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# Assessing Children's Autonomic Nervous System Activity During Structured Tasks: A Feasibility and Reliability Study in Ghana

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## ABSTRACT

The significance of physiological regulation in relation to behavioral and emotional regulation is well documented, but primarily in economically advantaged contexts. Few studies have been conducted in low- and middle-income countries. We investigated the feasibility and reliability of measuring autonomic nervous system (ANS) activity and behavior during challenge tasks in 30 children aged 8–10 years in Ghana during two visits, 1 week apart. Completeness of ANS data ranged from 80% to 100% across all tasks. There was low-to-moderate test–retest reliability of video mood induction (VMI) emotion ratings and balloon analog risk task (BART) pumps ($r = 0.34$–$0.52$). VMI elicited higher targeted emotion ratings in Visit 2 than Visit 1. Respiratory sinus arrhythmia (RSA) was higher, and pre-ejection period (PEP) was longer at Visit 2 than Visit 1 for baseline and both tasks. RSA was higher at baseline than during the VMI anger scene at Visit 1, whereas PEP was shorter at baseline than during all VMI emotion scenes at Visit 2. RSA was higher at baseline than during BART at both visits. In conclusion, ANS data collection within evocative and arousing challenge tasks was feasible in Ghana, and the tasks were generally reliable and effective in eliciting target emotions and risk-taking behavior in this sample.

## 1 | Introduction

The functioning of the body's internal regulatory system, the autonomic nervous system (ANS), in children, youths, and adults has been extensively studied in high-income countries, particularly in North America and Western Europe (Licht et al. 2010; Nederhof et al. 2015; Perlstein et al. 2021; Zhao, Guan, and Wang 2020). However, there is a paucity of research on ANS

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functioning in children and youths in Africa. Notably, even basic information, such as whether ANS functioning during common emotional or stress tasks can be feasibly and reliably assessed in pediatric populations in Africa, is currently unknown. This lack of research and data is a concerning issue given that ANS dysfunction has been linked to various health problems, such as cardiovascular disease (Baig et al. 2022; Dekker et al. 2000; Zhao, Guan, and Wang 2020), metabolic syndrome (Licht et al. 2010), chronic obstructive pulmonary disease (Alqahtani et al. 2023), and mental health disorders (Blood et al. 2017; Siciliano, Anderson, and Compas 2022).

Middle-to-late childhood (8–10 years) is an important time to examine ANS functioning as it is a critical period for the development of social, emotional, and cognitive abilities that are essential for preparing children for adolescence and adulthood (Brown and Jernigan 2012) and are supported by ANS functioning (Hastings and Kahle 2019; Quigley and Moore 2018). Yet, it is largely unknown whether patterns of biobehavioral regulation associated with well-being for children in higher income countries are similarly evident in low- and middle-income countries (LMICs) (Hastings, Guyer, and Parra 2022). Additionally, sub-Saharan Africa has the highest prevalence of children at risk of not reaching their developmental potential, including academic, behavioral, and socio-emotional competencies, due to physiologically impactful stressors such as undernutrition (Black et al. 2017). This highlights the need for further research on normative ANS functioning in African youths to inform interventions that could improve health outcomes. Therefore, this feasibility and reliability study was conducted to determine whether ANS activity and behavioral responses to commonly used emotional and risk-taking tasks could be assessed in children living in Ghana, Africa.

The ANS regulates the body's internal environment, including heart rate, breathing, digestion, and other involuntary functions. The ANS is composed of two main branches: the sympathetic nervous system (SNS) and the parasympathetic nervous system (PNS) (Quigley and Moore 2018). The SNS is essential for "fight or flight" responding, activating the body's stress responses by releasing norepinephrine (and in eccrine glands, acetylcholine) that prepares the body for active defensive behaviors by metabolizing resources and releasing energy reserves to increase heart rate, blood pressure, perspiration, and respiration while inhibiting digestive functions (Hamill et al. 2012). The PNS is primarily responsible for regulating the body's rest and recovery responses, with increased PNS activity slowing heart rate, decreasing blood pressure, and promoting digestion and relaxation. This antagonistic or homeostatic framing of the two branches of the ANS is overly simplistic, though, and the SNS and PNS coregulate somatic processes in multiple ways (Berntson and Cacioppo 2007).

Respiratory sinus arrhythmia (RSA) and pre-ejection period (PEP) are two measures that are commonly used to assess ANS activity. RSA, or the variability in heart rate that occurs in correspondence with breathing, is a measure of high-frequency heart rate variability (HF-HRV) that reflects the activity of the PNS (Hastings and Kahle 2019). Higher levels of RSA indicate greater PNS activity, which is associated with increased relaxation and better stress regulation. Consequently, greater baseline PNS activity is associated with emotion regulation capacities (Beauchaine 2015). In response to many stress and challenge tasks, the PNS decreases its influence on cardiac activity, lowering RSA compared to baseline, although the magnitude of RSA withdrawal varies across tasks and emotional conditions (Hastings and Kahle 2019). PEP is a measure of the time between the depolarization of the heart's left ventricle and the opening of the aortic valve, when the ventricle's contraction ejects blood into the left atrium; it reflects the activity of the SNS (Hastings and Kahle 2019). Shorter PEP values indicate greater SNS activity, which is associated with increased arousal and activation of stress and coping responses, such that PEP typically shortens (SNS activation) during laboratory challenge tasks, relative to baseline (Hastings and Kahle 2019).

RSA and PEP have been examined in mid-to-late childhood in high-income countries. For example, Hinnant, Elmore-Staton, and El-Sheikh (2011) examined the developmental trajectories of baseline RSA and PEP in middle childhood, with data collected three times, at 8–10 years, from 251 children in the United States. Baseline RSA did not change over time, whereas PEP lengthened, but their development varied by gender and ethnicity. Boys and African American children had longer PEP at age 8 years than did girls and European American children, respectively. African American children had higher initial RSA, whereas RSA increased over time for European American children, such that the groups had comparable RSA by age 10 years. To our knowledge, there remain no studies investigating ANS function in children within sub-Saharan African countries and very few studies in other LMICs (i.e., Brazil, see de Souza Filho et al. 2019; Mauritius, see Raine et al. 1997 and Scarpa et al. 1997; India, Singh et al. 2022). This gap underscores the need for studies that delve into ANS regulation and potential dysfunctions, specific to these regions.

