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Vagal Tone During Infant Contingency Learning and Its Disruption

Margaret Wolan Sullivan, Ph. D.

School of Nursing, Rutgers Biomedical & Health Sciences--Rutgers University

Abstract

This study used contingency learning to examine changes in infants' vagal tone during learning and its disruption. The heart rate of 160 five-month-old infants was recorded continuously during the first of two training sessions as they experienced an audiovisual event contingent on their pulling. Maternal reports of infant temperament were also collected. Baseline vagal tone, a measure of parasympathetic regulation of the heart, was related to vagal levels during the infants' contingency learning session, but not to their learner status. Vagal tone levels did not vary significantly over session minutes. Instead, vagal tone levels were a function of both individual differences in learner status and infant soothability. Vagal levels of infants who learned in the initial session were similar regardless of their soothability; however, vagal levels of infants who learned in a subsequent session differed as a function of soothability. Additionally, vagal levels during contingency disruption were significantly higher among infants in this group who were more soothable as opposed to those who were less soothable. The results suggest that contingency learning and disruption is associated with stable vagal tone in the majority of infants, but that individual differences in attention processes and state associated with vagal tone may be most readily observed during the disruption phase.

Keywords

parasympathetic regulation; contingency; temperament; frustration; infant

Vagal tone is an accepted measure of attention in the infant literature. Contingency learning requires that infants attend to and remain interested and engaged with the contingent feedback continuously during learning, presumably supported by physiological processes (Lewis, Hitchcock & Sullivan, 2004; Millar, 1988; Sullivan, Lewis, & Alessandri, 1992). Observing vagal tone during contingency learning and its disruption provides a window on these processes and a way to explore their association with individual differences in contingency response. Extinction is the term used in the learning literature for the experimental phase in which a previous contingency between an outcome and a response is disrupted. The withdrawal or disruption of expected contingent events during an extinction phase is associated with physiological changes including heart rate, and with increased

negative facial and vocal expressions in young infants (Crossman, Sullivan, Hitchcock & Lewis, 2009; Lewis et al., 2004; Lewis, Ramsay, and Sullivan, 2006; Millar, 1988). These responses signal infants' displeasure at the contingency disruption, thus providing an opportunity to observe how attention and physiology are altered in response to the unexpected stimulus change. In this paper, we prefer the term "disruption" rather than extinction since 1) the short extinction periods used in infant contingency studies are too brief to demonstrate significant "extinction" of behavioral responding, and 2) infants have been reliably found to either show "extinction bursts," (i.e., initially increased or sustained response) during this period that have been used to index immediate memory of the contingency (Hitchcock and Rovee-Collier, 1996; Sullivan & Lewis, 2003). In addition, considering extinction as a "disruption" allows us to understand this phase as one of a broader class of disruptions in young infants, such as the still-face and novelty paradigms, that have been used to study physiological differences as infants adapt to disrupted events (See for example, Lewis & Ramsay, 2005).

Individual Differences in Infant Contingency Learning

Individual differences in infants' ability to respond rapidly and appropriately to contingent feedback have not been considered systematically. Most studies of differences in contingency learning have focused on infants with disabilities or those thought to be at-risk due to perinatal or other environmental factors (Bhat, Galloway, & Landa, 2010; Dunst, Cushing, & Vance, 1985; Haley, Grunau, Oberlander, & Weinberg, 2008; Millar, 1985; Millar & Weir, 2007; Millar, Weir, & Supramaniam, 1992; Ohr & Fagen, 1991; Taylor et al., 2013). Historically, temperament has been examined to account for variation in learning within low-risk samples. It is reasonable to expect a relation between aspects of temperament and contingency response. Temperament scales seek to index variability in attention and emotional processes, however their success in accounting for variance in contingency learning among young infants has been limited. There has been little consistency observed in the relation of maternal reports of temperament to contingency learning. Some aspects of the Infant Behavior Questionnaire (IBQ, Rothbart, 1981) predicted vocal crying during contingency disruption or were related to subject loss during contingency sessions (Fagen & Ohr, 1990), suggesting that inability to tolerate novelty or abrupt stimulus change, but not learning itself, may be related to temperament. More recently, Millar & Weir (2014) reported that differences in baseline response levels were related to contingency learning outcomes, with greater baseline responding associated with poorer response to the contingency. They ruled out two factors, more rapid habituation to the stimulus and failure to detect the contingency, as explanations for this effect. Although they concluded that baseline differences in activity might be a random, nuisance variable, they acknowledged emotional or temperament factors might play a role.

Physiological processes related to attention and state regulation during contingency sessions may be more sensitive than temperament scales in accounting for variation in contingency response. Studies of cortisol response to contingency disruption and the "head drop" phase of the still face paradigm, as well as physiological differences (cortisol, heart rate and vagal tone) observed between preterm and full term births during contingency learning, suggest this may be a fruitful approach (Haley, Weinberg and Grunau, 2006; Haley et al., 2008;

Lewis & Ramsey, 2005). We chose vagal tone, one measure of heart rate variability, as our measure as it is well-established in the literature. Individual differences in vagal tone are stable during infancy and early childhood and show reliable associations with attention and emotional functioning (Berston, Cacioppo, & Quigley, 1993; Calkins & Keane, 2004; Moore & Calkins, 2004; Richards, 1995). Moreover, vagal tone can be measured relatively noninvasively as infants learn, offering a means of capturing differences in attention in conjunction with contingency learning and other cognitive processes (Brez & Colombo, 2011). Our primary goal was to assess whether vagal tone levels are related to either to the contingency learning or to its disruption. A secondary goal was to explore any relation observed between vagal tone and temperament with respect to contingency learning. Several different dimensions of temperament, including greater attention and greater soothability at 12 weeks, have shown relations with vagal tone, suggesting that some aspects of temperament may be important covariates in assessing how vagal tone is related to learning performance (Beauchaine, 2001; Huffman et al., 1998).

