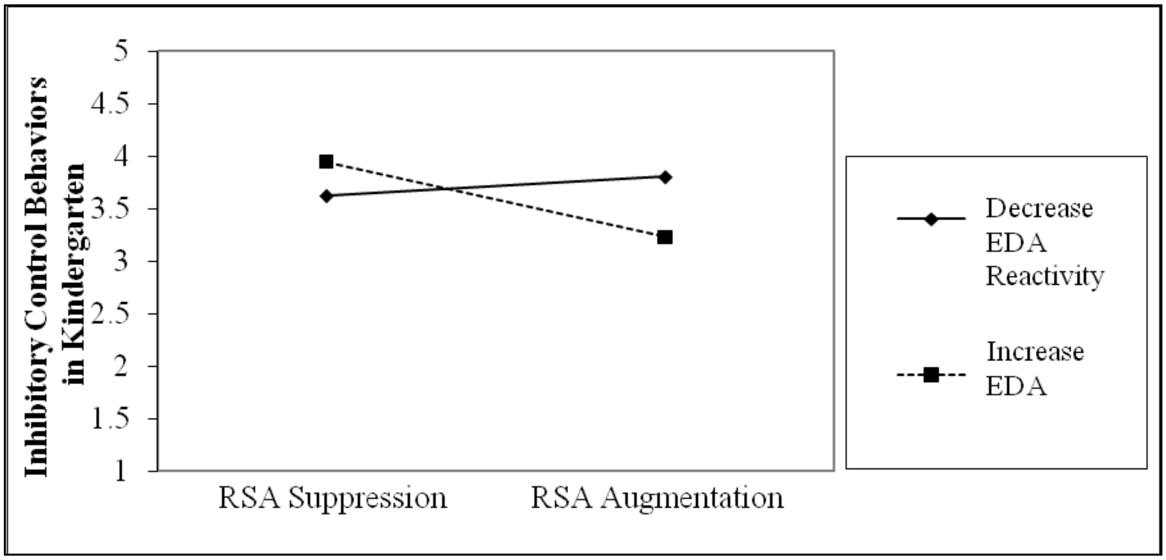
Figure 1. Effect of the Interaction between EDA and RSA Reactivity on Internalizing Problems



If the child experienced an increase in EDA reactivity during the frustration task, higher RSA suppression was correlated with greater internalizing behaviors (INTERNALIZING PROBLEMS - Increase in EDA reactivity (β = -.32, t(96) = 2.66, R^2 = .07, p < .05). Conversely, if the child experienced a decrease in EDA reactivity during the frustration task, greater RSA augmentation was associated with greater internalizing behaviors (INTERNALIZING PROBLEMS - Decrease in EDA reactivity (β = .30, t(54) = 2.75, R^2 = .10, p < .05).

Children were split into high and low risk groups and another ANOVA was run to test how EDA and RSA reactivity influence inhibitory control. The interaction between EDA and RSA reactivity were the predictors and inhibitory control was set as the dependent variable. The interaction between tonic period and RSA reactivity had a significant effect on inhibitory control for only the high risk group ($F(5,95) = 2.85$, $p < .05$). Children in the high-risk group who showed less inhibitory control showed disconnect between EDA and RSA reactivity. These children showed high RSA reactivity with a low corresponding EDA. Interestingly, the interaction between EDA and RSA reactivity was associated with inhibitory control behaviors, $\beta = -0.03$, $t(96) = 2.26$, $p < .05$, accounting for 24.6% of the variance. As recommended by Aiken and West (1991), the interaction was plotted (see Fig. 2).

Figure 2. Effect of the Interaction between EDA and RSA Reactivity on Inhibitory Control



If the child experienced an increase in EDA reactivity during the frustration task, higher RSA suppression was correlated with higher inhibitory control skills (INHIBITORY SYMPTOMS - Increase in EDA reactivity ($\beta = -.34$, $t(96) = 2.87$, $R^2 = .12$, $p < .05$).Conversely, if the child experienced a decrease in EDA reactivity during the frustration task, greater RSA augmentation was associated with poorer inhibitory control skills (INHIBITORY SYMPTOMS - Decrease in EDA reactivity ($\beta = .23$, $t(54) = 2.01$, $R^2 = .08$, $p < .05$).

