HOW EMOTIONS AFFECT RESPIRATORY SINUS ARRHYTHMIA

By

LINDSEY ANN FISCHER

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Dr. John J.B. Allen
Department of Psychology

Abstract

Respiratory sinus arrhythmia (RSA) is a measure of heart rate variability in relation to respiration. The current study investigated how the different induced emotional states (i.e., amusement, anger, disgust, happiness, fear, and sadness) affect RSA. This was done by comparing resting RSA to that occurring while watching short film clips intended to induce emotional states. It was hypothesized that RSA would be lower when negative emotions are induced and higher when positive emotions are induced. A difference between the resting RSA and RSA measured during emotion induction was also anticipated. Results indicated a marginally significant difference in RSA between film clip 1 and resting with eyes open and between film clip 1 and film clip 2. There was also a trend in RSA between male and female participants.

Introduction

Respiratory sinus arrhythmia (RSA) is a naturally occurring variation of heart rate in which the heart rate increases during inspiration and decreases during expiration (Berntson et al., 1993). RSA is used to gather data about the relationship between heart rate and respiratory rhythm and is measured using the R-R interval within the QRS complex, which is viewed by recording a heart rate with an electrocardiogram (EKG). It has been shown to be affected by tidal volume, breathing frequency, and age (Hirsch & Bishop, 1981), so that when tidal volume is increased, RSA amplitude increases at each breathing frequency. Additionally, research has found an inverse relationship between RSA amplitude and age in which there is a decrease in RSA amplitude with increasing age and heart rate (Hirsch & Bishop, 1981). RSA is used often in psychophysiological studies to measure vagal control of the heart and is a noninvasive way to measure parasympathetic control of cardiac functions (Berntson et al., 1993). It is also used as a predictor of emotional regulation; linked to emotion through the vagus nerve. The activity of this cranial nerve causes the fluctuations in heart rate coinciding with respiration. Research has demonstrated that RSA is determined by the activity of vagal fibers that begin in the medullary nucleus ambiguous and end in the sino-atrial node of the heart (Berntson et al., 1997). The nucleus ambiguous also has efferent nerves that enervate the larynx, which aids in communicating emotional states. Afferent fibers of the nucleus ambiguous are also believed to terminate in facial nerves, which control facial expressions (Porges, 1997). Given the direct influence that the vagus nerve enervates other regions closely associated to emotional expression, and the fact that RSA has been understood to be a measure of vagal control, it is logical that it has been utilized in numerous studies to investigate emotions.

Research has investigated the relationship between RSA and negative emotions such as worry and anxiety (Kogan et al., 2012; Watkins et al., Greaves-Lord et al., 2010; 1998; Sack et al., 2004; Hofmann et al., 2005). These studies have shown that RSA can reliably predict anxiety and is a dependable method, which is why it is often used to predict how well an individual will cope with anxiety-inducing situations. Kogan et al., (2012) researched cardiac vagal control as a prospective predictor of anxiety in women diagnosed with breast cancer. They found that RSA predicted the change in anxiety during the participant's follow-up period after overcoming cancer. It showed that participants with a higher baseline RSA had decreasing anxiety during the follow-up period and participants with a lower baseline RSA had increasing anxiety (Kogan et al., 2012). Similarly, Watkins et al. (1998) found RSA was significantly reduced in healthy participants with high trait anxiety scores, and research by Greaves-Lord et al. (2010) reported that low RSA predicted future anxiety levels in girls 2 years after they took a self-reported anxiety assessment. Another study using participants diagnosed with posttraumatic stress disorder (PTSD) showed that RSA decreased from the baseline when participants with PTSD were exposed to trauma-inducing stimuli. It also found that participants with low baseline RSA had more prolonged heart rate increases while viewing the trauma-inducing stimuli than participants with high baseline RSA (Sack et al., 2004). Taken together, theses studies suggest that low RSA is associated with and increase in anxiety, while high RSA is more indicative of low levels of anxiety.

Furthermore, reduced RSA has been used as an indicator of a greater display of emotions in response to negative affective stimuli in the form of film clips. A study by Demaree et al. (2004) showed that participants with low RSA were less able to amplify their facial expression when viewing a negative film than those with higher RSA. Those with low resting RSA also had a more negative facial response to the negative film under natural-watch conditions. This suggests that with negative stimuli, cardiac vagal control is inversely related to negative facial expression but positively related to facial regulation ability (Demaree et al., 2004).

