DISTINGUISHING EMOTIONAL FROM PHYSICAL ACTIVATION IN AMBULATORY PSYCHOPHYSIOLOGICAL MONITORING

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KEYWORDS

Affective Computing, Emotion, Psychophysiology, Autonomic Nervous System, Respiratory Sinus Arrhythmia, Inductive Plethysmography, Ambulatory Monitoring, Accelerometry, Physical Exercise, Wearable Computers

ABSTRACT

Ambulatory monitoring has gained powerful new tools due to recent electronic and computer advances. The capability simultaneously to monitor numerous physiological parameters and behavior enhances the ecological validity of field assessment, but methodological challenges abound that can compromise attempts to understand biobehavioral relations in the real world. A major obstacle is that physiological dysregulation or emotion effects can be masked by variation in physical activity. Using a multi-channel ambulatory recording system, a wide array of self-report, physiological and environmental measurements was collected from 28 participants during quiet sitting, physical exercise and an emotion induction consisting of a short commercial flight. Half of the participants were selected to respond to flying with intense anxiety, the other half, with moderate excitement. Recorded channels included ECG, EDA, calibrated respiration pattern, and skin temperature, from which 17 physiological parameters were calculated. Accelerometry and self-report in an emotion diary served as manipulation checks. Results indicate that many parameters, including heart rate, respiratory sinus arrhythmia, and skin conductance level and its fluctuation, were strongly and nonspecifically affected by both anxiety and exercise. However, parameters of respiratory volume were particularly responsive to exercise, while certain parameters of irregularity in breathing were to anxiety. Several respiratory timing parameters were responsive to both exercise and excitement. We conclude that physiological measures provide information helping to distinguish emotional from physical activation. However, additional context awareness is necessary for confident data interpretation in ambulatory recording. This can be achieved by specific channels such as accelerometry, items in an electronic diary, semi-structured protocols, and statistical modeling.

INTRODUCTION

Ambulatory monitoring has shown promise for investigating emotions in real life and for understanding clinical syndromes such as anxiety or depression [1]. New devices that allow the simultaneous ambulatory recording of a wide array of psychophysiological measures can extend scientific knowledge of emotional activation processes beyond laboratory findings [2, 3]. Although capable of tighter experimental control, laboratory studies generally have less ecological validity than studies in the natural environment. Moreover, only 24-h recording can begin to quantify variation of psychophysiological function throughout the day in an approach we term “circadian psychophysiology.”

Although such an approach is likely to yield new insights into the real-life interplay of behavior, emotion, autonomic and respiratory regulation in health and disease, there are a number of problems that need to be overcome. Reliable interpretation of ambulatory monitoring data is stymied by the fact that endogenous dysregulation or emotional effects of interest can be masked by environmental factors contributing to circadian and random variation in physical activity, social engagement, meal intake, sleep-wake effects, or light exposure. Thus, the complexity of data streams and multitude of factors influencing them requires a high degree of context awareness for successful data interpretation. The chief factor making interpretation of ambulatory data difficult is physical activity since it occurs frequently during the day at various levels of intensity. For example, an increase in heart rate (HR) from 60 to 120 bpm can indicate a severe panic attack – or it can simply mean that the monitored person was walking swiftly. Without any further context information, this HR increase is not interpretable.

In this study we investigated which physiological measures and combinations of measures were most useful for distinguishing emotional and physical activation under ambulatory conditions. Fear of flying is known to induce strong anxiety responses and flying is therefore an ideal situation for identifying emotional activation processes. Monitored participants were selected to respond to flying with different emotions – ranging from moderate excitement to strong anxiety – to simulate types of emotion that may occur in naturalistic studies. A physical activity comparison condition consisted of bicycling.

METHODS

Subjects. Data were collected as part of an exposure treatment study presented elsewhere [4, 5]. Twenty-eight women were recruited by local advertisement. Half of the participants met criteria for the DSM-IV diagnosis of Specific Phobia (flying) and received free treatment for their anxiety. The other participants were matched by age and were not afraid of flying, but were attracted by being offered a short flight free of charge. Sample characteristics are described in [5].