Vagal Tone

Respiratory sinus arrhythmia, a measure of vagal tone “assessed via the nucleus ambiguus” (V_{na}), estimates the level of parasympathetic control of the heart (Porges, 1998, 2001, 2007; Porges & Furman, 2011). Regulation of V_{na} level via this pathway is thought to enable adaptive responses to changing contexts or attentional demands in the absence of perceived threat (Porges, 2007). Vagal tone has been postulated to index calm, attentive states, supporting stimulus approach and engagement with the social and nonsocial world. For this reason, higher or increased vagal tone level and its accompanying decrease in heart rate are considered measures of active, focused attention in the developmental literature (Colombo et al., 2010; Porges, 2001). In contrast, withdrawal of V_{na} influence allows the mobilization of attention in response to perceived environmental demands as it allows heart rate to rise, potentially preparing for stimulus disengagement (Beauchaine, 2001; Porges, 2001; Porges & Furman, 2011). The context in which a stimulus is embedded (novel or familiar), the perceived stressfulness of that context, as well as pre-existing temperamental or learned response biases, likely influence the direction and amount of V_{na} change (Beauchaine, 2001; Berston et al., 1993; Davidson, 1998; Movius & Allen, 2005).

Two major indices of individual difference, baseline V_{na} level and its directional change have functional effects early in life. Resting or baseline V_{na} is a measure of vagal level taken during a period of minimal activity and stimulus challenge, hence the term “baseline V_{na} ,” which will be used in this paper. To obtain baseline V_{na} heart rate is recorded while a child is passively seated with the mother nearby. A non-arousing visual stimulus is typically presented to infants in order to record a quiescent period of electrocardiograph (ECG) data. Older children may be asked to sit quietly for a brief period. Baseline V_{na} has trait-like properties. Differences in baseline V_{na} are thought to more directly reflect biological factors, whereas differences in V_{na} responses to challenge have been hypothesized to reflect environmental influence (Calkins, Smith, Gill, & Johnson, 1998). Children with low baseline V_{na} are thought to be more vulnerable to negative emotion and less able to regulate attention (Porges, 2001, 2007). Low baseline vagal tone was also associated with a lack of positive affect in newborns and in young infants of depressed mothers. Among preterms,

higher, non-stress V_{na} levels have been linked with positive developmental outcomes (Field & Digeo, 2008; Hofheimer, Wood, Porges, Pearson, & Lawson, 1995). However, the reverse pattern has also been observed. Higher resting vagal tone characterized 8- to 11-month-old regulatory disordered and behaviorally difficult infants (DeGangi, DiPietro, Greenspan, & Porges, 1991). In a more recent study, such infants exhibited higher vagal levels during a developmental assessment despite comparable baseline levels relative to two comparison groups (Dale, O'Hara, Keen, & Porges, 2011). This range of findings suggests that both low and high vagal levels in infants may be indicative of problems in attention and state regulation which might potentially impact early learning.

The second measure of individual difference indexes a change in V_{na} level in response to a cognitive or social challenge and is considered a measure of regulation. The terms vagal withdrawal and vagal suppression have both been used in the literature to describe vagal decreases. They may not be interchangeable, although both terms refer to decreased vagal influence on heart rate. Greater V_{na} suppression has been related to defensiveness and low behavioral activation, indicators of fearful, anxious behavior (Movius & Allen, 2005). Vagal withdrawal has been the term used in most studies of change in non-threatening situations of cognitive challenge.

To study vagal regulation following a baseline phase, a series of challenges typically is administered. Change in V_{na} level is tracked across these successive periods which vary in cognitive demand (Bazhenova, Plonskaia, & Porges, 2001; Calkins, 2009). Tracking vagal change across a series of stimulus challenges allows observation of any increases and decreases in vagal level in order to observe the waxing and waning of focused attention and the maintenance of stimulus engagement. The amount of vagal decline across a series of nonthreatening tasks differentiated kindergarteners with externalizing, as opposed to mixed behavior problem profiles, but not internalizing problems (Calkins, 2009; Calkins, Graziano, & Keane, 2007; Calkins & Keane, 2004). However, vagal decline also characterized preschoolers' better performance during cognitively demanding tasks (Markovitch et al., 2010).

Among infants, the normal, reciprocal pattern between V_{na} and heart rate is observed during periods of social and non-social stimulus disruption, and in response to stimulus change, establishing its validity (Bazhenova et al., 2001; Haley et al., 2008; Lewis, et al., 2004; Porges, Doussard-Roosevelt, Portales, & Greenspan, 1996). Yet, disparate findings on vagal change also occur in infant studies in relation to attention and the ability to respond adaptively to stimulus change. For example, vagal declines occurred during cognitive processing among 8–11-month-olds, including those who were diagnosed as regulatory-disordered (DeGangi, et al., 1991). Among typically developing 5-montholds, those who exhibited vagal declines and recovery during social interaction, showed better regulation of behavioral response and recovery from the still-face disruption compared to those who did not show this pattern (Bazhenova et al., 2001). The still-face paradigm, which disrupts ongoing social contingencies between the infants and mothers, is a potent disruption analogous to contingency disruption and a significant social challenge to young infants (Lewis & Ramsay, 2005). Even so, approximately 50% of infants did not show vagal decreases in the still-face phase (Montrirosso, et al., 2014). Those that did, however, showed

consistency in this response two weeks later. As in preschoolers, vagal decline can be associated with positive outcome, but may also characterize those who are reactive in some contexts. The nature of the sample, the developmental context, especially the degree of novelty, or stress involved during the various procedures, may account for some of the differences observed among infants.

Vagal Tone When Infants Learn

Assessments of change in vagal level to non-social, cognitive challenges have as yet been few. They have included habituation and contingency learning (Bornstein & Seuss, 2000; Haley et al., 2008; Lewis et al., 2004). In the habituation and contingency studies, declines in vagal tone have been associated with attention. For example, short lookers had greater vagal declines during habituation and greater vagal declines were associated with more accumulated looking time (Bornstein & Seuss, 2000). Haley et al (2008) reported that vagal levels decreased from baseline through a final non-reinforcement phase (i.e., disruption/extinction) in 3-month-olds responding to a mobile contingency. Both pre- and full-term learners showed vagal declines in comparison to nonlearners. In 5-month-old learners, Lewis et al. (2004) reported that increased vagal levels occurred only across transitions in the contingency learning session (from baseline to contingency onset and from contingency to extinction/disruption). These increases mirrored inverse changes in heart rate, indexing attention. During the contingency itself, vagal levels showed consistency over session minutes. Although it is not clear whether age or the feedback differences between the two contingency studies (3 months versus 5 months; a conjugate versus a fixed ratio contingency) account for the difference in findings, change in vagal level during contingency learning sessions likely occurs in infants under 6 months of age.

