

Gastric myoelectrical activity as an index of emotional arousal

E.P.M. Vianna^{a,b}, D. Tranel^{a,*}

^a *Division of Cognitive Neuroscience, Department of Neurology, Roy J. and Lucille A. Carver College of Medicine, 200 Hawkins Drive, Iowa City, Iowa, 52242, USA*

^b *Graduate Program in Neuroscience, The University of Iowa, USA*

Received 18 October 2005; received in revised form 20 October 2005; accepted 27 October 2005

Available online 3 January 2006

Abstract

Autonomic nervous system parameters such as electrodermal activity, heart rate, and facial EMG have been utilized extensively as measures of emotional arousal. One measure that has rarely been employed in this setting is gastric myoelectrical activity, despite the fact that “gut feelings” have an obvious and even profound role in everyday emotional life. It has been shown that the gastrointestinal system changes wall tonus and contraction rate during stressful tasks. However, the effects of emotionally salient stimuli on gastrointestinal motility have scarcely been studied. In the current study, emotional film clips designed to elicit happiness, disgust, fear, sadness, or no emotion (neutral) were presented to 16 normal participants. Electrogastrogram (EGG), skin conductance, and heart rate were measured while the participants viewed the film clips, and participants rated subjective arousal intensity and pleasantness of the film clips. We found that emotional film clips reliably induced the intended subjective feeling states. Also, EGG peak amplitudes in fear, disgust, sadness and happiness were higher than in the no emotion condition. There was a strong positive correlation ($r=0.64$) between EGG peak amplitude and subjective ratings of arousal. This is the first evidence that gastric myoelectrical activity is strongly correlated with arousal ratings to emotionally salient stimuli, and it suggests that EGG may add useful information about how the body contributes to the phenomenology of emotion and feeling.

© 2005 Elsevier B.V. All rights reserved.

Keywords: Emotion; Arousal; Valence; Electrogastrogram; Film; Heart rate variability; Skin conductance; Autonomic nervous system; Stomach

1. Introduction

The body plays a key role in emotional states. In fact, everyday language is liberally sprinkled with references to this connection, especially in regard to the heart (“my heart raced,” “my heart sank,” “my heart skipped a beat”) and the gastrointestinal system (“my stomach turned,” “I had butterflies in the stomach”), and even for the skin (“my skin crawled,” “It gave me goosebumps”) and lungs (“he sighed in despair”). In psychophysiology, measures of electrodermal activity, cardiac function, facial EMG, and respiration have been used frequently to assess the emotional states of experimental participants (Bechara et al., 2000; Boiten, 1998; Bradley, 2000; Tranel, 2000). Remarkably, the gastrointestinal system has been almost completely neglected by emotion research.

Early descriptions of gastrointestinal physiology included references to changes in gastrointestinal activity associated with emotion and stress. One of the earliest reports of changes of stomach activity during “emotional states” is the famous case of Alexis Saint Martin, a man with a permanent gastric fistula due to a gunshot (Beaumont, 1833). This fistula allowed Beaumont to access the interior of the stomach and describe several physiological processes. Beaumont also noted changes in the color of the stomach mucous membrane due to stress and anger. After these quasi-anecdotal reports of changes in stomach activity during emotional states, Pavlov (1910) described the conditioning responses of sham feeding in dogs. He also showed that an established pattern of response could be disrupted by emotionally arousing events as described by the dog that did not produce salivary responses due to a stressful situation (Wolf, 1981). Later, Cannon (1929) reported diminished gastric acidity and motor activity in association with the fear response in cats, which he related to the fight or flight response. Wolf and Wolff (1947) also observed decreased acid

* Corresponding author. Tel.: +319 384 6050; fax: +319 356 4505.

E-mail address: daniel-tranel@uiowa.edu (D. Tranel).

secretion and motility of the stomach during fright and depression in a subject with a permanent gastric fistula. Additionally Cannon proposed that gastric contractions was a good measure for feelings of hunger (Cannon and Washburn, 1912). This relationship between a feeling state of hunger and gastric contractions was further demonstrated by Carlson (1916).

Changes in the gastrointestinal system during stress are well documented. For instance, Stern and coworkers reported changes in gastric myoelectrical activity in various stress-inducing tasks such as forehead cooling (Muth et al., 1999) and shock avoidance (Muth et al., 1998). There have been a few attempts to study changes of the gastrointestinal system associated with emotion. These studies are scarce, and there are conflicting findings. For instance, Baldaro et al. (1996) initially showed a decrease in electrogastragram amplitude while participants were watching an unpleasant film. However, another study with similar methodology did not show differences in electrogastragram when participants were presented with unpleasant films (Baldaro et al., 2001). Blomhoff et al. (2000) presented emotionally charged words to patients with irritable bowel syndrome and to normal subjects. The investigators measured rectal tone and brain event-related potentials. Overall changes in rectal tone occurred during exposure to emotionally charged words. However, the changes in rectal tone went in different directions (either positive or negative), and neither word type (positive v. negative) nor group predicted the direction of change. Overall, there is a striking paucity of data about the effects of emotionally salient stimuli on gastrointestinal motility.