Procedure. Participants were tested individually. After arriving in the laboratory and signing informed consent forms, transducers and electrodes were attached and a waist pack containing the recording device was fitted. Participants sat quietly for 6 min (baseline condition, **B**). Then they were asked to ride a stationary bike for 5 min at a moderate pace with a force equivalent to about 50 Watts (physical activity condition, **P**). After several other procedures were completed participants were brought to an airport and boarded a short commercial flight in a 20-seater turbo-prop airplane taking about 12 min from take-off to landing. They were asked to press a marker button attached to the device at the beginning of take-off (emotion condition, **E**). After landing, participants were brought back to the laboratory.

Physiological measurements. Psychophysiological measures and control measures were continuously recorded using a portable microcomputer device (Vitaport, Becker Meditec, Karlsruhe, Germany). The system is capable of recording 16 channels and includes amplifiers, analog and digital filters, an analog-to-digital converter, a microprocessor, and memory. The recorder weighs about 1050 grams. Data from the following channels were used in the analysis reported here. 1) An electrocardiogram (ECG) was obtained (400 Hz sample rate) from three electrodes attached to the chest. 2) Skin conductance (6 Hz) was recorded from the palmar surface of the middle phalanges of digits 3 and 4 of the left hand. Disposable Ag/AgCl electrodes with a contact surface area of 2.0 cm^2 and an isotonic electrode paste were used. A constant 0.5 V was applied across the electrodes. 3) Two channels of respiration were measured (each 12 Hz) using Respibands™ ("Respitrace", Ambulatory Monitoring, Inc., Ardsley, NY) placed around thorax and abdomen. Bands were calibrated against concurrent spirometric measurements of tidal volume. 4) Finger temperature (0.1 Hz) was taken from the palmar surface of the outer phalanx of digit 5 of the left hand. 5) Body movement was sensed (50 Hz) by an accelerometer attached to the right leg above the knee. The channel was high-pass filtered, rectified, integrated, and stored with 2 Hz sample rate. 6) Button presses, 7) ambient temperature, and 8) barometric pressure (each 2 Hz) were assessed as context markers (specific events marked by participants, outdoors vs. indoors temperature changes, ground vs. air pressure changes) with sensors attached to the outside of the waist pack (data not reported here).

Self-report measurements. Anxiety and excitement was rated on a Likert-type scale (anchored at 0="not at all" to 10="extreme") and recorded in an emotion diary immediately following each measurement period (B, P, E). The presence or absence of each of 16 physical symptoms often associated with emotional activation such as anxiety was rated on a scale from 0="not at all" to 3="to a high degree", and summed to obtain a total symptom score ranging from 0-48.

Data analysis. The first 2 min of each experimental period was analyzed. All data reduction procedures were programmed in MATLAB (MathWorks, Inc.) by the first author [6]. Computations included spectral analysis of RR-interval to estimate respiratory sinus arrhythmia (RSA) as natural log of spectral density in the high-frequency band and within-subject variability in respiration (SD of total time, SD of tidal volume, SD of duty cycle), in addition to standard parameters [for details, see 5]. Artifacts in the data were edited or excluded. Statistical analyses used repeated-measures ANOVAs with the factors Condition (B vs. E or P vs. E) and Group (anxious vs. non-anxious). In addition, for each condition, groups were compared using a one-way ANOVA.