Although they did not study vagal tone, Millar & Weir's (2007) analysis of heart rate (HR) patterns during contingency learning as a function of perinatal risk corroborated a relation between learner status and more stable cardiac regulation during contingency learning. High-risk infants in their study had a record of specific birth complications indicative of anoxia. They observed patterns of immediately increased and subsequently sustained HR in response to the introduction of contingency in low, but not high-risk infants, especially those who were strong learners. Such sustained HR changes, based on the Lewis et al. (2004) findings, should be related to stable V_{na} . Consistent with Haley et al. (2008), the evidence suggests that cardiac regulation is related to differences in learner status.

Hypotheses and Design Overview

Given that contingency learning involves the engagement and coordination of attention, emotion, and behavior (Haley et al., 2008; Lewis, et al., 2004; Millar & Weir, 2007; Sullivan & Lewis, 1989), we expected to observe vagal change in response to contingency learning and its disruption as a function of learner status. We expected that learner status would be related to individual differences in baseline V_{na} level such that those with lower baseline V_{na} would be less efficient learners. Learning efficiency was defined as significant response increases within an initial session. While the majority of typically developing infants can learn a pulling contingency within a single, short session, not all do and 15% of

infants may not learn after a second session (Crossman et al., 2009). The reasons for this are unclear, but may be due to differences in initial reactivity to the context or to poorer regulation during the contingency session. Patterns suggestive of poor HR regulation among “weak” learners who lacked any perinatal risk factors suggested that differences in contingency response may be related to lower baseline V_{na} or to V_{na} levels during the contingency itself (Millar & Weir, 2007).

To examine individual differences in vagal level during contingency learning and its disruption, our method was to examine a) baseline V_{na} and b) V_{na} levels during an initial contingency session and its disruption in relation to learning performance. We provided all infants with two training sessions, but focused our analyses on responses during the first session to observe whether infants differed in baseline V_{na} and in subsequent V_{na} levels during the session. In addition, we obtained maternal reports of infant temperament in order to explore the relations among temperament, learning performance and V_{na} .

First, we examined baseline V_{na} to assess whether low baseline level was associated with learner status or temperament. We did not have hypotheses about specific temperament dimensions and V_{na} , but planned to covary any observed correlates of V_{na} in the second phase of our analyses. Second, we observed vagal levels across all session minutes across the baseline, contingency and disruption/extinction phases. Our hypotheses about change in vagal level during contingency learning itself were informed by polyvagal theory (Porges, 1998, 2001, 2007; Porges & Furman, 2011). Contingency learning is a nonthreatening, stimulus-approach context rather than a defensive one, so we expected to observe steady vagal levels on average during the contingency phase. Regarding individual differences in learner status, we expected that infants who learned in a single contingency session might show a) higher baseline V_{na} than those who required a second session to demonstrate contingency learning, and b) evidence of increased V_{na} within the session. This hypothesis was based on Lewis et al.’s (2004) and Millar and Weir’s work (2007) suggesting that sustained attention (indexed by increased vagal tone or sustained HR) was consistent with a strong response to the contingency. Our hypothesis regarding the effect of contingency disruption on vagal tone was exploratory. Disruption of expected stimulation should be especially attention-getting to those infants who showed a strong contingency performance (i.e., Day 1 Learners), but two studies to date have been inconclusive. Among learners at this age, vagal tone increased from the end of the contingency phase in response to extinction/disruption, but levels did not differ from the baseline phase (Lewis et al., 2004). In another study, infants who learned in a single session sustained high behavioral responding during contingency disruption (Crossman et al., 2009). Sustained behavioral responding might require steady vagal levels rather than an increase, as infants are maintaining their attention and interest while they attempt to regain the disrupted contingency. In contrast to learners, we hypothesized that infants who did not learn in the initial session might show lower V_{na} levels during the session as this physiological pattern is associated with lower engagement and perhaps less efficient cardiac regulation, similar to the weak learners observed by Millar & Weir (2007).

Method

Participants

One hundred sixty, full-term, healthy 5-month-old infants (50% female) born in university-affiliated hospitals participated in this study. Both the hospitals' and the University's IRBs reviewed and approved the study. Mothers were initially contacted in the maternity unit shortly after delivery. A follow-up telephone call to those who expressed interest in participation was made when their infants were approaching 5 months of age. The study's procedures were reviewed at this time and at the lab visit, when parents signed the consent form. Participating families were offered reimbursement for transportation and received a gift pack of infant toiletries for their participation.

Participating infants were free of birth complications or known sensory and neurological deficits and were 38–40 weeks gestational age. The mean age of infants at the first lab visit was 21 weeks (149.3 days, $SD = 14.0$ days) and they were culturally diverse. See Table 1, section A for a summary of demographic characteristics of those recruited. Infants were predominantly White/Non-Hispanic (65%), but included the following minority groups: Black/African American, Hispanic, East and Southeast Asian, South-Asian, and multi-racial/ethnic. Birth-order ranged from first to fifth-born, but most were first or second births (86%). All but one mother had completed at least a high school degree, with a majority reporting post-secondary education. The majority of the mothers were married or cohabitating (90%). The fathers also had at least a high school diploma (98%) with more than half the sample reporting post-secondary education.

Thirty-six additional infants were recruited for study (18% of those recruited), but were excluded due to equipment issues (5), not returning for the second session (13), showing no evidence of contingency learning in either session (9), and having large amounts of either missing cardiac data, usually due to crying (9). This excluded a somewhat larger percentage of infants than studies of vagal tone using the still-face procedure (8%, Montirosso et al., 2014) and the mobile conjugate procedure (11% of full-terms; Haley, et al., 2008), but it was not different compared to the previously reported percentage for the pulling contingency (15%, Crossman et al., 2009). To be included in the analyses, infants had to have complete behavioral and cardiac data during the initial baseline phase and the contingency session and meet a minimum learning criterion in at least one session. The age and gender distribution of excluded infants did not differ significantly from the remaining sample.

Apparatus

Infants were trained in a three-sided booth while seated in an infant seat. The seat was placed approximately 62 cm from a monitor screen (17 in/43cm) mounted on the rear wall of the booth. Auditory feedback (at a level of 40–42 dB) was provided via speakers mounted on each side of the monitor.