The electrogastragram (EGG) is a reliable and noninvasive method of recording gastric myoelectrical activity (Nelsen and Kohatsu, 1968; Smout et al., 1980). The gastric myoelectrical activity paces the contraction of the stomach and originates in a pacemaker region lateral to the gastroesophageal junction and is characterized by regularly recurring potentials. The gastric slow wave is present all the time, and controls the frequency and propagation of the contractions of the stomach. The normal frequency of the electrogastric wave is 3 cycles per minute (cpm), and is termed normogastria (Stern et al., 2000).

In the present study, emotionally salient films were presented to normal participants. While participants were viewing the films, electrogastragram, skin conductance, and electrocardiogram were measured. Afterwards, participants were also asked to rate the arousal and valence of the emotion felt while watching films. The decision to use films to elicit emotional states was motivated by our desire to use strong, robust stimuli to induce emotion. Films involve more than one perceptual modality (Oatley, 2004), and they typically have a storyline. The principal psychophysiological measure of interest was the EGG. We also measured skin conductance response (SCR) and heart rate (HR), mainly as a means to have a point of comparison for these “tried and true” psychophysiological indices of emotional states. SCR and HR are reliable and well established measures of sympathetic and parasympathetic activation during emotional states (Akselrod et al., 1981; Burch and Greiner, 1960; Edelberg, 1972; Gunn et al., 1972).

2. Methods

2.1. Participants

All procedures were approved by The University of Iowa Institutional Review Board for Human Subjects Research. Sixteen participants (9 female; 7 male), mean age $M=26.7\pm 2.99$, mean education $M=15.88\pm 0.33$ years, were recruited for this study. Participants reported to the laboratory between 9 and 11 am after a 2-h fast. No participant had a history of gastrointestinal, neurological or psychiatric problems. Both length of fasting and medical history was based on self-report.

2.2. Psychophysiology

2.2.1. Apparatus

The transducers, amplifiers, analog to digital converter (MP100WSW) and data acquisition (AcqKnowledge) were from Biopak, Inc. (Santa Barbara, CA). All psychophysiology measures were sampled at 200 Hz.

2.2.2. Electrogastrography

EGGs were recorded using two disposable cutaneous Ag–AgCl electrodes. One electrode was placed above the umbilicus, and the second electrode was placed just below the lower left rib.

2.2.3. Skin conductance

Skin conductance was recorded using disposable Ag–AgCl skin electrodes. Electrodes were placed on the thenar and hypothenar eminences of the right hand. Skin conductance output voltage was amplified by a factor of 5 $\mu\text{S/V}$ and low-pass filtered at 10 Hz.

2.2.4. Electrocardiogram

ECG signals were recorded using disposable cutaneous Ag–AgCl cutaneous electrodes. One electrode was attached just above the right clavicle, and the second was placed in the upper quadrant on the left side, just above the costal margin.

2.3. Emotional stimuli

Ten standardized films were used to elicit the discrete emotions of happiness, disgust, fear, and sadness, as well as no emotion (neutral). The films were selected on the basis of being powerful inducers of target emotion, and fairly selective in terms of inducing the target emotion but no other emotions. Several films clips were piloted, and only the ones that had the desired qualities were included in the final list (Boiten, 1998; Gross and Levenson, 1995; Waldstein et al., 2000). The film clips used were:

1. Neutral:

A. Germany: *The Rhine and Mosel: The romantic road* (Steves, 1991). A scene showing the Mosel river. Length of film clip: 2.04 min.

- B. *Great Canadian Train Ride* (Jones and Jones, 1993). A scene showing a train ride through Canada, and teaching how the engineer controls the train. Length of film clip: 2.17 min.
2. *Happiness*:
- A. *Tortilla Soup* (Wang et al., 2001). A couple is cooking, laughing and hugging. Length of film clip: 2 min.
- B. *She's having a baby* (Hughes and Hughes, 1988). A woman tells her husband that she is pregnant, and they enjoy the several pregnancy stages. Length of film clip: 1.37 min.
3. *Disgust*:
- A. *Animal Hospital* (Animal Hospital, 1995). Dog undergoes hip replacement. Length of film clip: 2.7 min.
- B. *Pink Flamingos* (Waters and Waters, 1973). A woman eats dog feces. Length of film clip: 1.22 min.
4. *Sadness*:
- A. *The Champ* (Marion et al., 1979). A boy sees his father dying and starts crying. Length of film clip: 2.52 min.
- B. *She's having a baby* (Hughes and Hughes, 1988). A woman is having surgical problems. A nurse comes out of surgery room and tells husband. While the doctors are struggling with her life, the husband thinks about all the good moments they had together and wishes he could have a last chance to say he loves her. Length of film clip: 4.27 min.
5. *Fear*:
- A. *The Shining* (King et al., 1980). A boy is riding his tricycle in a corridor, when two girl apparitions materialize and frighten him with a bloody scene. Length of film clip: 1.25 min.
- B. *Pet Sematary* (King and Lambert, 1989). A kid enters a house, fetches a scalpel and hides. An older man starts looking for the kid. Length of film clip: 4.07 min.