Challenge tasks are often used to assess dynamic aspects of ANS functioning by exposing participants to stimuli that activate the ANS (Hastings and Kahle 2019). During these tasks, measures such as RSA and PEP reactivity are used to assess how the ANS responds to stressful, emotional, and other stimuli. Two such challenge tasks that have been widely used in the developmental psychobiology literature are the balloon analog risk task (BART) and the video mood induction (VMI) task.

The BART measures risk-taking behavior by having participants pump a series of simulated balloons to earn points, balancing the potential gain of accruing more points against the potential risk of losing all points accrued for that balloon if it bursts (Lejuez et al. 2007). A higher adjusted number of pumps on unexploded balloons indicate a greater risk-taking propensity. The adjusted average number of pumps reported in previous studies among youths, primarily conducted in high-income countries such as the United States and the Netherlands, has varied widely (between 10 and 52), with each balloon programmed to explode at random after 1–128 pumps (Aklin et al. 2005; Collado et al. 2015; Dekkers et al. 2020; Dougherty, Lake, and Mathias 2015; Lejuez et al. 2007; Loheide-Niesmann et al. 2021; MacPherson et al. 2010; Tieskens et al. 2018). BART has been assessed for reliability, including internal and test–retest reliability, with moderate-to-high correlations

(Collado et al. 2015; Lejuez et al. 2007; White, Lejuez, and de Wit 2008), but not in ages below 14 years, and no prior studies have evaluated BART in sub-Saharan African countries. Few studies have reported on the relations between BART risk-taking behavior and ANS measures in youths. In a large community sample of European adolescents aged 11–12 years, Loheide-Niesmann et al. (2021) found that higher resting RSA was associated with higher risk-taking behavior. In a study of European boys aged 12–19 years with and without attention deficit hyperactivity disorder - ADHD (Dekkers et al. 2020), the BART elicited lower RSA and shorter PEP compared to baseline, indicative of reciprocal SNS activation. Youths completed the BART with and without the presence of a peer; stronger SNS reactivity to the peer than solo condition was positively associated with greater risk-taking during the peer condition, relative to the solo condition (Dekkers et al. 2020).

The VMI task involves showing participants a series of video clips that are designed to elicit specific emotions, such as happiness, sadness, fear, or anger. Using such scenes from the Lion King movie, prior studies have reported the greatest RSA withdrawal during the anger scene, followed by fear (Fortunato, Gatzke-Kopp, and Ram 2013; Zhang et al. 2020). Happy and sad scenes elicited higher RSA levels than anger and fear (Fortunato, Gatzke-Kopp, and Ram 2013). Although there have been many studies examining emotions and physiological responses induced by film clips in both adults and youths (i.e., Gatzke-Kopp et al. 2012; Hastings et al. 2009; Kreibig 2010; Sacrey et al. 2021), there is a lack of research specifically focused on African youths. Cultural differences and experiences may impact physiological responses, so it is important to investigate this population to fully understand the generalizability of findings from previous studies (Hastings, Guyer, and Parra 2022).

### 1.1 | The Current Study

The present study of Ghanaian youths aged 8–10 years was conducted to assess the feasibility and reliability of measuring ANS and behavior during challenge tasks administered in a research office established in the field. Specifically, we investigated (1) the feasibility of administering the BART and VMI tasks with concurrent ANS data collection; (2) the reliability of BART and the VMI tasks across repeat administrations; (3) the effectiveness of emotion clips in the VMI task for eliciting targeted emotions; (4) PNS and SNS responses, via RSA and PEP, respectively, during the BART and VMI tasks; and (5) the relations between RSA and PEP responses to the tasks with emotion ratings and the adjusted number of pumps. No a priori hypotheses were posed, as this exploratory and descriptive study is, to our knowledge, the first to empirically examine these matters in a sub-Saharan African country.

## 2 | Methods

### 2.1 | Participants

We recruited a convenience sample of 30 children aged 8–10 years (M = 8.67 years, SD = 0.87; 12 girls, 18 boys) from semiurban communities in the Yilo and Manya Krobo districts of the Eastern Region in Ghana. Data were collected from October 26 to November 6, 2020. Informed consent and assent were obtained during a home visit from primary caregivers and children, respectively. This pilot study was approved by the University of California, Davis Institutional Review Board, and the Ethics Committee of the Ghana Health Services.

### 2.2 | Procedures

Participants completed two project office visits. Families worked with data collectors who were fluent in the families' preferred language. All children wore face shields, and all staff wore surgical masks during the assessments; all equipment was disinfected after each session; no transmission of the COVID-19 virus was reported. During the first visit (Visit 1), children's physiological responses were measured at baseline and after performing various challenges, including the BART and VMI tasks. Children returned a week later to repeat the same procedures (Visit 2).

### 2.3 | Physiological Assessment

To measure electrocardiography (ECG) and obtain RSA, three disposable pre-gelled silver/silver chloride (Ag/AgCl) electrodes were applied to the ventral surface of the child's torso in the Lead-II configuration. Following that, four disposable pre-gelled Ag/AgCl electrodes were placed on the child's torso, two on the front and two on the back, to measure cardiac impedance (ICG) and obtain PEP. Children's skin was cleaned using alcohol prep pads prior to affixing electrodes. The leads connected to the electrodes were attached to a portable MindWare ambulatory monitor device (MindWare Technologies), which was used to collect cardiac data. The ambulatory monitor was strapped to a belt around the child's waist for easy movement. The ambulatory monitors were wirelessly connected to a data acquisition laptop computer via a router, providing an intranet connection.