A pulling response was chosen because of its efficacy with infants of this age and its ecological validity (Lewis, Sullivan, & Brooks-Gunn, 1985; White, Castle, & Held, 1964). An elastic terrycloth band placed on the infant's right wrist was connected via a ribbon to a

leaf switch (CM-2, Zygo Industries) mounted behind the booth directly below the screen. With a pull on the ribbon toward the body of sufficient force, a colorful image of a happy baby appeared, accompanied by a 3-second recording of children's voices singing the *Sesame Street* theme song. The ribbon had enough slack so that hand to mouth activity would not produce a response. Infant pulls were recorded by a Dell Optiplex 755 computer, which also controlled the timing and delivery of the slide and music during each session.

An EZ-IBI interbeat interval monitor (UFI, Morro Bay, CA) was used to monitor the infant's electrocardiogram (ECG) throughout the entire session. The monitor sampled ECG at 1 kHz with minimal artifact. Two disposable pediatric ECG leads (M3M Red Dot 2560 ECG electrodes; Respironics) were attached to the chest in a diagonal configuration: one on the left shoulder, one on the right side.

Procedure

There were two procedurally identical contingency learning sessions, scheduled 8–10 days apart, an interval associated with obtaining good retention data (Hitchcock & Rovee-Collier, 1996). The contingency sessions were scheduled at a time of day when parents reported that their infants were most alert and playful. Once the experimenter placed the ECG electrodes on the infants, parents were instructed to place their infants in the infant seat in front of the screen and place the terrycloth band on the infant's right wrist. Parents (usually the mother) sat out of camera view behind their infant throughout the sessions. They were instructed that they could speak to reassure their infant if the baby fussed. They also were told they could terminate the session if they felt at any time their infant became too upset by just saying so, but that fussing and crying was expected at the end of the procedure, when the "slideshow" would be turned off.

Sessions consisted of three phases: baseline, contingency, and disruption/extinction. The initial 2-minute non-reinforcement phase, *baseline*, assessed the level of pulling responses without additional stimulation. This was followed by a 6-minute *contingency* phase, during which each response activated the 3-s audiovisual stimuli. The 6-minute time interval was sufficient to observe contingency learning at 3 months of age in a kicking contingency task (Hitchcock & Rovee-Collier, 1996) and at 4 to 6 months of age in the pulling response task (Lewis, et al., 1985), but is brief enough to minimize boredom or crying (Crossman, et al., 2009; Hitchcock & Rovee-Collier, 1996; Lewis et al., 1985; Sullivan & Lewis, 2003). Following this, infants were given another 1-minute non-reinforcement phase; i.e., the *disruption/extinction* phase. If infants cried continuously for more than 60 seconds during any part of the procedure, the session was terminated for that day. Regardless of infants' performance in the first session, all were invited to return to the lab for a second session. This paper considers the data from the first session in relation to simultaneously collected cardiac measures and temperament.

Behavioral Measures

Learner status—All pulls were continuously recorded online throughout the sessions and the number per minute was calculated. Pulling rate was used to determine whether each infant met a minimum criterion of an average pulling rate across 6 minutes of the

contingency session equal to or greater than 1.15 times their average baseline pulling rate. This criterion has been used in previous studies as a gross measure of above-baseline responding, and has been shown to discriminate between those infants who rapidly respond to the contingency and those who do not (Crossman et al., 2009; Sullivan & Lewis, 2003). To apply this criterion to the data, we averaged the two baseline minutes in Session 1 to yield an average baseline rate, as a few infants made no pulling responses in the first baseline minute and to be consistent with the prior method of calculating the learning criterion. The baseline pulling rate was 5.00 pulls/minute ($M_{160} = 4.99$, C.I. 4.20–5.79), within the range observed for infants of this age (Crossman et al., 2009; Sullivan & Lewis, 1989; 2003). The Session 1 baseline pulling rate was used to determine the day on which each infant learned the contingency, as the subsequent pulling baseline (Session 2) reflects both initial baseline pulling and any cued recall of the prior experience in the apparatus (Hitchcock and Rovee-Collier, 1996). We applied the criterion to infants' pulling data before examining their physiological responses. The learning criterion allowed us to divide infants into two Learner Status groups: those who learned the contingency in one session (Day 1 Learners), those who learned after two sessions (Day 2 Learners). There were 119 Day 1 Learners and 41 Day 2 Learners. There were no differences in age or gender by Learner Status. The percentage of Day 1 Learners (74%) was similar to that of past studies using this procedure (Crossman et al., 2009; Lewis et al., 2004; Sullivan et al., 1992).

Cardiac Measures

After each session was completed, the cardiac data recorded during the baseline, contingency, and disruption/extinction phases was downloaded for further analysis. V_{na} (the index of parasympathetic control of heart rate by the vagal nerve) was calculated by Cardio Batch software (Brain Body Center, 2007) using the methods developed by Porges and colleagues (Doussard-Roosevelt, Porges, Scanlon, Alemi, & Scanlon, 1997; Porges, 1998) and described extensively elsewhere (Riniolo & Porges, 1997). A frequency range of 0.24 to 1.04 Hz was used, which is equivalent to the spontaneous breathing rate in infants under 1 year of age (Porges, 1991; Porges, 1992). V_{na} values were based on sequential 30-s epochs which were then averaged with minute, yielding a mean V_{na} level during each minute of baseline (2 minutes), contingency (6 minutes), and contingency disruption/extinction (1 minute). The values observed during the baseline phase estimate resting V_{na} as infants are seated in the apparatus and not exposed to any additional stimulation except the visual novelty of the test context.

Artifacts and data editing—The ECG signal output and heart period data were visually inspected for artifacts and edited with the inter-beat interval editor within the Heart Period Variability Analysis Program (Cardio Edit, Brain Body Center, 2007). The ECG data editors each completed reliability training and were certified by the Brain Body Center. Editing consisted of dividing intervals between heart beats when R-wave detections were missed, or adding intervals when faulty R-R detections occurred. Thus, aberrant values were adjusted automatically by integer addition and division of the sequential R-R intervals to fit the preceding and following intervals. Baseline cardiac records of all infants were 95% artifact free while those from the contingency and disruption phases required editing of approximately 10% of records due to artifacts. The number of minutes with edited data

points for Day 1 Learners (5% of the cases) was 2–6; for Day 2 Learners (6% of the cases) the number was 1–5.

Maternal Reports of Infant Temperament

Mothers completed the Infant Behavior Questionnaire (IBQ, Rothbart, 1981) at the initial lab visit. IBQ is a well-constructed, widely-used, and reliable maternal report of infant temperament. It rates the following six behavioral dimensions on a 0–7 scale: activity level, smiling/laughter, fear, distress to limits, soothability, and duration of orienting.