The film clips were digitized and stored in a G4 PowerMac computer. The clips were edited on iMovie (Apple Computer, 2003), and saved in Quicktime format (Apple Computer, 2004). Due to the nature of the electrogastrogram analysis (see below), the following films were presented twice: *She is having a Baby*, *The Shining* and *Pink Flamingos*.

2.4. Subjective emotion ratings

Subjective reports of emotional experience were obtained for the standard two dimensions, namely, emotional *arousal* and *valence*. For arousal, participants rated their emotional experience during each film presentation on a scale of 1 to 7, with 1 corresponding to “I did not feel any emotion at all” and 7 corresponding to “I felt an extremely intense emotion.” For emotional valence, the rating scale also ranged from 1 to 7, with 1 corresponding to “Extremely unpleasant,” 4 corresponding to “Neutral,” and 7 corresponding to “Extremely pleasant.” Participants also reported the primary emotion they felt during each clip, choosing one label for each clip from a list of emotion labels (happiness, fear, disgust, sadness, and neutral).

2.5. Procedure

After arrival and explanation of the experimental procedure, electrodes were placed on the participant. Participants were allowed to sit comfortably in a chair approximately 1 meter away from a 20 in. monitor screen. Films were presented in a random order across participants. After each film clip was presented, the participant completed the subjective rating measures.

2.6. Data reduction

2.6.1. EGG

Data obtained during each film clip were subjected to fast Fourier transform (FFT) with a Hamming window. Maximum spectral value was calculated for each condition. Because of significant between-subject variability in the measure, the values for each participant were transformed into *z*-scores. Spectral estimates were summed for the following bands: normogastria (2.5–3.5 cpm), tachygastria (3.75–9.75 cpm), bradygastria (0.5–2.5 cpm), and total power (0.5–11 cpm). The percentages of total power found in the normogastria and tachygastria bands were also calculated. As noted earlier, normogastria is associated with normal rhythm of the stomach of a healthy individual. The function of bradygastria is not well understood, and tachygastria activity is usually associated with nausea (Stern et al., 2000). Because of the length of the film clips, bradygastria analysis was not included in the EGG, as the FFT analysis would have required longer film lengths.

2.6.2. Skin conductance

Skin conductance activity was measured as the area under the curve over a given time interval (Damasio et al., 2000; Naqvi and Bechara, in press). Raw skin conductance data were low-pass filtered to remove high frequency noise. The slow downward drift in baseline skin conductance level was removed using a moving difference function with a difference interval of 0.05 s (10 points for a 200 Hz sampling rate). Because the film clips had slightly different time lengths, the area under the curve was divided by total film clip time. For statistical analysis, *z*-scores of the participants were calculated.

2.6.3. Heart rate variability (HRV)

The heart rate signal was derived from the ECG recording by identifying the *R* peaks, calculating the *R*–*R* intervals, and interpolating the *R*–*R* intervals so that the time intervals between consecutive samples were equal. Overall power spectral analysis was applied to the HRV signal and the power in each frequency sub-band was calculated. The power in the low frequency band (0.04–0.15 Hz), LF, and the power in the high frequency band (0.15–0.5 Hz), HF, was calculated. It is thought that LF is associated with thermoregulatory and peripheral vascular sympathetic influences. LF may be mediated by both branches of the autonomic nervous system. HF has been validated as a measure of parasympathetic activity (Akselrod et al., 1981; Grossman, 1992). LF was calculated as peak value in the frequency range of 0.04–

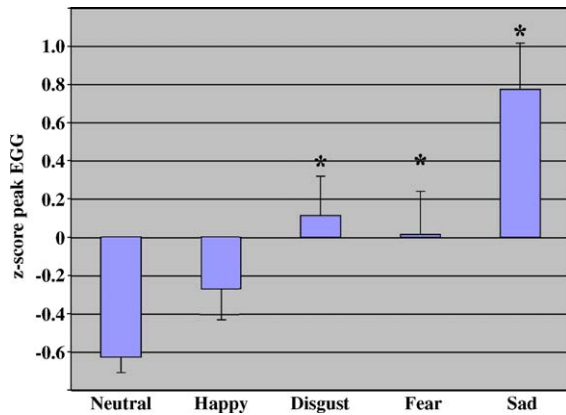


Fig. 1. Peak amplitude of the spectral EGG, represented in z-scores averaged across participants. All of the negative emotion conditions are significantly ($p < 0.05$) higher than the neutral condition. Positive emotion was not significantly different than the neutral condition.