During data acquisition, the ECG and ICG signals were viewed on the computer using MindWare Biolab software. This allowed the tester to detect and correct, if necessary, any interferences affecting signal quality, such as movement, electrical interferences, and equipment malfunction, including disconnection problems and electrode displacement.

Prior to collecting baseline ANS activity, the child sat quietly for 5 min. Baseline ANS activity was then recorded while the child watched a 3-min neutral video (low-action scenes from March of the Penguins, accompanied with gentle music and no narration). After obtaining baseline physiology, the child was taken to another room where physiological responses were recorded while performing the challenge tasks, including the BART and VMI tasks. The BART and VMI tasks were presented using E-Prime Version 3.0 software (Psychological Software Tools Inc.) on a tablet. The precise onset (start) and offset (end) times for baseline, BART, and VMI were programmed in E-Prime via the UDP Commands socket (Schmidt 2020) to transmit automatically from the task tablets to the physiological data acquisition computer running MindWare BioLab software.

## 2.4 | Challenge Tasks

### 2.4.1 | Balloon Analog Risk Task

The child participated in the BART to assess risk-taking behavior. In this task, the participants were shown a simulated balloon on the computer screen and offered the chance to earn points by inflating the balloon by pressing the right arrow key on the keyboard. Each press caused the balloon to incrementally inflate, and participants earned 5 points per press. Participants were taught that they would earn more points by inflating the balloon more, but at any time, the balloon could pop after a keypress, and they would receive no points for that turn. Thus, each key press conferred greater risk but also greater potential reward. Participants did not know how many key presses would cause a given balloon to pop, and they could choose to press the left arrow key on the keyboard to stop a trial and receive their points prior to the balloon exploding. Participants were told that if they got a high score, they could choose a more valuable prize than if they received a low score (all children got to choose from the same range of prizes, regardless of score). The BART task consisted of 2 practice trials and 20 test trials. For analyses, the average number of pumps on unexploded balloons, also called the adjusted number of pumps, was used as a risk-taking behavior index (Lejuez et al. 2002).

### 2.4.2 | Video Mood Induction

Prior to starting the VMI task, the child was seated in a chair in front of the tablet and instructed to close his/her eyes and relax for 1–2 min. Participants then rated how much they were currently feeling each of four emotions (scared, sad, happy, and angry), using a 5-point Likert scale (1 = least; 5 = most), anchored with emoticon faces ranging in size from small to large. The VMI included four 2-min video clips of fearful, sad, happy, and angry scenes (in that fixed order), each of which was followed by a 30-s neutral (no emotion content) video clip; all scenes were from *The Lion King* (1994) (Gatzke-Kopp et al. 2012), which was a familiar film for this sample. After each emotion scene, and before the 30-s neutral clip, participants were asked to rate how intensely they felt each emotion (scared, sad, happy, and angry) during the clip on the same 5-point Likert scale.

## 2.5 | RSA and PEP Analyses

The ECG data were edited in MindWare HRV Version 3.2.5, using a frequency band of 0.24–1.04 Hz, which is the frequency band of young children's natural respiration (Kahle et al. 2018). RSA was obtained automatically via spectral analysis. The ICG data were edited using MindWare IMP Version 3.2.8, which uses ensemble averaging to combine cardiac impedance and electrocardiogram signals (Kahle et al. 2018).

The RSA and PEP values were computed in 30-s epochs over the course of the baseline and challenge tasks. Baseline and BART RSA and PEP values were computed from the averaged values across epochs for each child. The final epoch was discarded if it was less than 15 s. For VMI, average RSA and PEP values were computed separately for each emotion and neutral clip, with four epochs for each emotion clip and one epoch for each of the four neutral clips, which were averaged together.

Each participant's cardiac data were visually inspected for any artifacts and edited by two trained editors to assess interrater reliability. Edits made to the ECG data in MindWare HRV included inserting R peak markers that were missed, either by manually marking an R peak that was visually identifiable or by using the midbeat function to add an R marker within noisy data between two identifiable peaks, and deleting erroneous R peaks when noisy data was flagged as a heartbeat. Editing in MindWare IMP included removing R peak markers from ECG data with poor QRS morphology and lacking corresponding $dZ/dt$ response such that those data points would not be included in IMP's calculation of the ensemble average for an epoch. In the ensemble for an epoch, Q points were inspected and, when necessary, manually edited to be 2 ms to the right of the lowest value in the Q notch. Rarely, the Z point of the ensemble was edited when misplaced (e.g., on a second, higher peak). B points were not edited, as clear B notches were rarely present. For any epochs in which the two editors had a discrepancy in RSA values > 0.05 $\ln(\text{ms})^2$, or PEP values > 4 ms, editors met to resolve the discrepancy, with consultation by senior editors (the first two authors and the last author) as needed.

## 2.6 | Statistical Analysis

A statistical analysis plan was posted to Open Science Framework before conducting analyses (https://osf.io/bmv9d/). All analyses were performed using SAS Studio. A $p$-value of <0.05 indicated statistical significance. Outliers were defined as values more than 3 standard deviations (SDs) from the mean and were winsorized by reassigning values that fell within 3 SDs of the mean. Paired sample $t$-tests were used to assess differences between Visits 1 and 2 in ANS measures, risky behavior on BART, and emotion ratings on VMI.

Feasibility was assessed by the percentage of children who (1) assented; (2) completed the BART, VMI, and ANS measurements (at baseline and during the tasks); (3) had complete behavioral and physiological data; (4) had behavioral data loss; and (5) had unusable physiological data.

We estimated intraclass correlations (ICCs) for test–retest reliability of the reported emotion ratings in VMI and risk behavior on BART total and sub-scale scores. ICC values of <0.5 are indicative of low reliability, values between 0.5 and 0.75 indicate moderate reliability, values between 0.75 and 0.9 indicate good reliability, and values greater than 0.9 indicate excellent reliability (Shrout and Fleiss 1979).