Discussion

This study found differences between high and low risk individuals in terms of reactivity to a frustrating stimulus, but did not find any significant differences between baseline levels. The low risk group showed a positive correlation between the parasympathetic and sympathetic system responses to a frustrating stimulus. As parasympathetic RSA suppression increased, sympathetic activity increased as well. This is indicative of synchronous ANS activity. Children in the high-risk group, however, showed no synchronicity between the PNS and SNS responses. This means that the low risk group, but not the high-risk group, showed synchrony in their autonomic nervous system responses to a frustrating stimulus. Synchronous autonomic response to a frustrating stimulus is characterized by withdrawal of the parasympathetic vagal brake in concert with increased sympathetic activity. This is the expected response to a challenging stimulus. It makes sense that the low risk group would respond this way and the high-risk group would not as the high-risk group has been identified as such because of their high rates of aggressive behavior. An asynchronous autonomic response to a stimulus indicates that an individual is responding atypically and that could lead to atypical or problematic behavior, such as aggression, internalizing problems or poor inhibitory control.

This study also found that synchronous ANS response to a frustrating stimulus was associated with better inhibitory control in high-risk individuals. Even if an individual had been previously identified as aggressive, synchronous response to the frustrating task was associated with better inhibitory control throughout the task. Children who showed increase in sympathetic activity along with suppression of the parasympathetic system were able to exhibit better inhibitory control than those who experienced sympathetic activation with no coordinated parasympathetic suppression. This demonstrates that the expected, synchronous ANS response to a frustrating stimulus can facilitate inhibitory control even in children who have been previously identified as aggressive. This inhibitory control may help these children avoid impulsive behavioral displays of their frustration.

Synchronous ANS response to a frustrating stimulus was also found to be associated with a greater incidence of internalizing problems in the overall sample of children. This indicates that although synchronous response by the SNS and PNS leads to better inhibitory control, it may also be somehow related to the experience of various internalizing problems. These internalizing problems are not necessarily experienced at the time of the frustrating task, but are noted in the child's overall behavior in school.

This study clearly indicated that behavioral outcomes are best predicted by the interaction between the PNS and SNS, rather than by measuring the activity of either system alone. The interaction between parasympathetic and sympathetic activity was predictive of both inhibitory control and internalizing behaviors. The PNS and SNS alone, however, had no significant correlation with any of the behavioral measures used in this study. This finding clearly indicates that both the PNS and SNS should be measured when doing research that compares behavioral findings with ANS activation.

This study did have some limitations that must be noted in considering these analyses. This study had a relatively small sample size. The sample was also not evenly divided between the high and low risk groups as there were significantly more high-risk participants as compared to low risk participants. There was also imbalance in terms of both race and gender. There were many more males than females and most individuals fell into the African American, rather than Caucasian, ethnic category.

There is also some missing data due to the nature of the study. Data collection for this study is dependent on children's participation as well as some degree of cooperation from the children in remaining still and not interfering with the application and continued presence of the physiological monitoring equipment. There is also some RA error and equipment malfunction, both of which lead to missing data.

Lastly, the questions asked of the individuals administering the tests, as well as the children's teachers, were not designed to be used in this particular paper. There were not a large number of questions that directly addressed the topic of frustration and children's behavioral responses to it. This limited the number of measures of children's outward behavior that were available for use in this paper.

This study is still worthwhile, however, as it utilized measures of both PNS and SNS reactivity, which allowed for the clear demonstration that examining the interaction between these measures is more useful that simply looking at either measure independently as an indicator of behavioral outcomes. Additionally, the questions that were asked did allow for the analysis of how inhibition control and internalizing behaviors were related to autonomic reactivity in response to a frustrating task. Significant correlations were found for both of these behavioral outcomes with the data that was available. Due to the split between high and low risk participants, the differences in reactivity between these two groups were also studied and significant differences were found in this area as well.

There are a number of future research avenues to explore based on the findings from this study. It would be worthwhile to replicate the same study with a larger sample size to see if the results are replicated with more individuals or if any other significant correlations are found. It would also be worthwhile to repeat the study with more questions that directly address the research aims of this paper. Both the children's teachers and the research assistants administering the tests could be asked a larger variety of questions which addressed their observable level of frustration during the frustration task and their behavioral outcomes both during the frustration task and throughout their typical school routine.

It would be valuable to repeat this study using a different stimulus to induce frustration rather than the go/ no go task used in this study design to see if similar results are achieved when frustration is induced by a variety of different stimuli. It would also be valuable to have a variety of age groups perform a frustrating task and to see if there are differences in reactivity and behavioral outcomes between age groups.

References

Abler, B., Walter, H., & Erk, S. (2005). Neural correlates of frustration. *NeuroReport*, *16*(7).

Amsel, A. (1992). Frustration theory- many years later. *Psychological Bulletin*, *112*(3).

Beauchaine, T. (2001). Vagal tone, development, and gray's motivational theory: toward an integrated model of autonomic nervous system functioning in psychopathology. *Development and Psychopathology*, *13*.

Berkowitz, L. (1989). Frustration-aggression hypothesis: examination and reformulation. *Psychological Bulletin*, *106*(1).