In addition, we created composite scores of positive and negative temperament using principal components analysis (PCA). Although factor analyses of IBQ are reported in the literature, the results were not directly translatable to this study. Rothbart (1986) generated positive and negative temperament composites that did not include the duration of orienting scale in her analysis, and included observed vocal responsiveness in the home, a measure not available in this study. Goldsmith and Campos (1990) and Kochanska, Coy, Tjebkes, & Husarek (1998) each reported factors of IBQ for 8–10 month-olds that were similar for the negative composite. The components of the positive composite differed in each study. Activity level was a separate factor for Goldsmith & Campos (1990), with the remaining scales loading on the positive factor. Both soothability and activity were included in Kochanska et al.'s (1998) positive factor. Given this variation, as well as the age difference and the greater diversity of the present sample, PCA allowed us to create composites that best reflect the sample data. Factor weights less than .6 were suppressed to identify the most strongly related components. VARMAX and oblique rotations yielded similar solutions of two factors with eigenvalues greater than 1.0. For this study the VARMAX rotation, accounting for 53% of the variance in temperament, was used. Smiling/laughter and duration of orienting (factor weights .70) constituted the positive temperament factor (28% of variance), and Distress to Limits and Fear (factor weights .60) constituted the negative temperament factor (25% of the variance). The negative factor replicated that reported in previous studies (Goldsmith & Campos, 1990; Kochanska et al., 1998; Rothbart, 1986), but the positive factor included only two dimensions unlike the previous reports. The IBQ dimensions loading on each factor were summed to create separate positive and negative temperament composites.

Analytic Plan

As a preliminary step, we inspected the minute-by-minute pulling data of the infants to validate that the Learner Status variable reflected actual differences in contingency response. Mean contrasts were used to test that there were between group differences in pulling rates during baseline and during disruption/extinction by Learner Status. Within group change in performance from 1) baseline to the final contingency minute and 2) from this minute to disruption/extinction were confirmed using paired t-tests. We also checked whether demographic variables were potential confounds of Learning Status. Following this preliminary validation of learner status, we examined 1) baseline V_{na} level in relation to Learner Status and IBQ scores, and 2) variation in V_{na} level over the contingency session in relation to Learner Status. Table 2 summarizes the research questions for each level of analysis, the groups included, our hypotheses, and the analytic methods.

RESULTS

Preliminary Analyses

Validation of Learner Status—Figure 1 shows the minute-by-minute pulling rate of all infants in the first session by Learner Status. As can be seen in Figure 1, Day 1 Learners had lower baseline pulling than Day 2 Learners ($t_{158}=3.12, p < .005$). The *mean difference* in baseline pulling of between the Learner Status groups was significant, *mean difference* = 2.81, *CI* [1.03, 4.59]. As can be seen in the figure, Day 1 Learners pulled more during the contingency minutes with gradual, sustained increases during the session. For the Day 2 Learners, pulling during the contingency minutes represented significantly decreased responding (baseline vs. contingency response: *paired* $t_{40} = -4.57, p < .001$). During the disruption/extinction phase, Day 1 Learners sustained a high pulling rate. In contrast, Day 2 Learners did not pull at a rate significantly different from their baseline, $t_{40}=1.90, p < .06$; *mean difference* = 1.78, *CI* [-.070, 3.62]. Day 2 Learners never exceeded their baseline pulling rate during the session.

The Session 2 data was not analyzed formally. However, we noted that baseline pulling of Day 1 and Day 2 Learners did not differ significantly during the second session (Day 1 Learners, 6.27 *SE* = 0.64 vs. Day 2 Learners, 5.00 *S.E.* = .42) and that these two groups did not differ during the contingency phase during Session 2 (See Figure 2). This pattern was consistent with the group classification, and supported the hypothesis that the initial response to the contingency might be the most informative with respect to individual differences.

Potential confounds—It was important to ensure that the observed group differences in contingency learning were independent of demographic characteristics. Therefore, we checked whether Learner Status varied by infant age, gender, birth weight, birth order, maternal age, paternal age, maternal schooling, paternal schooling, and minority ethnicity. None of these demographic variables predicted Learner Status (See Table 1, section B).

We also checked whether any temperament dimensions were related to Learner Status. Table 3 presents the data for the IBQ dimensions by Learner Status. There were no main effects or interaction observed for any IBQ dimension in a Multivariate ANOVA. That is, Learner Status ($F_{6, 151} = 0.48, p = .82$), gender ($F_{6, 151} = 1.78, p = .11$), and their interaction ($F_{6, 151} = 0.52, p = .79$) were not significant for any of the six IBQ dimensions. The analysis for the positive and negative composites, also found no effect of Learner Status ($F_{1, 151} = 0.24, p = 0.12$). Thus, differences in Learner Status, reflecting more versus less strong response to the contingency, were not associated directly with differences in infant temperament.

Question 1a: Learner Status and Baseline V_{na}

Table 4 presents the means and standard deviations of V_{na} by Learner Status over all session minutes. The top row presents the data for Baseline V_{na} . Learner Status was regressed on infant gender, and baseline V_{na} . Neither gender nor baseline differences in V_{na} were related to Learner Status. The interaction also was not significant.

Question 1b: Temperament, and V_{na} During Baseline and Other Session Minutes

IBQ temperament was uncorrelated with baseline V_{na} , and with V_{na} level in most contingency minutes, but one dimension, soothability, was correlated with V_{na} in the final contingency minute ($r_{159} = .27, p < .01$). Higher V_{na} level in this minute was related to higher maternal ratings of soothability. When this correlation was examined separately by Learner Status, this relation was stronger for Day 2 Learners. Among Day 2 Learners, V_{na} levels during the final contingency minute were significantly correlated with soothability ($r_{40} = .42, p < .05$). Among Day 1 Learners, there was little relation of V_{na} and IBQ soothability during this minute ($r_{118} = .18$, respectively, *ns*). As soothability showed some relation to V_{na} level and this relation varied with Learner Status, soothability was retained as a covariate in subsequent analyses.