0.15 Hz and HF was calculated as peak value in the frequency range of 0.15–0.5 Hz.

2.7. Statistical analysis

All data are presented as means \pm the standard error of the mean (SE). Repeated measures ANOVA was applied for the subjective ratings of arousal and valence, in order to ascertain elicitation of targeted emotional states. Repeated measures ANOVA was applied to investigate the difference in each of the psychophysiology parameters between emotions. Mauchly sphericity test was performed, and when necessary Huyn–Feldt correction was applied. For heart rate variability, a repeated measures contrast anova was performed assigning different weights to the groups according to observed trends in plotted graphs (Rosenthal et al., 2000). Finally, correlations between arousal and psychophysiology measures, and between valence and psychophysiology measures, were performed according to procedures outlined by Lang et al. (1993), where the average of the psychophysiological measure across subjects for each subjective response level was calculated.

3. Results

3.1. Subjective ratings

Significant effects were obtained for Arousal ($F_{4,60} = 35.477$, $P < 0.001$, Huyn–Feldt corrected, $\epsilon = 0.68$) and Valence ($F_{4,60} = 35.624$, $P < 0.001$, Huyn–Feldt corrected, $\epsilon = 0.59$) ratings. In a Bonferroni post-hoc analysis for Arousal ratings, all emotions were significantly ($p < 0.05$) higher than neutral condition, as expected (neutral: 1.75 ± 0.19 , happy: 3.65 ± 0.22 , disgust: 4.78 ± 0.30 , fear: 4.84 ± 0.31 , sad: 5.00 ± 0.35). Negative emotions (disgust, fear, sad) were rated as more arousing than the positive emotion (happy, $p < 0.05$), but were not significantly different from one another. In a Bonferroni post-hoc analysis for Valence ratings, all negative emotions were significantly lower than the neutral condition ($p < 0.05$), and the positive emotion was higher than neutral but not significantly different (neutral: 4.5 ± 0.15 , happy: 5.25 ± 0.23 , disgust: 2.65 ± 0.31 , fear: 2.61 ± 0.16 , sad: 2.53 ± 0.18).

The participants chose the expected labels for the emotion film clips. Specifically, happy film clips were labeled as happy 88.5% of the time; disgust film clips were labeled as disgust 79.9% of the time; sadness film clips were labeled as sad 96.2% of the time; fear film clips were labeled as fear 100% of the time; and neutral film clips were labeled as neutral 81.2% of the time. Overall, the subjective ratings data indicate that the film clips elicited the target emotions reliably. The ratings and labeling were comparable to previously published studies (Gross and Levenson, 1995), and to our pilot data on these film clips.

3.2. Electrogastragram

A significant main effect of emotion was obtained for the z-scores of maximum spectral value ($F_{4,60} = 5.5435$, $P < 0.01$, Huyn–Feldt corrected, $\epsilon = 0.69$). In a Bonferroni post-hoc analysis, all negative and positive emotions were significantly higher ($P < 0.5$) than the neutral condition (neutral: -0.62 ± 0.08 , happy: -0.27 ± 0.16 , disgust: 0.11 ± 0.21 , fear:

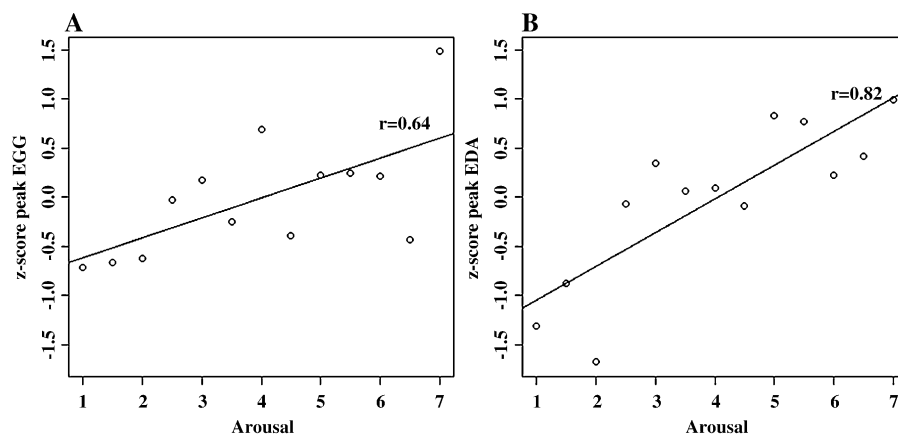


Fig. 2. Correlation of psychophysiological measures and subjective ratings of arousal. The data analysis was conducted according to a method described previously (Lang et al., 1993). Data points reflect mean psychophysiological response for a level of arousal. A: z-score peak amplitude of EGG correlates with arousal ($r = 0.64$, $P = 0.018$). B: z-score skin conductance correlates with arousal ($r = 0.82$, $P = 0.001$).

