Assessment of Heart Rate and Electrodermal Activity during Sustained Attention to Response Tests

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Abstract

Heart rate variation and electrodermal activity are both affected by the autonomic nervous system's response to psychological and emotional activity. The objective of this work is to use measures of these indices of autonomic function to assess the emotional responses of subjects undergoing a Sustained Attention to Response Test (SART). Errors of commission (failure to withhold responding to the no-go target), errors of omission (failure to respond on go trials), and response times were analyzed in conjunction with heart rate and electrodermal measurements.

Errors of omission were the most common errors made by participants while errors of commission occurred less frequently with both showing considerable skin conductance rises in subjects who made few errors. The RR interval tachogram showed little correlation to errors of commission, omission or electrodermal measures. However, the mean RR interval after a commission error increased in subjects with low error rates. Also analysis of the low frequency component of the RR interval variation displayed an amplitude variation, which did show close correlation and synchronization with electrodermal activity in some subjects. The results suggest that autonomic outflow affecting electrodermal activity during the SART test also affects heart rate variation and the use of both measures of autonomic function may give a beneficial and complementary insight into physiological responses to psychological and emotional states.

1. Introduction

The autonomic nervous system (ANS) is the involuntary nervous system of the peripheral nervous system, which subconsciously controls bodily functions such as heart rate, respiration, digestion, blood pressure and sweat. Recent psychophysiological studies however have highlighted a more dynamic relationship between brain and autonomic function and the complex interaction between external/internal stimuli, mental and emotional inputs and their effect on autonomic activity [1-4]. Indeed the reactivity of the autonomic system to environmental stimuli has been linked to physical pathologies such as hypertension and coronary heart disease [5,6] and psychological disorders such as anxiety and panic disorders [7,8]. To better understand the relationship between physiological, psychological and emotional autonomic interactions, measurements such as electrodermal response, respiration, blood pressure and cardiovascular variability have been used as indices of ANS activity.

In this study two of these measures, electrodermal and heart rate activity, are used to assess autonomic activity during a Sustained Attention to Response Test (SART) [9]. Electrodermal activity (EDA) is a commonly used indicator of ANS activity where changes in sweat gland activity are indicated by variations in the skin conductance responses (SCRs). These variations are mediated solely by the sympathetic branch of the ANS. In contrast, heart rate variability (HRV) as indicated by variations in the RR interval is mediated by both the parasympathetic and sympathetic branches of the ANS. We examine ANS effects on EDA and HRV and try to assess the relationship between these two indices and performance criteria from the SART test. We analyze both long term and short term responses of EDA and HRV. Standard time and frequency domain techniques are used to assess HRV over the complete test, while skin conductance responses, short term heart rate variations and complex demodulation of HRV are used to analyze transient responses of EDA and HRV during particular events in the SART test. SART performance indicators such as errors of commission (failure to withhold responding to the no-go target), errors of omission (failure to respond to go trials), and response times were evaluated. Participants were divided into two groups, those with high rates of errors of commission and omission and those with low error rates. The SART performance criteria for each group were then analyzed in conjunction with their EDA and HRV measures.

2. Methods

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10 male participants were recruited to participate in a SART test similar to the test outlined in [9]. A single stimulus (single number as target) was used as a predefined target. Participants are presented with a number between 1 to 9 every 1.15 seconds in a fixed sequence. Each digit was presented for 250 ms followed by a mask of 900 ms. The mask following each digit consisted of a ring with a diagonal cross in the center. Both mask and digit were presented centrally in white against a black background on a laptop computer screen approximately 40cm from the subject's eyes. All participants were asked to use their preferred hand to register responses. The participants were required to press the left mouse button in response to the mask after each digit except when the digit 3 preceded the mask. Response cues are used to reduce the variability in response times within and between subjects and minimize speed/accuracy trade offs [11]. The full SART test consisted of 1000 stimuli of which 889 were no-go trials and 111 were go-trials resulting in a total block duration of approximately 19 minutes. A practice period consisting of 27 digits, 3 of which were targets was presented to participants prior to the full test.

EDA measurements were taken using a BIOPAC MP100 unit (Biopac Systems, Inc) with the ECG100C electrocardiogram amplifier module, the GSR100C electrodermal activity amplifier module and a data acquisition card (National Instruments Corporation, NiDAQ 6024E). Two Ag/AgCl Biopac finger electrodes (TSD205) were secured on the index and middle finger of the participant and Signa electrode gel was applied to the contact areas to aid conductance. A five-minute rest period was undertaken to ensure skin hydration by the gel prior to the SART practice and SART test periods. The ECG leads consisted of EL500 electrodes used in conjunction with LEAD100 series electrode leads and the MEC110C extension cable. The three electrode leads were connected in modified V5 position.