RESULTS

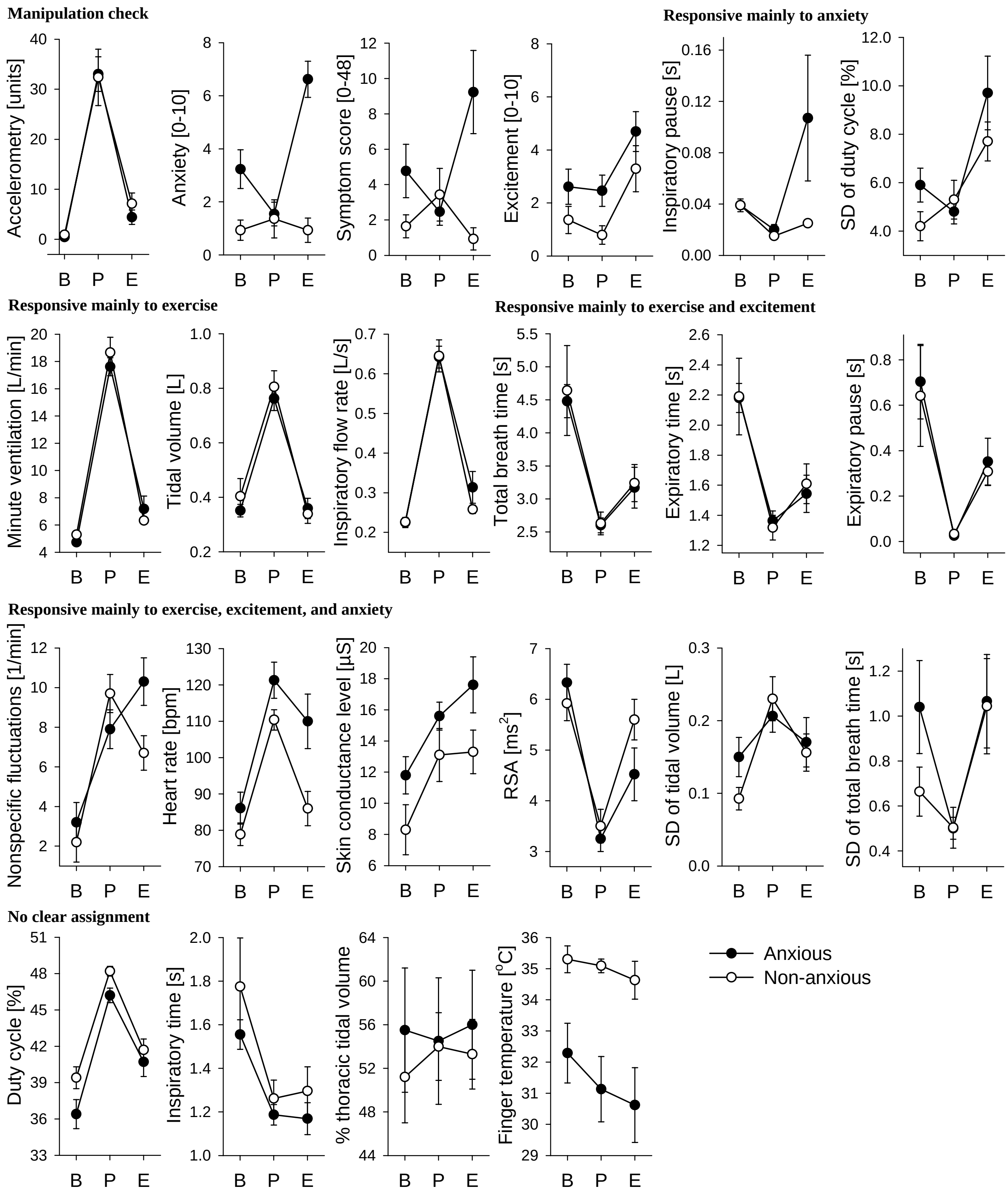
ANOVAs for all variables can be found in **Table 1**. Accelerometry and self-reported anxiety, excitement and symptom score indicated that experimental conditions induced physical and emotional activation as intended. Both anxious and non-anxious groups experienced increased excitement during flight, but only the anxious group reported much anxiety and symptoms.