RSA has also been studied in relation to depression. Licht et al. (2008) investigated if heart rate variability was lower in depressed individuals relative to healthy controls. The data analyzed was from a large depression cohort study from The Netherlands Study of Depression and Anxiety. It was found that individuals with a diagnosis of major depressive disorder (MDD) either earlier in life or currently had a lower mean RSA in comparison to the controls who were never diagnosed with MDD. They also found that depressed individuals who were using selective serotonin reuptake inhibitors, tricyclic antidepressants, or other antidepressants had significantly shorter RSAs compared to both the controls and depressed individuals not taking medication (Licht et al., 2008). However, another study that focused on the relationship between RSA reactivity over the course of depression showed that baseline RSA values in people not fully recovered from MDD were higher, although not significantly, than those for fully recovered depressed people (Rottenberg et al., 2005). This is contradictory to literature suggesting low baseline RSA to be associated with higher levels of depression and anxiety. Nonetheless, similarly to Rottenberg (2005), Chambers and Allen (2002), found that the baseline RSA was not related to baseline depressive severity. The findings also showed that an increase in RSA from before treatment to after treatment was related to a decrease in depression severity (Chambers & Allen, 2002). The mixed results in this area of study highlight the importance of further research on how emotion affects RSA, particularly in relation to positive emotions, which have received little attention.

Despite the relative interest in trait emotionality and RSA, it has been suggested that RSA is not capable of measuring induced short-term emotion. A yearlong study by Oveis et al. (2009) investigated the relationship between resting RSA and phasic reactivity to stimuli inducing positive emotion, as well as resting RSA and individual differences in positive and negative emotion. Interestingly, the results of the first aim of this study showed that resting RSA was associated with baseline positive emotions but not with phasic positive or negative emotions in response to emotion-inducing stimuli. The lack of effect on RSA was also shown in other studies that used film clips as stimuli. These studies failed to elicit effects of film content on RSA or the results were inconsistent (Baldaro et al., 2001; Demaree et al., 2006; Frazier et al., 2004). The results of the second aim indicated that during the participants' first year of college, the researchers found that the resting RSA was positively associated with trait optimism at 1 month and 6-8months, while trait pessimism was negatively correlated with resting RSA at 1 month and 6-8 months. This illustrates that resting RSA is associated with tonic positive emotionality but not with tonic negative emotionality.

The relationship between RSA and positive emotions has been relatively understudied. Herring et al. (2010) studied the subjective experience, behavior, and physiological responses during amusement and joy. The results showed there was no difference in RSA for participants watching film clips aimed to induce both amusement and joy. The author suggests that this may be because RSA is more closely associated with long-term tonic positive emotionality than short-term phasic positive emotionality. As a result, RSA was not sensitive enough to measure differences in the short-term emotion induction (Herring et al., 2010). Research to date has primarily focused on the relationship between RSA and negative emotions, such as anxiety and worry, rather than investigating a wider spectrum of human emotions. An area of research that has received little attention is that relating vagal control and RSA to positive emotions such as happiness and amusement. For this reason, the purpose of the current study is to expand on the relationship between negative emotions and RSA, while also exploring its relationship to positive emotion and the potential difference between them.

The data for the current study is part of a larger study investigating the effect of induced emotions on even related brain potentials (Zambrano-Vazquez, Dieckman, & Allen, unpublished). Different emotional states (i.e., amusement, anger, disgust, happiness, fear, and sadness) were induced via film clips while electroencephalogram (EEG), an electrocardiogram (EKG), and electromyogram (EMG) were recorded. Only the EKG data was considered for purposes of this study. The current study aimed to investigate whether there is a significant difference between positive and negative induced emotions in vagal control as measured by the state of RSA. It was hypothesized that regardless of emotion valence there would be a significant difference in RSA under emotion induction condition relative to a baseline period; and that RSA would be lower when negative emotions were induced and higher when positive emotions were induced.

Methods

Participants

The participants for this study were recruited through the University's Introductory Psychology course. There were 22 males and 15 females with an average age of 19.25 years. The demographic breakdown is shown below in table 1.