Question 2: Vagal Levels during the Session as a Function of Learner Status

Having established that Baseline V_{na} and Learner Status were unrelated, we next examined whether differences in Learner Status were associated with differences in V_{na} level during the contingency session. We used the General Linear Model with repeated measures to compare V_{na} trajectories of Day 1 vs. Day 2 Learners over minutes of contingency and its disruption. The repeated measure was V_{na} level (8 minutes: baseline, 6 minutes contingency, and disruption/extinction). Recall that disruption/extinction consisted of non-reinforcement. Learner Status was the fixed, between subjects factor. Baseline pulling and soothability were included as covariates in the analysis. Baseline pulling was included since the Learner Status groups differed in their behavioral activity during baseline and this increased pulling activity might be associated with differences in heart rate and therefore, V_{na} level (Lewis et al., 2004). Soothability was included because of its observed correlations with V_{na} . The analysis met the assumptions of homogeneity of variance. Greenhouse-Geisser-corrected univariate statistics are reported as the sphericity assumption of the model was not met. There was no effect of minutes ($F_{7, 770} = 0.48, p = .82$), and no main effect of Learner Status ($F_{1, 152} = 0.48, p = .82$), or baseline pulling ($F_{1, 152} = 0.48, p = .82$). However, Learner Status interacted significantly with Soothability ($F_{(1, 156)} = 8.52, p < .004, \text{partial } \eta^2 = .06, \text{power} = .83$).

To plot this interaction, we created a median split on soothability ratings (50% of Day 2 Learners were rated as low in soothability and 48% of the Day 1 Learners were rated as low in soothability). As shown in Figure 3, the vagal levels of Day 2 learners differed by Soothability, with less soothable infants showing significantly lower vagal levels than more soothable Day 2 learners, mean V_{na} difference = 1.00, $SE = .49, p < .03; CI [0.97, 1.87]$. This difference was not reflected in baseline pulling rates which did not differentiate the two soothability groups; $F_{1, 41} = 1.40, p = .14, ns$. Less soothable Day 2 Learners did tend to pull at lower rates overall session minutes than more soothable Day 2 Learners, but not significantly ($F_{1, 41} = 3.07, p = .08, ns$). There were no differences in either vagal tone level or pulling rate as a function of soothability among Day 1 Learners. Vagal levels of the more soothable Day 2 Learners did not differ from either group of Day 1 Learners.

To explore the interaction in greater detail, we re-ran the analysis, omitting baseline pulling as a covariate and incorporating Soothability Group as a factor. Minute was the repeated

measure as before. Figure 4 shows vagal tone levels during baseline, contingency minutes 1–6, and disruption by Learner Status and Soothability. Learner Status remained significant; $F_{(1, 156)} = 89.72, p < .03, \text{partial } \eta^2 = .04, \text{power} = .70$. The interaction Soothability by Learner Status interaction was weakened; $F_{(1, 156)} = 23.60, p < .10, \text{partial } \eta^2 = .02$.

Post-hoc exploration of mean differences between the four Learner Status/Soothability groups (Day 2/Low Soothable; Day 2/High Soothable; Day 1/Low Soothable; Day 1/High Soothable) were conducted using *Dunnett t*. The Day 2/Low Soothable group, with its low vagal level, was selected as the control comparison for the multiple planned contrasts. The results indicated that group differences were confined to the disruption minute. That is, there were no significant differences in vagal tone level during the baseline or any contingency minute as a function of the combination of learner status and soothability. However, during disruption, Day 2/Low Soothable Learners had lower V_{na} levels compared to Day 2/High Soothable Learners ($t=1.13, SE = 0.47, p = .025, CI = .18$) and compared to Day 1/Low Soothable Learners ($t=0.82, SE = 0.40, p = .048, CI = -.01$). They did not differ from Day 1/High Soothable Learners (n.s., $p = .10$).

Discussion

This study used contingency learning as a vehicle to examine individual differences in young infants' vagal tone in relation to learning status. The behavioral response of Day 1 and Day 2 Learners was consistent with previous reports (Crossman et al., 2009) and was unaffected by social demographic variables, consistent with a recent meta-analysis (Gerhardstein, Dickerson, Miller, & Hipp, 2012). Given this learning difference, we asked two questions: 1) Is lower baseline vagal tone related to learner status and/or to maternal reports of infant temperament; and 2) when infants don't respond to a contingency within a single session, do their vagal tone levels during the session differ from those who do? We also explored whether temperament had any influence on the observed differences.

First, consider the findings with regard to baseline V_{na} . The hypothesized effect of lower baseline V_{na} on contingency responses was not supported. Trait-like aspects of vagal tone were evident in the stable relations between baseline and subsequent contingency minutes, and in the relation of vagal tone to maternal reports of soothability. However, lower vagal tone during contingency learning was not associated with learner status, one estimate of learning efficiency. Those with lower baseline vagal tone in this study were no more likely to require a second session to demonstrate contingency learning than those with higher levels. Although our prediction regarding baseline vagal tone was not supported, the findings provide a positive "take away" message. Given a sufficiently salient contingency, infants with lower vagal tone during baseline did respond adaptively and so, were not disadvantaged by their lower baseline parasympathetic physiology. Factors other than low baseline vagal levels must account for the differences in subsequent contingency performance. Our analyses showed that one aspect of temperament, soothability, may be an important qualifier of this hypothesis. Alternatively, it is possible that this sample did not include infants with sufficiently low baseline V_{na} to demonstrate the hypothesized overall negative impact of low vagal tone level.

Second, in considering how vagal levels might differ as a function of contingency performance, we predicted one of two possible vagal patterns might characterize learning in the first session: We expected Day 1 Learners to show either sustained vagal tone levels throughout the contingency, or augmented V_{na} in the service of increased attentional demands. In contrast, we expected Day 2 Learners to show lower vagal levels. Both vagal patterns were observed, but they were not associated with learner status as expected.

For both groups of infants, even as pulling rate changed during the session, increasing for Day 1 Learners and decreasing for Day 2 Learners, vagal levels maintained a “steady state” over the session with no mean differences by Learner Status or minute. Overall, this pattern supports the view that vagal tone during contingency learning is related generally to the maintenance of calm attention states via vagal tone (Porges, 1991, 2001, 2007). Infants slower to respond to contingencies (Day 2 Learners) did not have lower parasympathetic physiology on average, but the 50% of infants in this group who were perceived by mothers as lower in soothability had the lowest vagal tone levels of all groups. It was the combination of lesser response to the contingency and lower soothability in this subgroup that qualified our initial hypothesis of lower vagal tone and less robust response in Day 2 Learners.