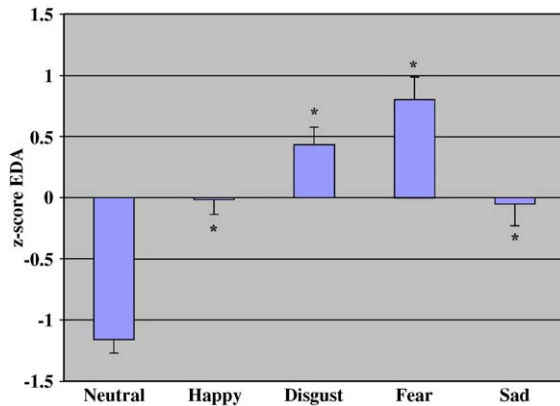


Fig. 3. Electrodermal activity (skin conductance). Values are z-scores across participants, graphed as area under the curve. All emotions are significantly higher than neutral condition (*). Disgust and fear produced the highest skin conductance changes, and sadness and happiness elicited a similar level of skin conductance changes.

0.01 ± 0.22 , sad: 0.74 ± 0.24 ; Fig. 1). The maximum spectral values were all within the normogastria range (neutral: 2.72 ± 0.48 cpm, happy: 2.63 ± 0.73 cpm, disgust: 2.64 ± 0.57 cpm, fear: 2.58 ± 0.51 cpm, sad: 2.70 ± 0.45 cpm). There was a strong positive correlation between the maximum spectral values and subjective ratings of arousal ($r=0.64$, $P=0.018$; Fig. 2A). There was no correlation with valence.

3.3. Skin conductance

A significant main effect of emotion was obtained for z-scores of the skin conductance measure ($F_{4, 60}=7.1689$, $P=0.0023$, Huyn–Feldt corrected, $\epsilon=0.62$). In a Bonferroni post-hoc analysis, all emotions are significantly higher ($P<0.05$) than neutral condition (neutral: -1.16 ± 0.11 , happy: -0.02 ± 0.12 , disgust: 0.43 ± 0.15 , fear: 0.79 ± 0.18 , sad: -0.05 ± 0.17 ; Fig. 3). There was a strong positive correlation between skin conductance score and ratings of arousal ($r=0.82$, $P=0.001$; Fig. 2B). Disgust and fear produced the highest skin conductance changes, and sadness and happiness elicited a similar level of skin conductance changes. This pattern of resembles data obtained from previously published studies (Damasio et al., 2000). There was no correlation with valence. Z-scores of EDA correlated with z-scores of EGG ($r=0.73$, $P=0.0042$).

3.4. Heart rate variability

In a repeated measures contrast ANOVA, there was a significant effect for HF ($F_{1, 60}=5.5818$, $P=0.022$). Neutral films elicited a higher HF response. All emotional movies triggered a lower HF compared to neutral, with fear and sadness being the lowest (neutral: $6.76 \times 10^7 \pm 2.48 \times 10^7$ ms², happy: $4.77 \times 10^7 \pm 1.44 \times 10^7$ ms², disgust: $4.54 \times 10^7 \pm 1.48 \times 10^7$ ms², fear: $3.15 \times 10^7 \pm 5.9 \times 10^6$ ms², sad: $2.73 \times 10^7 \pm 9.72 \times 10^6$ ms²; Fig. 4). HF did not correlate significantly with arousal ($r=-0.34$, $P=0.24$). However, low LF did not show any significant differences as a function of emotion

(neutral: $4.86 \times 10^7 \pm 1.84 \times 10^7$ ms², happy: $2.86 \times 10^7 \pm 6.29 \times 10^6$ ms², disgust: $6.14 \times 10^7 \pm 1.44 \times 10^6$ ms², fear: $5.29 \times 10^7 \pm 2.11 \times 10^6$ ms², sad: $3.43 \times 10^7 \pm 8.73 \times 10^7$ ms²). Also, LF did not correlate with arousal ($r=-0.22$, $P=0.45$).

4. Discussion

As expected, emotionally salient film clips elicited the intended emotional states in normal participants, as indicated by arousal and valence ratings. Participants also labeled the film clips with the expected emotion label. In regard to the conventional psychophysiological indices of electrodermal activity and cardiac function, the emotional film clips elicited increases in skin conductance and a decrease in the high frequency of the ECG spectrum, relative to neutral film clips. These findings are in accord with a large body of previous work in this area, documenting the effectiveness of emotionally charged stimuli in eliciting various emotions and corresponding subjective ratings of arousal and valence (Codispoti et al., 2001; Levenson et al., 1992). Also, the autonomic changes of the participants during emotional states provide additional evidence for so-called “emotional patterning,” insofar as there were different degrees of change in the psychophysiological parameters as a function of emotion type.¹ Emotional patterning can be defined as the autonomic specificity displayed by emotions. There is a growing body of evidence that the autonomic nervous system exhibits specific patterns of responses for different emotions (Ekman, 1999; Graham, 1962; Schwartz et al., 1981). These responses can be seen as manifestations of autonomic “programs” that contribute to the organism’s ability to respond appropriately to internal and external environmental stimuli, e.g., hunger, sex, and fight-or-flight responses.