Table1: Demographics

	Hispanic/Latino Ethnicity*	African-American	Asian	Caucasian	Other	Total
Male	4	1	4	14	3	22
Female	3	0	2	9	4	15

*Participants that identified as Hispanic or Latino ethnicity, first identified a race therefore the number of Hispanic participant are accounted within the total of other races.

Procedure

The present study was a between-subjects design with participants randomly assigned to induction of one of six potential emotional states (amusement, anger, disgust, happy, fear, or sad).

After the consent form was presented, the participants were prepped for EEG recording (per purpose of original study), which included EKG recording as detailed below. Participants then completed a set of demographic questions followed by the recording of a resting baseline. Instructions and practice trials for the task utilized for purposes of the original study were presented by using an emotionally neutral "practice" film clip. The participants then completed an initial emotion assessment via a Likert scale. Next the participants watched a clip intended to induce an emotional state. Participants then completed two blocks of 40 trials of a modified Erikson flankers' task, with frames of scenes from the clips shown between each trial in order to maintain mood throughout the task. A second clip inducing the same emotion was presented followed by two more blocks of 40 flankers trials. Once the trials were completed, a Likert scale was used to determine how the participant felt about the two film clips that were presented. Once the experiment was completed, participants were debriefed about the purposes of the original study. For the current report, only EKG data from the resting period and from the time during which participants watched the emotion clips were used.

Stimuli and Measures

The emotions were induced using two 1-2 minute film clips intended to stimulate amusement, anger, disgust, happiness, fear, or sadness, all of which were previously validated (Dieckman, Zambrano-Vazquez, & Allen, in preparation). The following movies were used: Anger: *My Bodyguard* and *Strange Days*; Disgust: *Dead Alive* and *Salo*; Fear: *The Ring* and *Halloween*; Happy: *Mrs. Doubtfire* and *Napoleon Dynamite*; Sad: *The Champ* and *Legends of the Fall*. Prior to each clip participants were presented with a brief introduction paragraph to provide a context for the scene. The clip was presented without sound. A Likert scale was used to determine how strongly the participant felt the emotion. The EKG data from this study, recorded from electrodes placed on the participant's collarbones, was used to determine RSA.

EKG data was recorded using a Lead 1 setup on a Neuroscan Synamps2 system (Charlotte, NC). Silver-Silver Chloride (Ag/AgCl) electrodes were attached to the participant's left and right collarbones, with a ground electrode at a recording site on scalp (just anterior of electrodes Fz of the 10-20 system; Jasper, 1958). The data was sampled at 1000 Hz and was recorded continuously in AC mode with bandpass filter of 0.5-200Hz. After data collection, raw digitized EKG data was reviewed using QRSTool to identify interbeat interval (IBI) series (Allen et al., 2007). Data were hand-scored and corrected for artifacts such as missed, erroneous, or ectopic beats to minimize the effect of these artifacts on estimates of respiratory sinus arrhythmia. Heart rate variability (HRV) was then derived using CMetX Cardiac Metric Software (Allen et al., 2007), from which an estimate of RSA was calculated from the high frequency band (0.12 - 0.4 Hz) for each minute block during the resting period for each participant. The estimate of RSA was the natural log of the variance of this filtered waveform.

Results

To analyze the data a 4 (Segment) x 2 (Valence) repeated measures ANOVA was used with RSA as the dependent variable. The different clips were clustered together to compare the effect of emotion valence (e.g., positive vs. negative) on RSA. Additionally, segment effects (e.g., resting with eyes open, closed, clip 1, and clip 2) were investigated within participants. It was hypothesized that a significant segment effect would be observed that indicated a difference in RSA between resting and clip periods. The results of this experiment show a marginally significant effect ($F(3, 23) = 2.961$, $p=.053$) for the RSA within the four segments of film clip 1, clip 2, and the two resting blocks. Post hoc analysis indicated that there is a significant difference between film clips 1 and 2 where clip 2 had a higher RSA, $p=0.042$, and between film clip 1 and resting with eyes open where the resting clip had a higher RSA, $p=0.045$. These results partially support the hypothesis since a significant difference was found between one resting and clip period. It was also hypothesized that there would be a valence effect for RSA with a lower RSA for negative emotions relative to positive emotions. The results showed there was no significant main effect or interactions with valence.