The NiDAQ sampled the ECG and skin conductance signals at 256 Hz and this data was stored with the number stimuli and the mouse button responses on the laptop for post processing. A rise in skin conductance level was associated with a response if it occurred between 1 and 5 seconds after a particular stimulus (no-go stimulus, error of commission/omission). Fluctuations in heart rate were assessed using RR intervals (QRS peak to following QRS peak). The beat-to-beat RR interval series was converted to a time-based signal by linear interpolating the signal at 1Hz. Complex demodulation was used for continuous assessment of the low frequency (LF) and high frequency (HF) components of the RR interval variations [12,13]. Center frequencies of 0.09 and 0.30 Hz were selected for the LF and HF components and a 61-term low pass filter was used with cutoff frequencies set at 0.05 and 0.15 Hz [13]. The frequency bands for the LF and HF components were therefore 0.04 – 0.14 and 0.15 – 0.45. For overall assessment of HRV we used Burg parametric spectral measures of order 13. These measures were then analyzed in conjunction with the EDA and SART performance measurements.

3. Results

Participants were separated into two groups, those with a total error rate (omissions and commissions) greater than 15 and those with a total error rate below 15. For each group the average SART performance measures outlined above were calculated. HRV and EDA measures were also evaluated for each group. HRV time domain measures included mean RR interval, SDNN, SDANN, RMSSD and pNN50. HRV frequency domain measures include LF, HF spectral power and the LF/HF ratio. LF and HF components are expressed as a percentage of the total power spectral density. For EDA responses the mean SCRs for no-go targets, errors of commission and errors

Measures	Participants with high total error rate (>15)	Participants with low total error rate (<15)	*t Test p*
Commission	13.20 ± 10.28	2.83 ± 2.31	0.038*
Omission	17.00 ± 13.09	5.16 ± 1.83	0.054
Response Times (ms)	472.95 ± 111.09	562.82 ± 49.95	0.107
RR mean (ms)	887.00 ± 152.20	868.60 ± 169.90	0.855
SDNN (ms)	67.70 ± 20.00	70.5 ± 28.10	0.869
RMMSD (ms)	43.50 ± 24.9	49.10 ± 25.0	0.72
pNN50 (%)	0.21 ± 0.18	0.25 ± 0.20	0.713
LF (%)	44.24 ± 9.08	39.26 ± 16.40	0.562
HF (%)	8.92 ± 5.07	11.78 ± 5.21	0.383
LF/HF	6.87 ± 4.64	4.93 ± 4.81	0.515
SCR (no-go) (µS)	11.27 ± 7.95	28.17 ± 12.4	0.028*
SCR (Commission) (µS)	18.72 ± 21.19	43.55 ± 32.98	0.182
SCR (Ommission) (µS)	15.97 ± 16.64	27.42 ± 23.28	0.069

Table 1: RR interval measures for duration of test and SCR values during events [Mean ± SD] *p < 0.05

of omission were calculated. The results of these measures are shown in Table 1.

The difference in errors of commission and omission between the two groups is as expected as they are divided into two groups on the total error criteria. The only other significant difference between the two groups was seen in the mean SCR result during no-go targets. Participants in the lower total error group showed much larger mean rises in skin conductance levels during no-go trials, errors of omissions and error of commissions. This may be due to increased emotional response in subjects in the low error group to the occurrence of the no-go target and to errors. The response times although not significant showed differences between the high and low error rate groups. The response times are calculated from the time of the digit being presented and include the 250 ms between the digit and the cueing mask. Subjects with the higher error count on average showed reduced response times. Quicker response times have been shown to relate to more errors [9]. The HRV time and frequency domain indicators showed no significant differences between the groups. Of all the HRV measures the HF spectral component showed the most difference between the two groups. The HF component of HRV is associated with parasympathetic activity and respiratory sinus arrhythmia (RSA), and has been linked to emotional responses, working memory and ability to sustain attention [14,15].