To assess the effectiveness of the emotion clips in the VMI task, we sought to investigate the following questions: (1) Is the child's rating of the target emotion higher than the other emotions after watching the targeted emotion clip? (2) Is the child's rating of the reported emotion after watching the targeted emotion clip higher than at baseline? For Question 1, each clip was assessed in separate linear mixed models. The outcome was the 1–5 emotion rating scores from all four emotion intensity questions, and the exposure was the four-level categorical variable indicating which emotion question to which the rating corresponded. The random effect of child on intercept was included to account for the repeated measures on each child. Post hoc pairwise comparisons set at $p < 0.05$ were used to assess whether each emotion had a higher or lower rating than the target emotion. For Question 2, paired samples $t$-tests were used to determine whether there was a change in a child's emotion ratings before and after watching the targeted emotion clip.

To examine the autonomic activity across the behavioral tasks, linear mixed models were used for the VMI tasks, and paired sample $t$-tests were conducted for BART. Linear mixed models were used to examine the mean RSA and PEP activities in each emotion clip (scared, sad, happy, and anger) and neutral clips. The outcomes were RSA and PEP in separate models. Exposure was the type of clip that is the five-level variable (scared clip, sad clip, happy clip, angry clip, and neutral clip). Post hoc pairwise comparisons were used to assess whether each clip had a higher or lower RSA or PEP than the other clips.

Spearman's rank correlation was used to examine the relations between RSA and PEP responses, computed as change scores to the reported emotion ratings in VMI and risk behavior on BART. To compute the change scores, we subtracted the baseline value from the task value (change = task − baseline). For RSA, positive change scores mean RSA augmentation (higher RSA in task than baseline; increased PNS), and negative change scores indicate RSA withdrawal (or suppression; decreased PNS). For PEP, positive change scores mean PEP lengthening (longer PEP in task than baseline; decreased SNS), and negative change scores mean PEP shortening (increased SNS).

## 3 | Results

### 3.1 | Feasibility Outcomes

A total of 31 children were enrolled, but 1 was excluded from analyses because of ineligible age (younger than 8 years). All children assented to wearing the Ag/AgCl electrodes and ambulatory monitors, and to completing the challenge tasks. For the challenge tasks, complete data ranged from 97% to 100%, with any missing data being due to technical issues. For the physiological data, we had 80%–100% complete data across tasks, with most missing data due to technical issues and only one participant having some unusable segments due to noise in the signal, likely due to movement (see Figure 1).

### 3.2 | Effectiveness of the Emotion Clips Used in the VMI Task

There were significant differences in emotion ratings after watching the target clips at both visits, all $F > 17$, all $p < 0.0001$. At both visits, post hoc pairwise comparisons of each model consistently showed that happy was rated significantly higher than the other three emotions after watching each clip, regardless of the target emotion (see Figure 2). At both visits, sad ratings were significantly higher than scared ratings after watching the sad clip, but not higher than angry ratings, and angry ratings were significantly higher than scared ratings after watching the angry clip, but not higher than sad ratings.

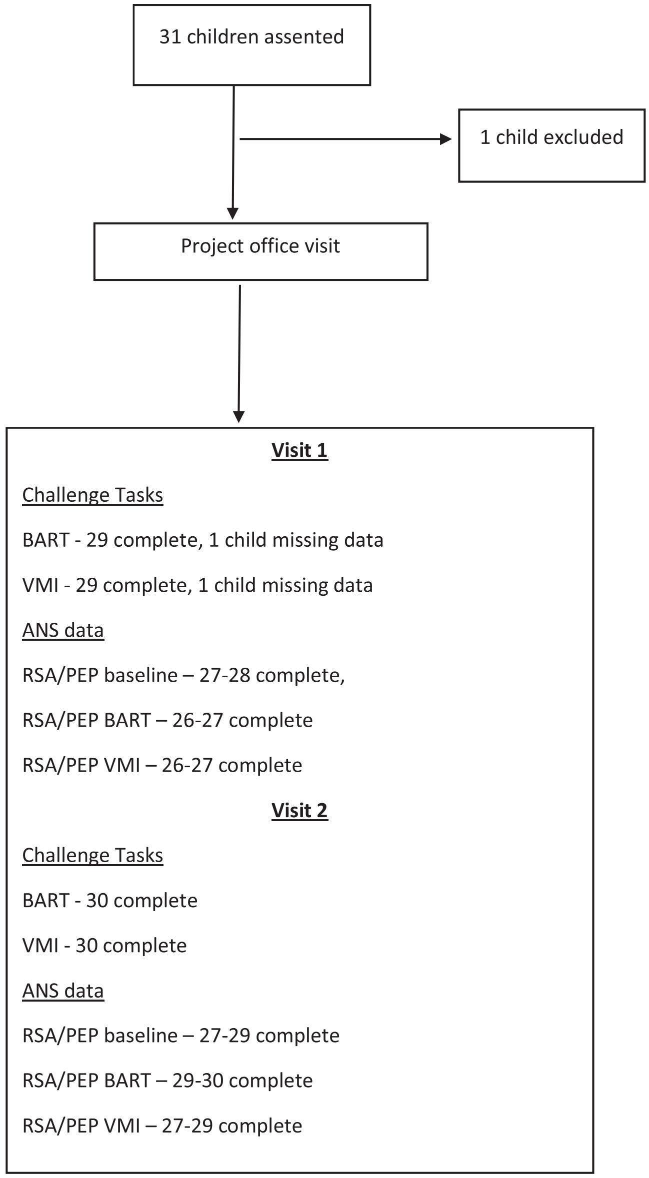


**FIGURE 1** | Participant flowchart. BART, balloon analog risk task; PEP, pre-ejection period; RSA, respiratory sinus arrhythmia; VMI, video mood induction.