To control for the effectiveness of the clips in inducing the intended emotions, a 4 (Segment) x 2 (Valence) repeated measures ANOVA was run including a covariate of the participants' self-reported scores on how intensely they felt the targeted emotion (e.g., anger for anger clips on a 0-8 likert scale). It was predicted that if the participant reported a low rating of the targeted emotion RSA would not be affected but if they reported a high rating, and therefore were presumably affected by the emotion, an effect on RSA would be observed. There were no significant main effects of segment or valence, even when controlling for self-reported effect of emotional induction. The mean RSA under different segment and valence are plotted in Figure 1.

Figure 1: The Effect of Valence and Segment on RSA with Self-Reported Ratings as a Covariate.

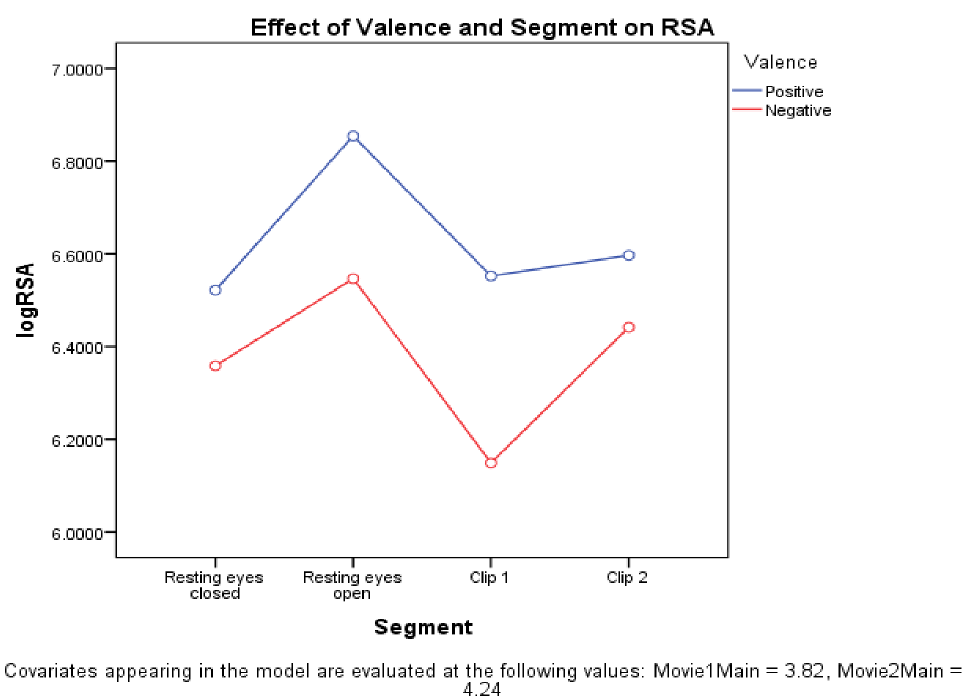

Figure 1 shows a line graph for the mean RSA of each segment for positive and negative film clips, using self-reported scores as a covariate.

The relationship between segments and valence was also analyzed to include sex in order to determine if it had a significant effect on RSA for these two variables. No predictions were made for how sex would impact segments and valence. A 4 (segment) X 2 (valence) X 2 (sex) repeated measures ANOVA was used to investigate this relationship. Only a marginally significant effect of sex was found $F(1,22)=3.043$, $p=0.095$, where females had a higher RSA than males. No other significant effects were found. This model was repeated to include a covariate of how intensely the participants reported feeling the targeted emotion. The results indicated a trend in the relationship between segment and sex, but no significant effects were found. The mean RSA under different segment and valence are plotted for each sex in figures 2 and 3.