Table 1. *F*-ratios of Group x Condition ANOVAs and one-way ANOVAs comparing groups for the 3 conditions

Measurement	**Baseline vs. Emotional**			**Physical vs. Emotional**			**Anxious vs. Non-anxious**		
	Group	**Condition**	**G x C**	**Group**	**Condition**	**G x C**	**Baseline**	**Physical**	**Emotional**
Manipulation check									
Accelerometry	1.30	18.94 ****	0.92	0.08	64.72 ****	0.25	1.01	0.02	1.13
Anxiety	39.05 ****	11.55 ***	11.55 ***	22.10 ****	17.31 ****	24.28 ****	8.18 ***	0.05	48.66 ****
Symptom score	14.82 ****	1.88	3.59 +	5.86 **	2.32	10.95 ***	3.80 +	0.32	12.39 ***
Excitement	2.44	13.95 ****	0.02	4.96 *	13.10 ****	0.04	2.33	6.10 **	1.47
Responsive mainly to anxiety									
Inspiratory pause	2.97 +	1.29	3.01 +	3.32 +	4.34 *	2.71	0.00	1.58	3.04 +
SD of Duty cycle	3.80 +	25.77 ****	0.05	0.74	19.92 ****	2.41	3.59 +	0.34	1.99
Responsive mainly to exercise									
Minute ventilation	0.08	13.60 ***	2.24	0.01	319.67 ****	0.15	2.92 +	0.62	0.80
Tidal volume	0.09	1.32	2.20	0.44	266.27 ****	1.77	0.57	0.00	0.15
Inspiratory flow rate	1.33	8.92 ***	1.97	0.05	189.24 ****	0.98	0.01	0.33	1.89
Responsive mainly to exercise and excitement									
Total breath time	0.04	26.14 ****	0.03	0.03	10.90 ***	0.01	0.05	0.02	0.03
Expiratory time	0.03	45.07 ****	0.12	0.01	8.50 ***	0.49	0.00	0.18	0.14
Expiratory pause	0.10	7.08 **	0.01	0.09	26.86 ****	0.19	0.05	0.43	0.14
Responsive mainly to exercise, excitement, and anxiety									
Nonspecific fluctuations	3.62 +	52.38 ****	2.58	0.77	0.09	8.38 ***	0.56	2.06	6.34 **
Heart rate	5.61 *	26.83 ****	7.97 ***	6.29 **	29.41 ****	3.71 +	1.77	3.64 +	7.62 **
Skin conductance level	4.08 +	26.70 ****	0.13	2.84	1.73	1.13	2.45	1.13	3.40 +
RSA	0.41	17.08 ****	8.28 ***	1.21	32.90 ****	0.48	0.67	0.36	2.71
SD of tidal volume	1.65	3.01 +	0.80	0.02	8.58 ***	1.02	3.51 +	0.39	0.11
SD of total breath time	0.83	1.81	1.42	0.00	14.00 ****	0.03	2.72	0.08	0.01
No clear assignment									
Duty cycle	2.85	13.85 ****	1.26	2.93 +	68.96 ****	0.51	4.16 +	9.68 ***	0.48
Inspiratory time	0.91	38.95 ****	0.44	0.92	0.02	0.24	0.84	0.58	0.89
% thoracic tidal volume	0.42	0.15	0.02	0.13	0.01	0.73	0.37	0.01	0.40
Finger temperature	0.65	12.11 ***	3.63 +	14.86 ****	0.70	0.00	8.66 ***	14.69 ****	9.27 ***

Note: Levels of significance: **** < 0.001, *** p < 0.01, ** p < 0.025, * p < 0.05, + p < 0.1; RSA: Respiratory sinus arrhythmia

To answer the question which variables were differentially sensitive to emotional and physical activation, statistical configurations of physiological parameters in Table 1 were classified into four patterns. These patterns are visualized in **Figure 1**. Variables are ordered in decreasing conformity to the pattern.



Pattern 1. Responsive mainly to anxiety. This pattern is characterized by a lack of response to P for either group and greater response of anxious participants to E or B (for which self-reported anxiety indicates a group difference). All variables grouped in this pattern have a low *F*-ratio for Condition for B vs. P and a high *F*-ratio for Group during E and/or B.

