Peripheral Arterial Tone As an Index of ANS Trade-Off

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ABSTRACT

The present study investigated the possibility of a tradeoff between generalized and sympathetic autonomic arousal. We examined participants' Heart Rate (HR) and Peripheral Arterial Tone (PAT) during completion of vigilance Go/No-Go task. PAT is considered to be a relatively pure measure of sympathetic arousal. The two measures tended to be consistent within each participant. However, as predicted by the notion of Individual Response Specificity, across individuals there was a negative correlation between the two measures. Additionally, each measure had a different correlation with the performance indices, suggesting that the sympathetic and parasympathetic branches of the Autonomic Nervous System (ANS) modulate different cognitive strategies. These results challenge the view that measures of the autonomic system are indicators of the same psychological construct.

Author Keywords

Peripheral arterial tone, heart rate, autonomic nervous system, cognitive load.

INTRODUCTION

A variety of ANS indices are used to asses mental load, including Heart Rate (HR), Pupil Dilation (PD), and Galvanic Skin Response (GSR). However, the ANS has two branches, sympathetic and parasympathetic, which affect physiological indexes differently. For example, HR is modulated by sympathetic and parasympathetic affecters [2] whereas GSR, PAT, and the Pre-Ejection Period (PEP) are mainly affected by sympathetic affecters [16]. The relationship between the different ANS measures and behavior is unclear [1] and the few studies that have examined this report mixed findings [7, 9].

Studies of Individual Response Specificity (IRS) suggest that individuals tend to have a typical autonomic response that is more elevated than other responses across diverse conditions [11]. IRS implies a negative correlation across performers between different measures because different people consistently have different reactivity patterns [1]. However, this research direction was not taken up and subsequent studies did not replicate the negative correlation [7]. Furthermore, [12] found a low positive correlation across participants between HR and PEP.

The idea of IRS also predicts a positive correlation between measures ***within*** individuals; consistent with the view of the two ANS branches being complementary affecters of "fight or flight" vs. "rest and digest" [2]. Yet as far as we know, the inter-individual correlation between measures has not been examined. Another under-studied line of investigation concerns the functional difference between the two systems. Studies focusing on PAT have shown that pure sympathetic channels tend to be more sensitive to increases in arousal than general measures. For example, PAT was found to be a better indicator of cognitive load than HR in memory [6] and complex perceptual motor tasks [5]. Additionally, sympathetic and parasympathetic branches are differently sensitive to psychological stimuli of different valence [10]. Similar findings were observed using PAT as an index of sympathetic activation and PD as a general index [4]. This is consistent with literature suggesting that parasympathetic activity is highly related to stress responses [3].

The main goal of the present study was to re-examine the correlation between general and sympathetic measures of arousal using the Peripheral Arterial Tone (PAT; a sympathetic measure that is not a direct component of heart activity) and HR (a general measure of ANS activation). In the current study we used a passive effort vigilance Go/No-Go task to enable simultaneous examination of the focus on positive and negative events (decision bias) and performance level (decision accuracy). The use of the vigilance task enabled the continuous monitoring of relationships between the arousal measures over a longer time periods with the participant's task being homogeneous throughout. Moreover, this task is particularly sensitive to mental load investment [18], allowing for the comparison of the functional significance of general and sympathetic measures of arousal.

The results revealed that within each participant, HR and PAT correlated, whereas across participants the measures were negatively correlated. The results suggest that the two branches of the ANS modulate different arousal strategies that vary across participants.

METHODS

Participants

Forty undergraduate students from the Israel Institute of Technology (Technion; 17 females) volunteered to complete the experiment. Their average age was 23.6, ranging from 18 to 28. Reimbursement ranged from 30 to 90 New Israeli Shekels (NIS) depending on task performance.

Go/No-Go Task

Participants completed a single block computerized Go/No-Go task that involved the presentation of 100 two-digit Go (98 of 100 trials) and No-Go cues (2/100) randomly presented between trials 20 and 100. The meaning of each cue was told in advance and this information was continuously presented using a cue card placed next to the computer. Participants were rewarded NIS 10 for hits (correct response to Go cues), penalized NIS 20 for misses (failure to respond to Go cues), and penalized NIS 5 for false alarms (incorrect response to No-Go cues). The payment asymmetries were designed to highlight the importance of the rare stimuli.