Figure 2: Effect of Valence and Segment on RSA for Female Participants

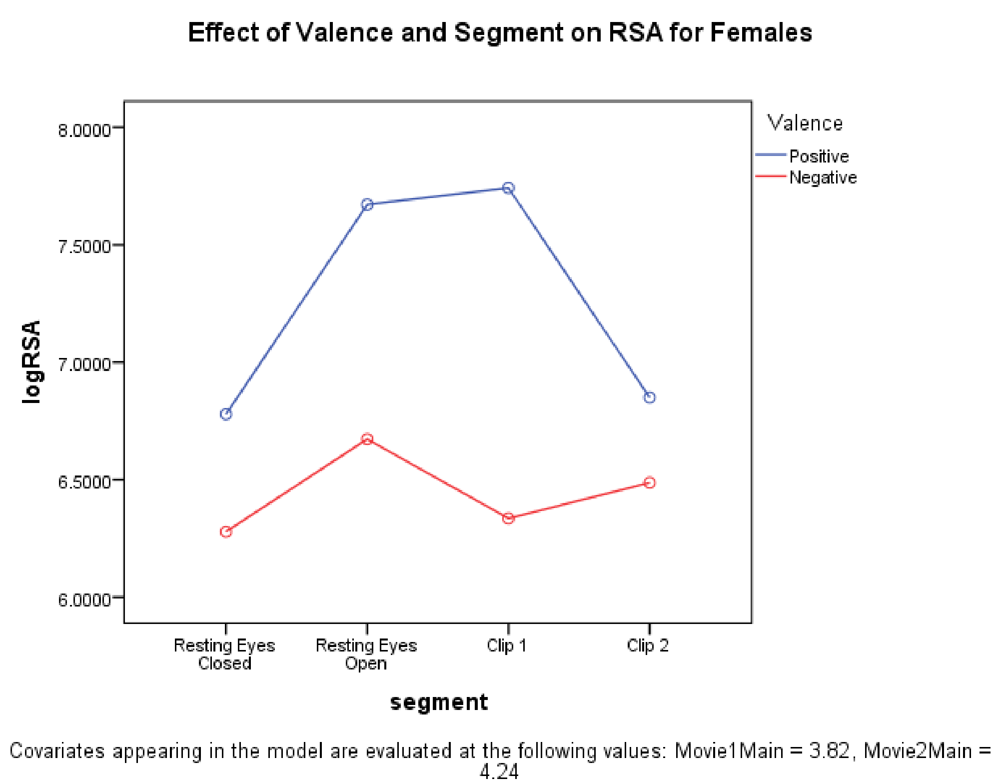

Figure 2 shows a line graph for the logRSA of each segment for positive and negative film clips for female participants.

Figure 3: Effect of Valence and Segment on RSA for Male Participants

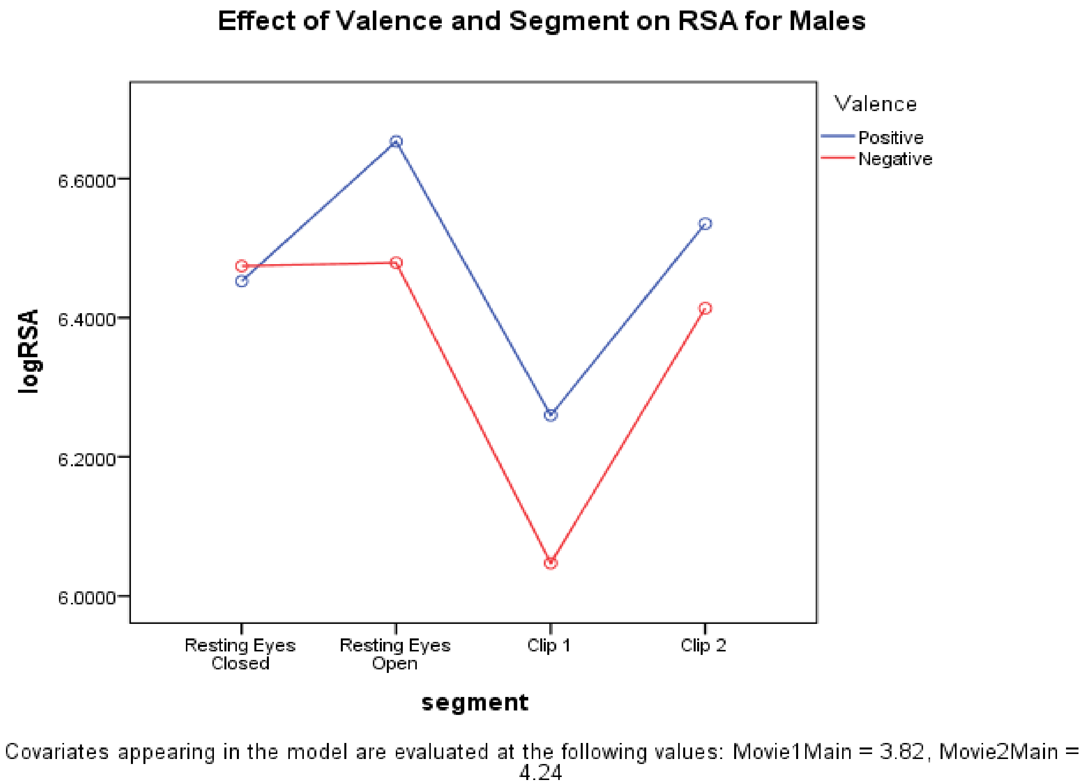

Figure 3 shows a line graph for the logRSA of each segment for positive and negative film clips for male participants.