At both visits, for certain clips, the mean ratings for the targeted emotion were higher after watching the targeted emotion clips than ratings collected before VMI (see Table 1). At Visit 1, the mean sad rating was significantly higher after watching the sad clip than the sad rating before VMI. There were no other significant differences observed for the remaining three emotions. At Visit 2, mean ratings for the targeted emotions were significantly higher after versus before watching the sad clip, happy clip, and angry clip. At both visits, the mean ratings for scared were marginally but nonsignificantly ($p < 0.06$) higher after watching the scared clip than prior to the VMI task.

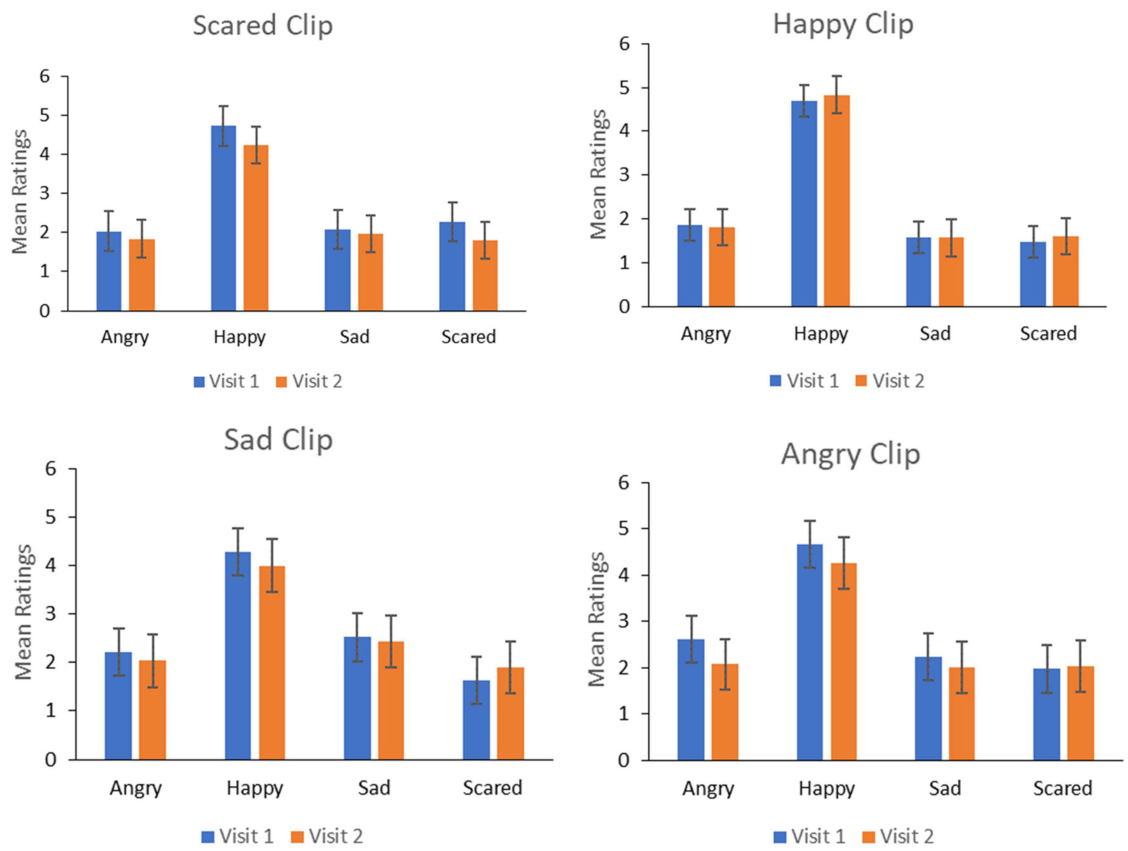


**FIGURE 2** | Mean emotion ratings (95% CI) at Visits 1 and 2 after watching each video mood induction clip among children in Ghana ($n = 30$).

### 3.3 | Test–Retest Reliability of VMI Task and BART

For the VMI task, there were no significant differences between the emotion ratings of targeted emotions at Visits 1 and 2 (see Table 2). The test–rest reliability also showed low-to-moderate reliability in the range of $r = 0.34–0.52$. For BART, the mean adjusted number of pumps (risk behavior) did not significantly change over time. The adjusted number of pumps showed moderate test–retest reliability, $r = 0.43$, over the 1-week period.

### 3.4 | Average RSA and PEP Activity During Tasks at Visits 1 and 2

Table 3 shows the results of average RSA and PEP activities at baseline and during the VMI task and BART. Baseline RSA was significantly lower at Visit 1 than at Visit 2, $t(25) = -3.23$, $p = 0.003$. Baseline PEP did not differ significantly between visits, $t(25) = 0.01$, $p = 0.988$.

For VMI, there were statistically significant differences in mean RSA activity across emotion clips at Visit 1, $F(4, 110) = 5.40$, $p = 0.001$, and Visit 2, $F(4, 112) = 3.57$, $p = 0.009$. At Visit 1, post hoc pairwise comparisons showed that the mean RSA for the angry clip was significantly lower than for the sad, $t(110) = 2.94$, $p = 0.004$, and scared, $t(110) = 3.51$, $p = 0.001$, clips, and the mean RSA for the happy clip was significantly higher than for the angry, $t(110) = -4.22$, $p < 0.0001$, and neutral, $t(110) = 2.40$, $p = 0.018$, clips. At Visit 2, post hoc pairwise comparisons showed that the mean RSA for the angry clip was significantly lower than for the sad, $t(112) = 2.35$, $p = 0.021$, happy, $t(112) = -2.20$, $p = 0.030$, and scared, $t(112) = 2.05$, $p = 0.042$ clips. The mean RSA for the neutral clips was significantly lower than for the happy, $t(112) = 2.63$, $p = 0.010$, sad, $t(112) = 2.78$, $p = 0.006$, and scared, $t(112) = 2.48$, $p = 0.015$, clips. There were marginally significant differences in mean PEP activity across emotion clips at Visit 1, $F(4, 109) = 2.08$, $p = 0.089$, and Visit 2, $F(4, 107) = 2.32$, $p = 0.062$. At Visit 1, the mean PEP for angry clip was significantly longer than for neutral, $t(109) = 2.12$, $p = 0.036$, sad, $t(109) = 2.14$, $p = 0.035$, and scared, $t(109) = 2.22$, $p = 0.028$, clips. At Visit 2, the mean PEP for the neutral clips was significantly shorter than for angry, $t(107) = 2.73$, $p = 0.008$, happy, $t(107) = 2.46$, $p = 0.016$, and scared, $t(107) = -2.08$, $p = 0.040$, clips.