Temperament and learning

Of all the IBQ dimensions, soothability emerged as an important influence on vagal levels during contingency learning and its disruption. A soothable temperament influenced vagal tone levels only among Day 2 Learners. The vagal levels of Day 1 Learners did not differ as a function of maternal ratings of soothability. Among Day 2 Learners, less soothability meant lower vagal tone levels throughout the session, and especially during disruption. Vagal tone levels of less soothable Day 2 Learners differed from that of their more soothable Day 2 counterparts and from low soothable Day 1 Learners during this minute. The lower vagal tone of less soothable Day 2 Learners may indicate that they were less able to focus sustained attention on the contingency, in part, due to poorer ability to dampen negative affect. In contrast, the higher levels of vagal tone among more soothable Day 2 Learners may reflect a capacity for sustaining focused attention.

Understanding the behavioral implications of maternal soothability also seems important in interpreting our findings. Reports of greater soothability may reflect maternal perceptions that their infants' attention can be refocused or distracted by stimulus change. During the contingency and when it was disrupted, the more soothable Day 2 infants sustained their attention despite the fact that their behavioral performance suggested little behavioral response to the contingency. In contrast, the less soothable Day 2 learners had the lowest in vagal tone of all groups, in response to the disruption suggesting low engagement throughout.

Limitations

There are several limitations which can be noted in regard to this study: a lack of concurrent measures of visual fixation, inclusion of only a parasympathetic measure of cardiac regulation, use of an older temperament tool, and the limited disruption/extinction phase.

First, we did not score changes in looking behavior or gaze direction in this study since heart rate change mediated by vagal tone is a valid and sensitive measure of attention. We felt justified in doing this as direct measures of looking behavior would not yield information about attention in the same way that vagal tone can. Moreover, selection of an looking appropriate metric is problematic. Looking at the contingent display in this procedure is consistent during contingency activation and infants will often remain fixated on the screen after the audiovisual event ceases. Other investigators have also reported that looking at the stimulus source approaches 80% or more in contingency studies (Rovee-Collier & Gekoski, 1979; Sullivan & Lewis, 1989; Weir, Soule, Bacchus, Rael & Schneider, 2000). This differs from habituation studies wherein looking at a visual target and then away over time defines the phenomenon. In learning studies, infants will also often look at their hand and the ribbon after or while they are pulling, so “attention to the contingency” cannot be defined exclusively as looking at a particular location (Sullivan & Lewis, 1989). Anticipatory looking is also not an option as anticipatory looking and contingency response are unrelated at this age. Anticipatory looking emerges by about 10 months of age (Johnson, Posner & Rothbart, 1991; Kenward, 2010). Collectively, these studies suggested to us that looking behavior might not be especially informative. On the other hand, vagal tone differences have shown differences in attention processes in the absence of fixation differences (Brez & Colombo, 2011). Thus vagal tone provides a unique, and potentially useful, perspective on how an attentive state is sustained or altered during infant contingency learning in contrast to fixation or gaze direction.

Second, to best appreciate the dynamics of cardiac regulation and the balance of autonomic nervous system components during contingency learning and disruption, observation of both parasympathetic and sympathetic influences are needed. Yet, studies of young children rarely assess both sympathetic and parasympathetic regulation simultaneously (but see Buss, Goldsmith, & Davidson, 2005). Sympathetic influences can be studied relatively non-invasively in infants through the measure of pre-ejection period (DeHaan, 2015). However, to do so requires additional electrodes and impedance cardiography. Adding this apparatus was judged to sufficiently lengthen preparation time and to burden infants’ tolerance that we decided against it. We sacrificed the measure for the likelihood of maintaining more infants in the procedure.

Third, our use of the original IBQ (Rothbart, 1981) rather than the IBQ-R (Gartstein & Rothbart, 2003) may be regarded as a limitation; however, it also was a practical choice. Both versions of the instrument are still available. The original IBQ takes 20–30 minutes to complete versus the hour-long IBQ-R (<http://www.bowdoin.edu/~sputnam/rothbart-temperament-questionnaires/faq/#Answer10>). Most contingency work examining temperament used the original IBQ, so we chose to make the current study more directly comparable to past literature rather than use the newer IBQ-R with its additional scales. The length of the IBQ-R has prompted the development of shorter forms, which were developed while this study was in progress. Replication studies should make use of these, as validity and reliability studies comparing them with the full IBQ are now available (Putnam, et al., 2014).

Fourth, the use of one minute of disruption is a limitation restricting our understanding how infants adapt to the disruption of extinction. It is doubtful that additional disruption/extinction minutes can be added to one session, as most infants begin to cry as this phase lengthens, leading to loss of both behavioral and physiological data. One solution is to increase the number of sessions to see if and how disruption/extinction becomes tolerated. But multiple visits to the lab may be burdensome for parents, leading to participant drop-out. Another solution might be to observe vagal levels over alternating, shorter periods of contingency and disruption/extinction. This study suggests that four or five minutes of contingency is sufficient to get a reliable index of vagal level as well as increased behavioral response to the contingency. It might be possible to alternate brief disruption/extinction phases with shorter contingency phases to better assess vagal change over these repeated disruption/extinctions, and approximate the sequential paradigms used with older infants.

One final comment on limitations: The contingency offered in our lab is an invariant stimulus delivered in a fixed ratio to the infants' responses. Its standard nature makes it "insensitive" compared to conjugate reinforcement used with younger infants or to sensitive maternal behavior, which is dynamically modulated and synchronized to the infant as the partners interact. While this "insensitive" characteristic itself might be regarded as a limitation by those interested in maximizing the number of infants who learn, the fact that there are differences in response to this type of contingency is of some interest. For the majority of infants in our study, active, engaged behavior supported by parasympathetic control characterized responses to the contingency, suggesting that most could tolerate its relative insensitivity. For some, though, responding was more tentative initially. These infants were able to learn the "less sensitive" contingency with a second experience. The evidence suggests their behavioral and emotional responses to the contingency are equivalent given that additional experience (Crossman et al., 2009). Contingency experience in one session offered them an extended period to attend and a second session gave them the opportunity to demonstrate learning. The additional experience (or perhaps more sensitive, modulation of stimulation) seems to be needed by these infants to support their learning and engagement.