The average of each participant's self-reported rating for all film clips was calculated to determine how intensely they felt each emotion (anger, amusement, disgust, happy, fear, sad) as well as the targeted emotion, of which they were randomly assigned. This is shown below in table 1. No ratings could be found for the sad emotion and therefore could not be included in the analysis. Only one of the participants who were assigned the disgust emotion had ratings. As a result, only one out of the five participants who experienced the disgust emotion had ratings included in this table. The table indicates that anger received the lowest rating of targeted emotion while disgust received the highest.

Table 1: Average Self-Reported Rating for Each Film Clip per Emotion

Emotion	Film	Anger	Sad	Fearful	Grossed Out	Moral Disgust	Happy	Amused	Targeted Emotion
Anger	*Strange Days*	1.33	0.67	1	0.67	2.33	0.33	1.33	1.33
	Witness	1.5	0.33	0.66	0.33	1.33	0.33	1	1.5
Amusement	*Napoleon Dynamite*	0.67	0.08	0.08	0.67	0.50	3.50	4.17	4.17
	Mrs. Doubtfire	0.17	1.00	0.17	0.42	0.33	4.75	4.67	4.67
Disgust	*Dead Alive*	3	4	3	7	3	0	0	7
	Salo	3	3	4	8	4	0	0	8.00
Fear	*Halloween*	0.75	3	2.75	3.75	2.5	2	3	3.50
	The Ring	2.75	3.25	3.25	1.75	3	1.25	3.75	3.25
Sadness	*Legends of the Falls*	N/A							
	The Champ	N/A							
Happy	*The Holiday*	1.33	2.5	2.17	1	0.67	5.33	2.67	5.33
	How to Lose a Guy in 10 Days	0.5	0	0.33	0	0	4.67	4.67	4.67

Table 1 shows the average of each participant’s self-reported emotion rating for each film clip per emotion.

The frequency of each participant’s targeted emotion rating for film clips 1 and 2 are shown below in figures 4 and 5, respectively. These histograms indicate that the frequency at which participants reported no emotion induction effect after viewing the film clips was 6 for film 1 and 2 for film 2. They further indicate that the frequency at which participants reported a mid-level emotion score was a 4 for film 1 and a 6 for film 2. However, there are 11 participants whose data is missing from film 1 and 12 missing from film 2.