Berntson, G.G., Quigley, K.S., & Lozano, D. (2007). *Cardiovascular Psychophysiology.* In J.T. Cacioppo, L.G. Tassinary, & G.G. Berntson, (Eds.). *Handbook of Psychophysiology* (3rd edition; pp. 182-210). Cambridge, UK: Cambridge University.

Butler, E.A., Wilhelm, F.H., & Gross, J.J. (2006). Respiratory sinus arrhythmia, emotion, and emotion regulation during social interaction. *Psychophysiology*, *43*.

Calkins, S.D., Dedmon, S., Gill, K., Lomax, L. & Johnson, L. (2002). Frustration in infancy: Implications for emotion regulation, physiological processes, and temperament. *Infancy,3*, 175-198.

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).

Calkins, S.D., & Johnson, M.C. (1998). Toddler regulation of distress to frustrating events: temperamental and maternal correlates. *Infant Behavior and Development*, *21*(3).

Crossman, A.M., Sullivan, M.W., Hitchcock, D.F., & Lewis, M. (2009). When frustration is repeated: behavior and emotion responses during extinction over time. *Emotion*, *9*(1).

Dawson, M.E., Schell, A.M., & Filion, D.L. (2007). The electrodermal system. In J.T. Cacioppo, L.G. Tassinary, & G.G. Berntson (Eds.). *Handbook of Psychophysiology* (3rd edition; pp. 159-181). Cambridge, UK: Cambridge University Press.

Doussard-Roosevelt, J.A., Montgomery, L.A., & Porges, S.W. (2003). Short-term stability of physiological measures in kindergarten children: respiratory sinus arrhythmia, heart period, and cortisol. *Developmental Psychobiology*, *43*.

Fowles, D.C., Kochanska, G., & Murray, K. (2000). Electrodermal activity and temperament in preschool children. *Psychophysiology*, *37*.

Frazier, T.W., Strauss, M.E., & Steinhauer, S.R. (2004). Respiratory sinus arrhythmia as an index of emotional response in young adults. *Psychophysiology*, *41*.

Goodman, R. (1997). The Strengths and Difficulties Questionnaire: A Research Note. *Journal of Child Psychology and Psychiatry, 38,* 581-586.

Lewis, M., Hitchcock, D.F.A., & Sullivan, M.W. (2004). Physiological and emotional reactivity to learning and frustration. *Infancy*, *6*(1).

Marshall, P.J., & Stevenson-Hinde, J. (1998). Behavioral inhibition, heart period, and respiratory sinus arrhythmia in young children. *Developmental Psychobiology*, *33*.

Moadab, I. , Gilbert, T. , Dishion, T.J., & Tucker, D.M. (2010). Frontolimbic activity in a frustrating task: covariation between patterns of coping and individual differences in externalizing and internalizing symptoms. *Development and Psychopathology*, *22*.

Porges, S.W. (2007). A phylogenetic journey through the vague and ambiguous xth cranial nerve: a commentary on contemporary heart rate variability research. *Biological Psychology*, *74*.

Quas, J.A., Hong, M., Alkon, A., & Boyce, W.T. (2000). Dissociations between psychobiologic reactivity and emotional expression in children. *Developmental Psychobiology*, *37*.

Robertshaw, D. (1977). Neuroendocrine control of sweat glands. *Journal of Investigative Dermatology*, *69*.

Stifter, C.A., & Grant, W. (1993). Infant responses to frustration: individual differences in the expression of negative affect. *Journal of Nonverbal Behavior*, *17*(3).

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Education:

Bachelor of Science Degree in Biology, Penn State University, Spring 2011
Minor in Kinesiology
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Thesis Title: Correlation Between Behavior and Autonomic Nervous System Activation in Children Exposed to a Frustrating Stimulus
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Related Experience:

EMT- B, University Ambulance Service ***Volunteer: January 2009- December 2009***
Crew Member: January 2010- May 2010
Training Officer: May 2010- May 2011

- Performed patient care when responding to 911 calls
- Over 1000 hours of service recorded

Undergraduate Research Assistant, Child Brain Development Lab September 2009- Current

- Worked as a research assistant for a laboratory in the department of Human Development and Family Studies at Penn State University

Teaching Assistant, Kinesiology 403:Emergency Medical Technician January 2010-Current

- Taught EMT students in lecture as well as lab settings

CPR and First Aid Instructor, American Heart Association October 2009- Current

- Volunteer position teaching AHA CPR and First Aid to groups at Penn State's University Park campus

Nurse's Aide, The Pottsville Hospital and Warne Clinic May 2008- September 2008

- Worked within team of doctors and nurses to provide highest level of patient care in various hospital departments

Activities and Awards at Penn State University:

Treasurer of the Emergency Medical Services Association
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