It would not be controversial to assert that the gastrointestinal system also has some role in emotion and feeling, and this would surely not come as news to the average person on the street. However, there has been a remarkable scarcity of empirical data regarding the interplay between the gastrointestinal system and various emotions and feelings, and this is even more the case at the level of systems neuroscience. Our data indicate that the gastrointestinal system changes in response to emotionally salient stimuli. Specifically, there is an increase in the peak amplitude in the normal gastric contraction range during an emotional event. This increase in the peak amplitude reflects an increase in contraction amplitude of the stomach (Stern et al., 2000). The amplitude of the normal 3-cpm EGG increases as contractile activity in the stomach increases. The gastric myoelectric activity is regulated by the enteric nervous system in the stomach. The autonomic nervous system, through

¹ Our study was not designed to explore emotional patterning per se, and thus we do not feel that a detailed post hoc analysis of this phenomenon is warranted. Moreover, this is a complicated and challenging domain that often calls for sophisticated data analysis strategies and non-trivial data reduction applications (cf. Rainville et al., 2006). Nonetheless, our data do hint at the possibility of emotional patterning, and we feel it would be remiss not to at least mention this issue.

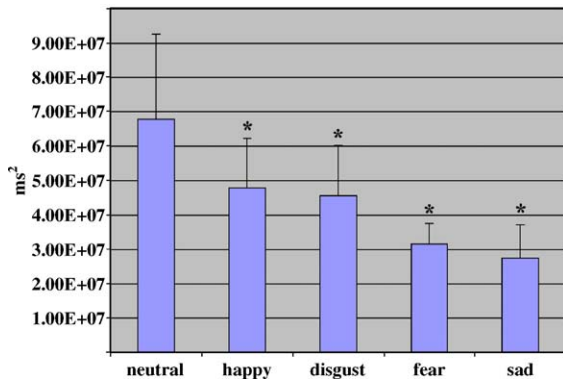


Fig. 4. Heart rate variability. High Frequency (HF) of heart rate. All emotional movies had a lower HF, compared to neutral (*).

the vagus nerve (parasympathetic nervous system) and splanchnic nerves (sympathetic nervous system), is closely integrated with the enteric nervous system. However, the precise regulatory mechanisms of the gastric myoelectric activity are unknown (Stern et al., 2000).

Both EDA and EGG were highly correlated with arousal ratings, but measures of HRV did not correlate with arousal ratings. It is thought that the HF spectrum reflects parasympathetic activity (Akselrod et al., 1981; Grossman, 1992). On the other hand, EDA is well-known measure of sympathetic nervous system and has been widely used as a measure of arousal (Bechara et al., 1997; Critchley et al., 2000). This suggests that changes in the gastric myoelectrical activity are related to changes in the sympathetic nervous system. The relationship between the sympathetic nervous system and gastric activity has been noted elsewhere (Rossi et al., 1998). Stepwise proximal gastric distension causes an increase in muscle sympathetic nerve activity and blood pressure. This phenomenon, termed gastrovascular reflex, is thought to be responsible for the increase in peripheral arterial resistance to compensate for the decrease of splanchnic arterial resistance that occurs during food consumption (Rossi et al., 1998). In our study, however, it was not possible to determine causality between gastric myoelectric activity and sympathetic nervous system activation. An important limitation of this study was the lack of power to analyze gender differences. It is important to notice that Parkman and coworkers (1996) showed gender differences in electrogastragram, and this could have implications in the way the gastrointestinal system might take a differential role in subjective emotional states.

Most importantly, this is the first evidence that gastric myoelectrical activity is strongly correlated with arousal ratings to emotionally salient stimuli, and it suggests that EGG may add useful information about how the body contributes to the phenomenology of emotion and feelings. For instance, it has been shown that decision-making processes are often strongly influenced by emotional factors that can be partially indexed through autonomic changes, and patients with impairments in such autonomic changes (e.g., patients with lesions in the ventromedial prefrontal cortex) are often impaired in decision-making (Bechara et al., 1997). The question of how the body contributes to emotion and feeling, and how such contributions

influence various cognitive processes, remains a central issue in affective neuroscience (Bechara et al., 2005). Therefore, it is very important to add new research tools, and electrogastragram may hold much promise in this regard. For instance, this paradigm could be used to investigate whether patients with pathological gastrointestinal states (and possibly different EGG patterns), will manifest altered subjective feelings of arousal in response to emotional stimuli.

Acknowledgements

This study was supported in part by Program Project Grant NINDS NS19632. We thank David Rudrauf for assistance in data analysis.