Comparisons between visits showed that RSA was significantly higher at Visit 2 than at Visit 1 for each of the four emotion clips, all $t(>26) = -3.79$, all $p < 0.0005$. For PEP, only Visit 2 scared PEP, $t(26) = -2.30$, $p = 0.030$, and sad PEP, $t(26) = -2.26$, $p = 0.033$, were significantly longer than at Visit 1. Comparisons between baseline RSA and emotion clips at each visit showed that RSA for angry, $t(24) = 2.61$, $p = 0.015$, and neutral, $t(24) = 2.45$, $p = 0.022$, clips were significantly lower than baseline RSA at Visit 1. There were no significant differences between baseline RSA and emotion clip RSA at Visit 2. For PEP, there were no significant differences between baseline and emotion clips at Visit 1. At Visit 2, baseline PEP was significantly shorter than PEP during each of the emotion clips: happy, $t(27) = -3.29$, $p = 0.003$, angry, $t(27) = -2.79$, $p = 0.010$, sad, $t(26) = -2.62$, $p = 0.015$, and scared, $t(26) = -2.23$, $p = 0.035$.

**TABLE 1** | Comparisons of emotion ratings before and after watching targeted emotion clip at Visits 1 and 2.

| Ratings | Visit 1 ($n = 29$) | | | | Visit 2 ($n = 30$) | | | |
|---|---|---|---|---|---|---|---|---|
| | Before | After | | | Before | After | | |
| | Mean (SD) | Mean (SD) | *t*-value | *p*-value | Mean (SD) | Mean (SD) | *t*-value | *p*-value |
| Scared | 1.83 (1.23) | 2.28 (1.60) | −2.04 | 0.051 | 1.43 (0.94) | 1.80 (1.37) | −2.01 | 0.054 |
| Sad | 1.62 (1.35) | 2.52 (1.53) | −2.27 | 0.031 | 1.47 (0.97) | 2.43 (1.72) | −3.54 | 0.001 |
| Happy | 4.55 (1.06) | 4.69 (0.71) | −0.60 | 0.556 | 4.47 (1.25) | 4.83 (0.75) | −2.08 | 0.046 |
| Angry | 2.10 (1.26) | 2.62 (1.57) | −1.49 | 0.146 | 1.50 (1.01) | 2.07 (1.64) | −2.29 | 0.030 |

*Note:* Within visit, mean emotion ratings before and after watching the targeted emotion clip were compared using a paired *t*-test.

RSA during BART was significantly lower than baseline RSA at both Visit 1, $t(24) = 2.16$, $p = 0.041$, and Visit 2, $t(28) = 4.11$, $p = 0.0003$. RSA during BART was significantly higher at Visit 2 than at Visit 1, $t(26) = -2.32$, $p = 0.029$. PEP during BART was significantly shorter than baseline PEP only at Visit 1, $t(23) = 2.70$, $p = 0.013$. PEP during BART and baseline did not differ significantly at Visit 2, $t(26) = 0.84$, $p = 0.411$, and PEP during BART did not differ between Visits 1 and 2, $t(24) = -0.61$, $p = 0.550$.

### 3.5 | Correlations Between RSA and PEP Responses and Task Measures

Table 4 shows the correlations between RSA and PEP responses to the tasks with the adjusted number of pumps and emotion ratings. The adjusted number of pumps was not significantly associated with RSA and PEP at either visit. For VMI at Visit 1, stronger RSA withdrawal to the happy clip was significantly associated with higher ratings of happy, and PEP lengthening to the angry clip was significantly associated with higher ratings of angry. There were no significant associations between physiology and emotion ratings at Visit 2.

## 4 | Discussion

The present study aimed to assess the feasibility and reliability of collecting ANS data during two challenge tasks among children in Ghana. Additionally, the study aimed to evaluate the effectiveness of the emotion clips used in the mood induction task to elicit the intended emotions and to document the corresponding physiological responses using measures of RSA and PEP during each task. Overall, the collection of ANS data alongside behavior within challenge tasks proved to be feasible, and the tasks generally demonstrated reliability and effectiveness in eliciting the intended emotions and actions.

To our knowledge, this is the first study to collect children's ANS data during two challenge tasks in the sub-Saharan African region. Our feasibility results, showing 80%–100% completeness of physiological data, shed light on the successes encountered during the data collection process. The wearing of the electrodes and mobile devices while performing the challenge tasks was well received by the children. The small percentage of incompleteness in the data mainly stemmed from connectivity issues, particularly in the early stages of the study. To address this, we redesigned the setup of the testing rooms prior to initiating Visit 2 testing so that the stations where the children would be tested were as close as possible to the intranet router. The main building material in Ghana and most African countries is cement/concrete; it appeared that signals could not pass through the concrete consistently, causing these connectivity issues.