Figure 4: Film 1 Targeted Emotion Frequency

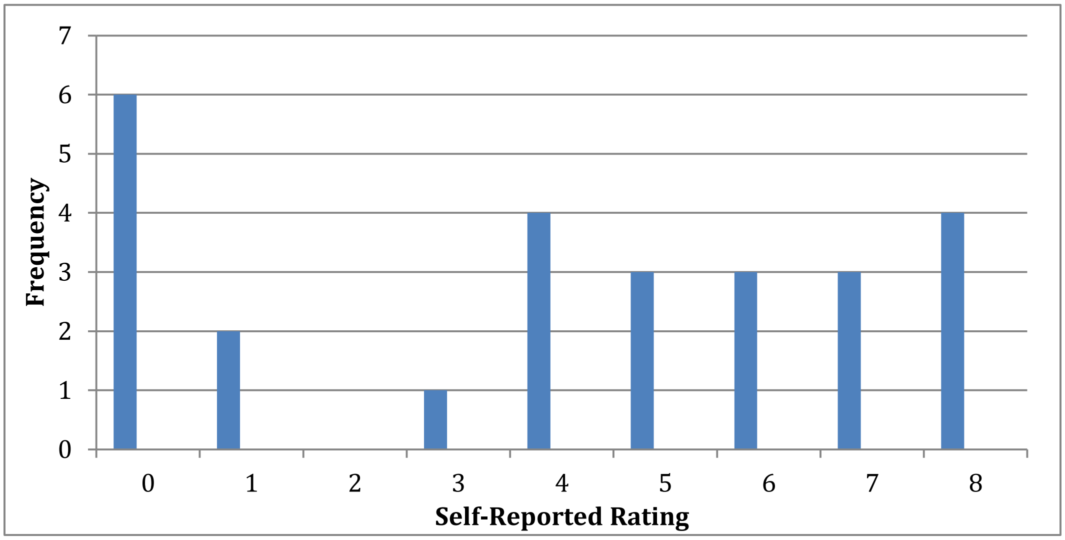

Figure 4 shows the frequency of each participant's averaged self-reported rating for film 1.

Figure 5: Film 2 Targeted Emotion Frequency

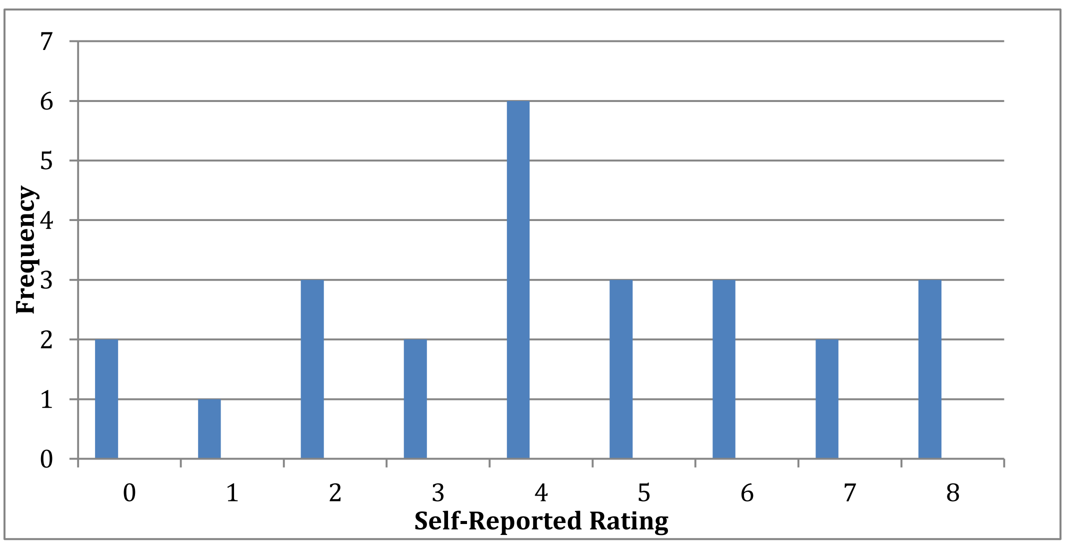

Figure 5 shows the frequency of each participant's averaged self-reported rating for film 2.

Discussion

The current study investigated whether there is a significant difference between positive and negative induced emotions in vagal control as measured by RSA. It was hypothesized that there would be a significant difference in RSA between emotion induction condition relative to a baseline period regardless of valence. It was also predicted that RSA would be lower for negative emotions induced than for positive emotions. In this exploratory study, the results did not conclusively support the predictions, with a marginally significant difference in RSA between film clip 1 and resting with eyes open; with the latter associated with higher RSA. These results show a trend of emotional state affecting RSA, which only partly supports the hypothesis. Although at a trend level, the results suggest an overall decrease in RSA relative to baseline upon watching an emotion-induction clip. This pattern may suggest that despite the fact that an equal number of participants viewed each emotion valence, the effects of RSA on negative valence emotions may be stronger than changes, if any, under the positive emotions condition. However, further analysis does not appear to support this idea. It is unclear why a difference was only observed between clip 1 and resting with eyes open but not any other conditions; particularly in light that no differences were expected between the two resting conditions (designed to test other purposes of the original study). Unexpectedly, a marginally significant effect of RSA within segments film clip 1 and film clip 2 was also observed, suggesting perhaps that one of the film clip conditions was more influential in inducing emotion. Nonetheless, clips within each emotion were randomly assigned to be labeled clip 1 and clip 2 and they were presented in counterbalanced order. Both clips were intended to induce the same emotion with an approximately equal intensity, and as a result a significant difference in RSA within the two clips was not expected. Although it is possible that perhaps under one emotion condition (e.g.; anger, amusement, disgust, happy, fear, or sad), there was a more powerful video clip, given the small data set in this study it would be difficult to address this question with confidence. Therefore, replication with a larger sample size is needed.