Pattern 2. Responsive mainly to exercise. This pattern is characterized by a large response to P for both groups and a comparatively small and similar response of both groups to E. All variables grouped in this pattern have a high *F*-ratio for Condition for B vs. P and a low *F*-ratio for Group during E.

Pattern 3. Responsive mainly to exercise and excitement. This pattern is characterized by a large response to P for both groups and a similar response of both groups to E. All displayed variables have a high *F*-ratio for Condition for B vs. P and a high *F*-ratio for Condition for B vs. E, but a low F-ratio for Group during E.

Pattern 4. Responsive mainly to exercise, excitement, and anxiety. This pattern is characterized by a comparable response to P for both groups but greater response of anxious individuals to E or B. All displayed variables have high *F*-ratios for Condition for B vs. P, high *F*-ratios for Condition for B vs. E, and high *F*-ratios for Group during E or B.

DISCUSSION

This study systematically varied physical and emotional conditions to identify how physiological parameters relate to these factors. Results indicate that many parameters, including heart rate, RSA, and skin conductance level and its fluctuation, were highly nonspecific markers of physical *and* emotional activity. However, all three parameters of respiratory volume were particularly responsive to exercise, while two parameters of irregularity in breathing, inspiratory pause and SD of duty cycle, were to anxiety. Several respiratory timing parameters were responsive to both exercise and excitement. A few parameters, like respiratory duty cycle and finger temperature, did not fall into any of these categories. Thus, results indicate that measures of emotional activation most commonly used in laboratory assessments – namely heart rate, electrodermal activity, and RSA – provide especially ambiguous information during ambulatory psychophysiological monitoring since they are reactive to both emotional and physical activation. This may lead to inconclusive results in studies not acquiring any context information to identify periods of physical activity. Our results indicate that such “context markers” may be provided by respiratory volume parameters like minute ventilation, tidal volume, and inspiratory flow rate. Increases in respiratory volume during ambulatory recording are highly related to increases in metabolic demand related to physical activity [7], while emotion conditions appear to affect these parame ters only to a relatively small extent. On the other hand, parameters of respiratory timing like total and expiratory time, were also strongly affected by physical activity, but were in addition sensitive to even small levels of emotion activation represented by excitement.

Thus, our results demonstrate that respiratory parameters separate resting, physical activity, and emotional conditions, emphasizing the high informational content of respiratory pattern analysis and the fact that respiratory responses are multidimensional in nature [8]. Especially promising for indexing anxiety appears the measurement of expiratory pause and within-subject variability in respiratory duty cycle, both indicators of irregular breathing. Tidal volume variability, another indicator of irregular breathing, has been found to be a diagnostic marker for panic disorder [9-11]. The current study demonstrates that it also increases with state anxiety and excitement. Moreover, it also increases during physical activity and therefore will be difficult to interpret in 24-h monitoring studies of panic disorder unless physical activity is held constant.

Accelerometry, button presses, and self-report in an emotion diary served as effective non-physiological context markers. Without this information it would have been difficult to segment conditions correctly and assign the labels 'excitement' or 'anxiety' to certain response patterns. In addition, the activities in this study were structured to provide comparability across subjects. Statistical methods that regress out physical activity confounds from ambulatory HR to obtain its emotional component termed "additional heart rate" have been described [12]. Pattern recognition algorithms have not yet been applied to ambulatory physiological measurements but are uniquely suited to augment data interpretation [13].

CONCLUSIONS

We conclude that physiological measures provide information that can help distinguish emotional from physical activation. However, additional context awareness is necessary for confident data interpretation in ambulatory recording. This can be achieved by specific channels such as accelerometry, items in an electronic diary, semi-structured protocols, and statistical modeling. Novel devices like the LifeShirt system are uniquely suited to collect this kind of information [2, 3, 7].

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