The modest test–retest reliability of BART reported in our study contrasts with previous studies reporting moderate-to-high correlations, ranging from 0.62 to 0.82, in risk-taking behavior on the BART (Collado et al. 2015; Lejuez et al. 2007; White, Lejuez, and de Wit 2008). It is noteworthy that except for White, Lejuez, and de Wit (2008), which was a study of 2-week test–retest reliability in 40 adults aged 18–35 years, all the other known reliability studies obtained data on a single day; therefore, they

**TABLE 2** | Test and retest reliability and mean ratings of targeted emotions and mean adjusted number of pumps between the two time points (Visits 1 and 2).

| | Visit 1 ($n = 29$) | Visit 2 ($n = 30$) | | | |
|---|---|---|---|---|---|
| | **Mean (SD)** | **Mean (SD)** | ***t*-value** | ***p*-value** | **ICC** |
| VMI ratings[a] | | | | | |
| Scared | 2.28 (1.60) | 1.80 (1.37) | 1.66 | 0.108 | 0.52 |
| Sad | 2.52 (1.53) | 2.43 (1.72) | 0.12 | 0.909 | 0.50 |
| Happy | 4.69 (0.71) | 4.83 (0.75) | −0.89 | 0.380 | 0.34 |
| Angry | 2.62 (1.57) | 2.07 (1.64) | 1.64 | 0.113 | 0.43 |
| BART | | | | | |
| Adjusted number of pumps | 17.23 (7.52) | 15.89 (7.51) | 1.02 | 0.320 | 0.45 |

*Note:* Adjusted number of pumps = risk-taking behavior.

Abbreviations: BART, balloon analog risk task; ICC, intraclass correlation; VMI, video mood induction.

[a]Ratings after watching the target clip.

differ from our assessment of test–retest reliability across multiple days. Comparing our findings to those of Collado et al. (2015), who studied 184 Black and White youths aged 9–12 years in the United States (Collado et al. 2015), we observed a lower adjusted number of pumps in both administrations. Collado et al. (2015) reported that Black and White youths had average adjusted numbers of pumps of 31 and 33, respectively, whereas the youths in Ghana had average adjusted numbers of pumps of 17 and 15 at Visits 1 and 2, respectively. The risk-taking behavior of youths in our study fell within the low end of the range (10–52) reported in previous studies conducted in high-income countries (Aklin et al. 2005; Collado et al. 2015; Dekkers et al. 2020; Dougherty et al. 2015; Lejuez et al. 2007; Loheide-Niesmann et al. 2021; MacPherson et al. 2010; Tieskens et al. 2018), which could suggest that children in Ghana are somewhat more risk-averse than children in high-income countries.

Considering the VMI, the mood ratings reported in our study are fairly consistent with those from previous studies. In 11- to 16-year-old adolescents in the United States, Hastings et al. (2009) reported that film clips presenting anger, fear, sadness, and happiness elicited the intended emotions as well as some nontargeted emotions in the youths. We also found moderate emotion-specificity for ratings in Visit 2, and in both visits, increases in some nontarget emotions, such as happiness during the scared, sad, and angry clips. von Leupoldt et al. (2007) examined the affective responses of elementary school-aged children in Germany to pleasant and unpleasant film clips, including one unpleasant scene from The Lion King. They found that the positivity of children's valence ratings increased from unpleasant to pleasant film clips (von Leupoldt et al. 2007). Similarly, in our study, although children consistently rated happy more highly than the other emotions across clips, ratings of happy were higher for the happy clip than for the negatively valenced films eliciting fear, sadness, and anger.

Emotion ratings of the mood induction clips showed varying test–retest reliability, ranging from low to moderate. The test–retest reliability of children's mood ratings to VMI procedures has not been reported in previous studies, to our knowledge. Although the effectiveness of a set of film clips in inducing basic emotions, as measured by self-reported ratings after watching the clips, has been extensively studied, most of this work has been conducted in Western cultures with adult populations. For example, Gross and Levenson's (1995) landmark study examining the effectiveness of film clips in eliciting specific target emotions in 18- to 40-year-old undergraduates was important for validating the use of film clips as reliable emotional stimuli for future research. Comparing the mean ratings before and after watching the emotion clips in our present study, it is evident that the VMI worked better for eliciting significant increases in targeted emotions during the second visit compared to the first. This finding is in line with the results of Gross and Levenson (1995), who observed greater levels of target emotions in adults who had previously viewed the films, compared to adults for whom the clips were unfamiliar stimuli.

Unexpectedly, baseline RSA was significantly lower at Visit 1 than at Visit 2, and at Visit 1, RSA remained relatively lower across the tasks. This suggests that children experienced the novelty of the field lab procedures to be evocative and that this novelty had worn off by their second visit, although the lack of difference in baseline PEP across visits suggests that the children were not in a state of fight-or-flight activation during Visit 1 (Hastings and Kahle 2019). It is rare for psychophysiological studies to include test–retest reliabilities of baseline ANS measures across a period of several days, and this finding could suggest that underestimation of baseline RSA may be an issue for developmental psychobiology studies that utilize only a single visit of children to a laboratory or similar facility. Financial or practical restrictions may preclude some researchers from testing children on multiple days, but future studies could benefit from other ways to increase opportunities for children to become familiarized and comfortable with the facility and procedures. For example, children could visit the testing site on a day before data collection, and more time could be allowed to pass between arriving at the testing site and beginning physiological data collection and/or between affixing electrodes and obtaining baseline recordings. In addition, collecting baseline data at multiple points during a single visit could provide more accurate estimations of baseline ANS measures (i.e., RSA and PEP) by computing average or latent scores.

**TABLE 3** | Mean respiratory sinus arrhythmia (RSA) and pre-ejection period (PEP) during tasks at Visits 1 and 2.

| | Baseline M (SD) | Scared clip M (SD) | Sad clip M (SD) | Happy clip M (SD) | Angry clip M (SD) | Neutral clip M (SD) | BART M (SD) |
|---|---|---|---|---|---|---|---|
| Visit 1 | | | | | | | |
| RSA ($n = 29$) | 6.21 (1.81) | 6.17 (1.51) | 6.13 (1.59) | 6.21 (1.53) | 5.96 (1.47) | 6.08 (1.58) | 6.14 (1.29) |
| PEP ($n = 29$) | 82.44 (9.81) | 80.79 (8.27) | 80.83 (8.23) | 81.46 (7.99) | 82.25 (7.00) | 81.59 (7.51) | 79.58 (10.03) |
| Visit 2 | | | | | | | |
| RSA ($n = 29$) | 7.20 (1.42) | 7.12 (1.30) | 7.14 (1.38) | 7.13 (1.20) | 6.94 (1.29) | 6.90 (1.22) | 6.46 (1.56) |
| PEP ($n = 29$) | 81.90 (6.96) | 84.24 (8.35) | 83.54 (6.76) | 83.58 (6.86) | 83.68 (6.90) | 82.29 (7.00) | 80.85 (9.90) |

*Note:* Results are presented as mean (SD). RSA values are in ln(ms$^2$), and PEP values are in milliseconds.
Abbreviation: BART, balloon analog risk task.