Results analyzing the interaction between segment and valence and within valence showed no differences in RSA for participants viewing film clips inducing positive or negative emotions. These results do not support the second hypothesis, which states RSA will be higher for positive emotions and lower for negative emotions. These results are also contradictory to the findings of other studies where high RSA was associated with positive emotion and low RSA was associated with negative emotions, specifically anxiety, which could be compared to fear in relation to the current study (Kogan et al., 2012, Watkins et al., 1998, Sack et al., 2004). Although these results were unexpected, they should be interpreted with caution given the small sample size of the study and call for additional replication to be able to support this pattern of findings. Alternatively, it is possible the clips did not elicit the emotional responses intended by the original experiment, where the participants felt neither the same emotion nor the degree of intensity the clips intended. This appears to be the reason based on table 1 and histogram figures 4 and 5.

Due to the non-significant results found between valence and within film clips, it is possible, as stated previously, that the participants were not affected by the film clips as strongly as the original study intended. To determine this, further results of the relationship between valence and segment on RSA were investigated while controlling for how the participants rated their targeted emotions. No significant results were found; suggesting the film clips' effect on each participant did not account for the initial null findings in RSA. This means that regardless of how strongly the participants felt the film clip affected them, it had no effect on RSA.

The average emotion ratings for each film, found in table 1, indicates the two disgust films were the most effective at inducing emotion. However, this is probably due to the fact that only one out of the five participants assigned to the disgust emotion had ratings included in this table. If that participant was particularly affected by the emotion and the others were not, it would skew the average ratings to seem as if the films were more effective at inducing disgust. Further, none of the ratings for the sad film clips could be found. It is therefore unknown how effective the clips were and how the participants responded to them. This alters figures 4 and 5 because the sad rating frequencies are not included. Table 1 and figures 4 and 5 are also slightly inaccurate because there are 11 rating files missing for film 1 and 12 missing for film 2. However, most of these missing files belonged to the same participant. A participant missing the clip 1 rating file was also missing the clip 2 rating file. Consequently, with only 37 participants in the study, having 11 and 12 files missing drastically lowers the number of participants included in the targeted emotion ratings analysis.

There was also a trend suggesting gender differences in RSA. There was a difference in RSA between male and female participants where females had a higher RSA. Although there were no specific predictions regarding sex effects on RSA, this is an area of interest considering there may be disparities in how females and males responded to emotional induction. It would be useful for future studies to investigate this trend more thoroughly.

This exploratory study generated results that did not coincide with literature findings from many previous studies, as no significant difference was found between valences or within film clips. However, the findings do concur with a study by Oveis et al. (2009), which found that RSA is not able to measure induced short-term emotion. Their results showed that resting RSA was associated with baseline positive emotions but not with phasic positive or negative emotions in response to emotion-inducing stimuli. Although the baseline RSA for the current study is not associated with any emotion, the results are similar in that there was no RSA associated with phasic induced emotion. Other previous studies using film clips as stimuli also failed to elicit effects of film content on RSA or the results were inconsistent (Baldaro et al., 2001; Demaree et al., 2006; Frazier et al., 2004). This suggests that film clips are not a reliable method to measure RSA. The clips do not induce a strong enough effect to produce a reliable index of vagal activity. In order to get a larger effect of RSA, a stronger stimulus needs to be used to induce emotion.

However, certain limitations need to be considered when looking at the results of this study, particularly its small sample size. Since there are 37 participants in the study and six emotions induced on these participants, there were few participants assigned to each emotion. This makes the results less reliable because there were not a wide range of RSA scores for each emotion. There was also an uneven gender ratio, with 22 males and only 15 females participating in the study. Another limitation is that it was a between subjects design. Each participant's RSA was recorded per single emotion. Since it was not a within subjects design, it is impossible to deduce how strongly the individual felt the emotion in relation to the other emotions used in the current study.

Future studies would benefit from testing these effects in a within subject design, with a larger number of participants, and a balanced gender ratio. This will give more reliable results that may have greater significance than those found in the current study. Other studies can also be completed using methods that are more likely to induce a stronger emotion. This can be done using personal items from participants such as photographs or meaningful songs.

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