Summary

Even in a context meant to engage infants, not all will respond in the same way. Moreover, when infants appear not to learn, they may not have performed for different reasons. Contingency learning differences within typical samples, as opposed to those at-risk, may be useful in understanding individual differences in attention and adaptive processes, since "simple" contingency learning involves coordination of multiple systems. When infants do not respond rapidly to potentially pleasant, contingent stimulation, differences in parasympathetic regulation, specifically vagal tone, and soothability each contribute to this outcome. Such differences likely have broader implications both for infants' general encounters with nonsocial contingencies as well as with contingent social interactions.

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Figure 1. Pulling over minutes in response to initial contingency exposure as a function of learner status (Day 1 Learners, Day 2 Learners). Standard error bars are shown.

Figure 2.

Pulling over minutes in response to a second contingency exposure as a function of learner status (Day 1 Learners, Day 2 Learners). Standard error bars are shown.

Figure 3. Average vagal tone level by learner status (Day 1 Learners, Day 2 Learners) and median split of IBQ soothability ratings. Standard error bars are shown.

Figure 4. Vagal tone level during a contingency session as a function of learner status (Day 1 Learners, Day 2 Learners) and median split of IBQ soothability ratings. Standard error bars are shown.

Table 1

Descriptive Statistics for Demographic Variables for a) the Full Sample and b) by Learner Status

	A. Recruited Sample (N=196)	B. Learner Status Group		
		Excluded Non Learners (n =36)	Learned Day 2 (n =41)	Learned Day 1 (n=119)
Variable	Mean (S.D.)	Group Means (S.D.) ^a		
Infant's age in weeks	21.50 (1.66)	21.75 (1.64)	21.25 (0.84)	21.50 (.93)
Birth order	1.7 (0.90)	1.9 (0.88)	1.5 (0.60)	1.7 (0.87)
Birth weight	7.47 (1.38)	7.17 (1.03)	7.26 (1.04)	7.22 (1.22)
Age of Mother	32.05 (4.81)	31.58 (5.99)	32.42 (4.15)	32.15 (4.67)
Age of Father	34.05 (5.71)	31.3 (11.0)	36.0 (5.43)	34.8 (4.96)
	Percentage	Percentage of Group ^b		
Married or Co-Habiting	90%	99%	90%	95%
Ethnicity:				
White/Non-Hispanic	65%	69%	63%	67%
Black or Hispanic	9%	8%	13%	10%
East Asian or Indian Subcontinent	8%	9%	3%	13%
Multi-ethnic or Not Reported	17%	14%	21%	10%
Parental Education:		Post-secondary education completed		
Mothers	73%	69%	71%	74%
Fathers	61%	51%	63%	58%

^aNo mean differences were observed by one-way ANOVA and Bonferroni-corrected contrasts.^bNo group differences in percentages were observed by *Chi Square*.

Table 2

Summary of Hypotheses and Analytic Plan

Question	Measure/Groups	Hypothesis	Analytic Tools
1. Are individual differences in a) learning, or b) temperament related to baseline V_{na} levels?	Baseline V_{na} level a. Day 1 vs Day 2 Learners b. All learners and by Learner Status	a) Baseline V_{na} will be related to Learner Status: Day 1 Learners are may have higher baseline V_{na} . b) Less negative and/or less positive temperament may be related to higher baseline V_{na} .	a) Logistic Regression b) Correlation of temperament dimensions and composites with baseline V_{na} . Follow-up of specific dimensions if warranted.
2. Do V_{na} levels during the contingency session differentiate those who learned on Day 1 from those who Learned on Day 2?	V_{na} levels during learning and disruption Day 1 vs Day 2 Learners	V_{na} levels in at least some minutes will distinguish infants who learned on Day 1 as opposed to those who learned on Day 2. V_{na} levels in Day 2 Learners may show little or no change during the session.	MANOVA of V_{na} levels using General Linear Model with repeated measures (minutes): a. Polynomial contrasts assessing differences in over minutes, if a main effect of minutes is observed. b. Follow-up analysis of interactions with Learner Status via planned contrasts. Correction for multiple comparisons in assessing interactions.

Table 3IBQ Temperament Dimension Scores by Learning Status (N=160)^a

IBQ Temperament Scale Ratings	Learning Status After Two Sessions	Mean	Sd. Error	95% Confidence Interval	
				L. Bound	U. Bound
Activity	Learned day 2	3.89	.134	3.62	4.15
	Learned day 1	4.03	.079	3.87	4.18
Pleasure	Learned day 2	5.05	.147	4.76	5.34
	Learned day 1	5.04	.086	4.87	5.21
Distress to Novelty	Learned day 2	2.52	.132	2.26	2.78
	Learned day 1	2.47	.077	2.32	2.62
Duration of Orienting	Learned day 2	4.61	.162	4.29	4.93
	Learned day 1	4.58	.095	4.39	4.76
Distress to Limits	Learned day 2	3.41	.128	3.16	3.66
	Learned day 1	3.50	.075	3.35	3.65
Soothability	Learned day 2	5.33	.159	5.02	5.65
	Learned day 1	5.15	.093	4.97	5.34
Positive Temperament	Learned day 2	9.91	.259	9.10	10.12
	Learned day 1	9.35	.157	9.16	9.78
Negative Temperament	Learned day 2	6.12	.223	5.68	6.56
	Learned day 1	6.00	.135	5.74	6.01

^aNo group differences were observed in any of the six IBQ temperament dimensions or the positive or negative temperament composites in MANOVA.

Table 4

Descriptive Statistics for Vagal Tone Level by Learner Status During the Contingency Learning Session

	Status Group	Mean Level ^a	(S.D.)
Baseline			
	Learned Day 2	3.54	(1.45)
	Learned Day 1	3.72	(1.31)
Contingency Minute 1			
	Learned Day 2	3.64	(1.73)
	Learned Day 1	3.70	(1.37)
Contingency Minute 2			
	Learned Day 2	3.52	(1.48)
	Learned Day 1	3.81	(1.33)
Contingency Minute 3			
	Learned Day 2	3.57	(3.31)
	Learned Day 1	3.65	(1.36)
Contingency Minute 4			
	Learned Day 2	3.61	(1.67)
	Learned Day 1	3.71	(1.38)
Contingency Minute 5			
	Learned Day 2	3.58	(1.79)
	Learned Day 1	3.81	(1.39)
Contingency Minute 6			
	Learned Day 2	3.69	(2.04)
	Learned Day 1	3.58	(1.17)
Disruption/Extinction			
	Learned Day 2	3.52	(1.77)
	Learned Day 1	3.54	(1.25)

^aThere were no mean differences in vagal tone by Learner Status during the session.