References

- Akselrod, S., Gordon, D., Andrew Ubel, F., Shannon, D.C., Clifford Barger, A., Cohen, J.C., 1981. Power spectrum analysis of heart rate fluctuation: a quantitative probe of beat to beat cardiovascular control. *Science* 213, 220–222.
- Animal Hospital (Writer) (1995). [TV series]. In D. Harkin (Producer), Animal Hospital. London: BBC.
- Apple Computer, I., 2003. iMovie (Version 3.3).
- Apple Computer, I., 2004. Quicktime Player (Version 6.5).
- Baldaro, B., Battachi, M.W., Codispoti, M., Tuozi, G., Trombini, G., Bolzani, R., et al., 1996. Modifications of electrogastrographic activity during the viewing of brief film sequences. *Perceptual and Motor Skills* 82, 1243–1250.
- Baldaro, B., Mazzetti, M., Codispoti, M., Tuozi, G., Bolzani, R., Trombini, G., 2001. Autonomic reactivity during viewing of an unpleasant film. *Perceptual and Motor Skills* 93, 797–805.
- Beaumont, W., 1833. Experiments and Observations on the Gastric Juice and the Physiology of Digestion. Allen, New York.
- Bechara, A., Damasio, H., Tranel, D., Damasio, A.R., 1997. Deciding advantageously before knowing the advantageous strategy. *Science* 275 (5304), 1293–1295.
- Bechara, A., Damasio, H., Damasio, A.R., 2000. Emotion, decision making and the orbitofrontal cortex. *Cerebral Cortex* 10 (3), 295–307.
- Bechara, A., Damasio, H., Tranel, D., Damasio, A., 2005. The Iowa Gambling Task and the somatic marker hypothesis: some questions and answers. *Trends in Cognitive Sciences* 9, 159–162.
- Blomhoff, S., Spetalen, S., Jacobsen, M.B., Vatn, M., Malt, U.F., 2000. Intestinal reactivity to words with emotional content and brain information processing in irritable bowel syndrome. *Digestive Diseases and Sciences* 45 (6), 1160–1165.
- Boiten, F.A., 1998. The effects of emotional behaviour on components of the respiratory cycle. *Biological Psychiatry* 49, 29–51.
- Bradley, M.M., 2000. Measuring emotion: behavior, feeling, and physiology. In: Lane, R., Nadel, L. (Eds.), *Cognitive Neuroscience of Emotion*. Oxford University Press, New York, pp. 242–276.
- Burch, N.R., Greiner, T.H., 1960. A bioelectric scale of human alertness: concurrent recordings of the EEG and GSR. *Psychiatric Research Report* 12, 183–193.
- Cannon, W., 1929. *Bodily Changes in Pain, Hunger, Fear and Rage*. Appleton, New York.
- Cannon, W.B., Washburn, A.L., 1912. An explanation of hunger. *American Journal of Physiology* 29, 441–454.
- Carlson, A.J., 1916. *The Control of Hunger in Health and Disease*. University of Chicago Press, Chicago.
- Codispoti, M., Bradley, M.M., Lang, P.J., 2001. Affective reactions to briefly presented pictures. *Psychophysiology* 38, 474–478.
- Critchley, H.D., Elliot, R., Mathias, C.J., Dolan, R.J., 2000. Neural activity to generation and representation of galvanic skin conductance responses: a functional magnetic resonance imaging study. *The Journal of Neuroscience* 20, 3033–3040.