The physiological responses to the tasks that we observed in our study align with previous research. For instance, among the US children aged 5–6 years who viewed the same The Lion King scenes, the mean RSA was lowest during the angry clip (Fortunato, Gatzke-Kopp, and Ram 2013). Similarly, in our study and across both visits, the mean RSA during the angry clip was consistently significantly lower than that during the sad, happy, and scared clips, indicating that the angry scene was the most provocative or attention-grabbing (Hastings and Kahle 2019). Conversely, we found that the mean PEP for the angry clip was significantly longer than for the neutral, sad, and scared clips, which suggests lower SNS activity. These findings contrast with previous studies, primarily conducted with adults (Kreibig 2010), which typically report a shortening of PEP during anger provocation tasks or emotion video clips, indicating increased sympathetic activity. Indeed, at the second visit, despite the children's endorsement of the targeted emotions, PEP was longer for all emotion clips than at baseline, suggesting that the children remained physiologically quiescent. Further research will be needed to determine whether this is a consistent pattern for children in Ghana and other countries in sub-Saharan Africa, and what the implications may be for their psychobiological functioning and well-being.

The BART evoked significant PNS withdrawal in both visits and significant SNS activation in Visit 1 only; this suggests the children progressed from states of reciprocal sympathetic activation to ones of uncoupled parasympathetic activation as the BART task became more familiar (Berntson and Cacioppo 2007). Sympathetic activation by BART has been observed previously; Dekkers et al. (2020) also reported shorter PEP during BART than during baseline. Although PEP during BART and baseline did not differ significantly at Visit 2, there also was not a significant difference in task PEP between the two visits, suggesting a consistent level of sympathetic activation during the BART task across the two visits. These results contribute to the understanding of physiological regulation during risk-taking tasks in children and provide insights into the stability of sympathetic activity in this population.

There were notably few significant associations between the ANS and behavioral measures for VMI and BART, although it should be recognized that our sample was not well powered for detecting significant correlations. Previous studies investigating BART and ANS in adolescents have shown correlations of risk-taking behavior with both baseline RSA (Loheide-Niesmann et al. 2021) and PEP reactivity (Dekkers et al. 2020). It is uncertain whether we failed to replicate these associations due to working with a younger sample, a Ghanaian sample, or for other reasons, but additional research on youths' ANS regulation and their behavior on standardized and widely used tasks is needed.

The present study has several strengths. The pilot study provides valuable preliminary data on the reliability of behavioral and physiological responses to the VMI and the BART in this specific population. It serves as a foundation for future research in Ghana and other countries in Africa and can inform the development of large-scale studies. Including both RSA and PEP as measures of ANS activity provides a comprehensive assessment of physiological responses. Limitations should also be noted. First, the study's small sample size of 30 participants may limit the power

**TABLE 4** | Correlation coefficients of respiratory sinus arrhythmia (RSA) and pre-ejection period (PEP) responses with adjusted number of pumps and emotion ratings at Visits 1 and 2.

| | RSA | | PEP | |
|---|---|---|---|---|
| | Visit 1 | Visit 2 | Visit 1 | Visit 2 |
| Adjusted number of pumps | −0.30 | −0.29 | 0.12 | 0.18 |
| Scared ratings | −0.26 | 0.08 | 0.29 | 0.08 |
| Sad ratings | 0.06 | 0.00 | 0.17 | 0.14 |
| Happy ratings | −0.42* | −0.23 | −0.05 | −0.07 |
| Angry ratings | −0.15 | −0.01 | 0.40* | −0.05 |

*Note:* RSA and PEP responses are computed as change scores (change = task − baseline). Ratings represent ratings given after watching each target emotion clip.
*Significant at $p < 0.05$.

to detect small effects and the generalizability of the findings to the broader population of Ghanaian children. In addition, the findings may not apply to children outside the middle- to late-childhood period or to children living in different cultural, economic, and geographical contexts.

In summary, our study documented the feasibility of the collection of ANS and behavioral data during challenge tasks in Ghana, an LMIC. This indicates that similar studies can be conducted in similar settings, expanding our understanding of ANS functioning in children globally. In addition to being the first study to our knowledge that has examined children's ANS responses to such tasks in sub-Saharan Africa, this was one of the first studies to formally assess the test–retest reliability of the VMI and BART in children. Notably, the tasks exhibited low-to-moderate reliability for behavior and, for the VMI, effectiveness in eliciting the targeted emotions. We also showed that unfamiliar laboratory contexts may result in underestimations of RSA, even after children are given several minutes to adjust to the setting. These findings have implications for studies—across all nations—that typically include only single administrations of baseline procedures and challenge tasks.

### Author Contributions

P.D.H., S.A-.A., E.P., B.O., A.E.G., A.M., M.E.D., and B.A. designed the research. H.J.B., S.A-.A., H.Y., and M.M. conducted the research. H.J.B., M.M., H.Y., and E.M.D. processed the data. C.D.A. and H.J.B. analyzed data. H.J.B. drafted the manuscript. All authors reviewed and approved the final manuscript.

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### Ethics Statement

Ethical approval for the current follow-up study was obtained from the Institutional Review Board of the University of California, Davis (IRB ID: 1489918), and the Ghana Health Service Ethical Review Committee (GHS-ERC: 027105119).

### Conflicts of Interest

The authors declare no conflicts of interest.

### Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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