The main difference between the HRV and EDA measures in Table 1 is that the HRV measures are averaged over a 19-minute response. This gives us little information on the transient nature of the heart rate variation during responses. To get a better insight into how heart rate indices may vary during responses we looked at RR interval measures during no–go targets, errors of commission and errors of omission. For this analysis we calculated the mean RR interval for the preceding 5 seconds and post 5 seconds of a particular event and subtracted the preceding mean from the post mean. Table 2 shows the results for this analysis. The RR interval measures for the no-go target (digit 3) and errors of omission showed no significant differences between the two groups. However the RR interval measure in response to an error of commission showed a very significant difference between the two groups. This contrasts with the results from the SCR analysis where no-go targets provided us with the significant difference between the two groups. The post response mean RR intervals were higher than the pre response RR interval

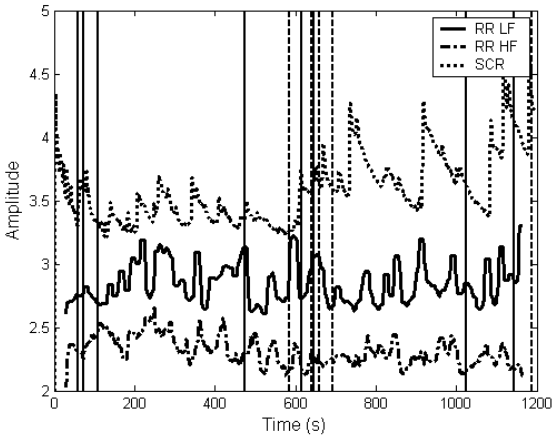

Figure 1. Skin conductance response and the median filtered LF and HF components (scaled and offset) of the RR interval variations. Solid straight lines are location of errors of omission and broken straight lines are location of errors of commission.

values. This suggests that the error of commission may have resulted in an increase in parasympathetic activation, which may be respiratory related, as there was an increase in RR interval length and it occurred within 5 seconds of the response.

Finally we looked at the transient behaviour of the LF and HF components of the RR interval using complex demodulation. Figure 1 shows the plots of the median filtered LF and HF components with the SCR signal and the solid and broken straight lines representing errors of omission and error of commission respectively. It is clear from this figure that variations in SCR and RR interval frequency components vary both in response to errors and independent of errors. In some subjects the LF component showed close correlation between the LF component and electrodermal activity.

4. Discussion and conclusions

In this study we analysed electrodermal and heart rate variability responses to the sustained attention to response test (SART). Limitations of this study include the number of participants and the difficulty in matching a specific physical response to a specific stimulus. With the small number of participants, caution must be taken in the interpretation of the significance levels presented. More participants are required to validate these current results.

Measures	Participants with high total error rate (>15)	Participants with low total error rate (<15)	*t Test* *p*
ΔRR mean (ms) (no-go)	-5.43 ± 2.49	-3.28 ± 3.89	0.3163
ΔRR mean (ms) (Commission)	0.36 ± 0.29	15.73 ± 5.59	0.0054*
ΔRR mean (ms) (Ommission)	3.16 ± 4.09	4.16 ± 4.08	0.6952

Table 2: Change in 5 second mean RR interval change preceding and post event [Mean ± SD] *p < 0.05

The slow reaction time in both electrodermal activity and heart rate responses to stimuli means that it is necessary to use a 1 to 5 second window post stimulus to monitor physiological responses. This makes it difficult to match specific responses to specific stimuli as each stimulus lasts 1.15 seconds. To aid in the analysis of physiological responses and SART performance criteria participants were separated into two groups. Those that showed a high error rate of errors of commission and omission (>15) and those who achieved a lower error rate. Errors of omission occurred the most among participants with error of commission occurring less frequently. Response times although not significant showed that participants in the high error group were more likely to respond quicker to stimuli. Both averaged time and frequency heart rate variability indicators showed no significant difference between the two groups while SCR responses for no-go showed significant differences between the two groups. Errors of commission and omission also showed a difference, although this was not significant between the two groups, with increased SCR levels in participants with low error rates. This suggests that participants in the low error rate may show increased emotional response during no-go targets and errors. To investigate possible short-term heart rate responses to particular events we calculated the mean RR interval 5 seconds prior and post event. In contrast to the SCR responses this showed a significant difference between the two groups with respect to errors of commission. The increased rise in RR interval was indicative of parasympathetic activation and again is in contrast to the sympathetic activation of the electrodermal activity during no-go targets. Finally transient analysis of the LF and HF components of RR interval analysis was assessed using complex demodulation. The LF component in some subjects showed close correlation and synchronisation with electrodermal activity although further investigation is required to quantify this effect.

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