- Damasio, A.R., Grabowski, T.J., Bechara, A., Damasio, H., Ponto, L.L., Parvizi, J., et al., 2000. Subcortical and cortical brain activity during the feeling of self-generated emotions. *Nature Neuroscience* 3 (10), 1049–1056.
- Edelberg, R., 1972. Electrical activity of the skin: its measurements and uses in psychophysiology. In: Greenfield, N.S., Sternbach, R.A. (Eds.), *Handbook of Psychophysiology*. Holt, Rinehart and Winston, New York, pp. 367–418.
- Ekman, P., 1999. Basic emotions. In: Dalglish, T., Power, M. (Eds.), *Handbook of Cognition and Emotion*. John Wiley & Sons, Sussex, pp. 45–60.
- Graham, D.T., 1962. Some research on psychophysiological specificity and its relation to psychosomatic disease. In: Roessler, R., Greenfield, N.S. (Eds.), *Physiological Correlates of Psychological Disorder*. University of Wisconsin Press, Madison, pp. 221–238.
- Gross, J.J., Levenson, R.W., 1995. Emotion elicitation using films. *Cognition and Emotion* 9 (1), 87–108.
- Grossman, P., 1992. Respiratory and cardiac rhythms as windows to central and autonomic biobehavioral regulation: selection of window frames, keeping the panes clean and viewing the neural topography. *Biological Psychology* 34, 131–161.
- Gunn, C.G., Wolf, S., Block, R.T., Person, R.J., 1972. Psychophysiology of the cardiovascular system. In: Greenfield, N.S., Sternbach, R.A. (Eds.), *Handbook of Psychophysiology*. Holt, Rinehart and Winston, New York.
- Hughes, J. (Writer), & J. Hughes (Director), 1988. *She's Having a Baby*. In B. Brown, R. Colby & J. Hughes (Producers). Hollywood: Paramount Pictures.
- Jones, D. (Writer), & D. Jones (Director), 1993. *The great Canadian train ride*. In D. Jones (Producer). Los Angeles.
- King, S. (Writer), & M. Lambert (Director), 1989. *Pet Sematary*. In M. Galin, R. P. Rubinstein, R. S. Singleton and T. Zinnemann (Producers): Paramount Pictures.
- King, S., Kubrick, S., & Johnson, D. (Writer), & S. Kubrick (Director), 1980. *The Shining*. In R. Fryer, J. Harlan, M. L. Johnson, S. Kubrick & M. Richards (Producers). Hollywood: Warner Bros.
- Lang, P.J., Greenwald, M.K., Bradley, M.M., Hamm, A.O., 1993. Looking at pictures: affective, facial, visceral, and behavioral reactions. *Psychophysiology* 30, 261–273.
- Levenson, R.W., Ekman, P., Heider, K., Friesen, W.V., 1992. Emotion and autonomic nervous system activity in the Minangkabau of West Sumatra. *Journal of Personality and Social Psychology* 62, 972–988.
- Marion, F., & Newman, W. (Writer), & F. Zeffirelli (Director), 1979. *The Champ*. In D. Lovell (Producer). Hollywood: Metro-Goldwyn-Mayer (MGM).
- Muth, E.R., Thayer, J.F., Stern, R.M., Friedman, B.H., Drake, C., 1998. *Biological Psychology* 47, 265–278.
- Muth, E.R., Koch, K.L., Stern, R.M., Thayer, J.F., 1999. Effect of autonomic nervous system manipulations on gastric myoelectrical activity and emotional responses in healthy human subjects. *Psychosomatic Medicine* 61, 297–303.
- Naqvi, N., and Bechara, A., in press. Psychophysiological approaches to the study of decision-making. In Senior, C., Russel, T., Gazzaniga, M., (Eds.), *Methods in Mind: The Study of Human Cognition*. Cambridge: MIT Press.
- Nelsen, T.S., Kohatsu, S., 1968. Clinical electrogastrography and its relationship to gastric surgery. *American Journal of Surgery* 116, 215–222.
- Oatley, K., 2004. Emotional payoffs. *Trends in Cognitive Sciences* 8 (2), 55–57.
- Parkman, H.P., Harris, A.D., Miller, M.M., Fisher, R.S., 1996. Influence of age, gender, and menstrual cycle on the normal electrogastrogram. *American Journal of Gastroenterology* 91, 127–133.
- Pavlov, I.P., 1910. *The Work of the Digestive Glands* (W. H. Thompson, Trans.). Charles Griffin, London.
- Rainville, P., Bechara, A., Naqvi, N., Damasio, A.R., 2006. Basic emotions are associated with distinct patterns of cardiorespiratory activity. *International Journal of Psychophysiology* 61, 5–18.
- Rosenthal, R., Rosnow, R.L., Rubin, D.B., 2000. *Contrasts and Effect Sizes in Behavioral Research: A Correlational Approach*. Cambridge University Press.
- Rossi, P., Andriess, G.I., Oey, P.L., Nlemeke, G.H., Roelofs, J.M., Akkermans, L.M., 1998. Stomach distension increases efferent muscle sympathetic nerve activity and blood pressure in healthy humans. *Journal of Neurological Sciences* 161, 148–155.
- Schwartz, G.E., Weinberger, D.A., Singer, J.A., 1981. Cardiovascular differentiation of happiness, sadness, anger and fear following imagery and exercise. *Psychosomatic Medicine* 43, 343–364.
- Smout, A.J.P.M.S., Van der Schee, E.J., Grashuis, J.L., 1980. What is measured in electrogastrography? *Digestive Diseases and Sciences* 25, 179–187.
- Stern, R.M., Koch, K.L., Muth, E.R., 2000. The gastrointestinal system. In: Caccioppo, J.T., Tassinari, L.G., Bertson, G.G. (Eds.), *Handbook of Psychophysiology*, 2nd ed. Cambridge University Press, Cambridge.
- Steves, R. (Writer), 1991. *Germany: The Rhine and Mosel; The romantic road*, Travel City.
- Tranel, D., 2000. Non-conscious brain processing indexed by psychophysiological measures. *Progress in Brain Research* 122, 317–332.
- Waldstein, S.R., Kop, W.J., Schmidt, L.A., Hauffer, A.J., Krantz, D.S., Fox, N.A., 2000. Frontal electrocortical and cardiovascular reactivity during happiness and anger. *Biological Psychiatry* 55, 3–23.
- Wang, H.-L., Lee, A., & Schamus, J. (Writer), & M. Ripoll (Director), 2001. *Tortilla Soup*. In S. G. Jr. (Producer). Hollywood: Samuel Goldwyn Company.
- Waters, J. (Writer), & J. Waters (Director), 1973. *Pink Flamingos*. In J. Waters (Producer).
- Wolf, S., 1981. The psyche and the stomach: a historical vignette. *Gastroenterology* 80, 605–614.
- Wolf, S., Wolff, H.G., 1947. *Human Gastric Function: An Experimental Study of a Man and his Stomach*, 2nd ed. Oxford University Press, New York.