Stimuli were presented for 1.5 seconds with a response window of two seconds (SOA = 19 s). For 17.5 s following the removal of the stimulus, the computer screen was blank. Participants were tested individually using a PC (Intel ® Core 2 CPU 6400 @ 2.13 GHz, 1.98 GB of RAM). The numbers representing Go and No-Go cues ("21" and "32", or "22" and "31") were counterbalanced between participants. ***Physiological measures***. PAT and HR were measured throughout the experiment using a Site-Pat200 device (Itamar Medical, Ltd, Israel). This system is a finger cup shaped photo-cell sensor plethysmograph that is placed at the end of the first finger of the non-dominant hand. The cup envelops the finger up to and beyond its tip with uniform pressure so that only arterial volume is measured and the aggregation of the venous blood is prevented (Lavie, Schnall, Sheffy, & Shlitner, 2000). The device includes a light-emitting diode and a photo-sensitive cell that increases in sensitivity by unloading the arterial wall tension and allowing arterial volume to vary with each pressure wave. The arterial tone affects the translucence of the light through the finger tissue, which, in turn, affects the output measures. The amount of light transmitted through the finger is measured in Volts (V). When the artery is constricted (sympathetic activation) the blood is more concentrated and less light is transmitted through the finger. Thus, sympathetic activation (arterial constriction) leads to lower PAT. The system records PAT for each heart beat and thus HR is also measured. Because higher amounts of light represents lower levels of arousal, we used the level of vasoconstriction (-V) as a positive index of mental effort according to the level of PAT. This index is referred to as PAT Vasoconstriction, or PATV.

Procedure

Participants were given general information about the experiment's approximate length and possible payment. They were seated in front of the experiment computer, connected to the PAT system, and provided with a written information and consent form. After signing the form, the instructions were presented verbally and written. Participants were instructed to remain attentive to a series of numbers to be flashed on the screen in front of them. They were told that two types of numbers existed, "friends" and "foes" and that they must respond only to foes by clicking the left mouse key while ignoring the friends. Participants were then told which numbers denoted friends and foes and were informed of the points gained or lost following a response to each cue type. Participants were also given a card repeating this information.

Participants were provided with an initial sum of NIS 70 and their updated gains or losses were continuously displayed on the screen. Participants were given ten practice trials at the beginning of the experiment to become familiar with the task. The total duration of the experiment was approximately 50 minutes. At the end of the experiment the participants were paid according to the total amount of points earned.

RESULTS

Behavioral Data

The amount of correct and incorrect responses (and SE) from each type of stimuli was as follows; hits=1.4 $\pm$ 0.42, misses=0.6 $\pm$ 0.42, false alarms=1.12 $\pm$ 0.14, and correct rejections=96.88 $\pm$ 0.14. Misses were more frequent then false alarms. Task performance was not at floor or ceiling levels and there was room for error.

Physiological Data

PATV and HR values were calculated using a 10 second window from 5 s before to 5 s after the stimulus averaged across participants. Repeated measures analysis shows a significant decrease in HR (F(1,85) =9.41, p<0.001) and a non-significant increase in PATV across successive blocks (F(1,78)=1.98, p=0.15). Additionally, there was a significant decrease in PATV from pre-task to block 1 (t(39)=-2.44, p< 0.05). PATV was also significantly higher pre- compared to post-stimuli (t(39=4.91 , p<0.001). These findings thus suggest discrepancies between the changes of the two measures during the task. The differences were further examined using a correlation analysis.

Correlations Between Physiological Measures

First, the average Pearson correlation between PATV and HR within each participant across the 100 trials was examined. The results showed that the average within-participant correlation between the two measures was 0.18 pre- and 0.17 post-stimulus presentation. In both cases the correlations were significantly above zero (***t***(39)=4.29, ***p***<0.01 and ***t***(39)=4.08, ***p***<0.01). For correct rejections the average correlation was approximately the same as the overall correlation between PAT and HR. Due to the low number of hits, misses, and false alarms, the within participant correlation between measures could not be calculated for these events. For 75 % of participants there was a positive correlation between PATV and HR. Thus, it appears that within individuals the two measures correlated. Second, the association between PATV and HR across individuals was examined. The pre-task correlation taken 5 s before the start of the experiment was not significant (***r***= -0.004, ***p***=0.49). During the task, however, there was a negative and approaching significance pre- (***r***=-0.27, ***p***=.09), and post- (***r***=-0.26, ***p***=.10) stimulus correlation that was not driven by extreme values. Finally, there were no differences between genders in the correlation between the two measures (-0.32 for females and -0.23 for males).

Correlations with Performance

Because the number of hits had only three levels, a Spearman Correlation was used for this analysis (Table 1). There were conflicting correlations between the HR, PATV, and performance. There was a negative pre- and post-cue correlation between PATV and misses. The lack of correlation between HR and performance suggests dissociation between the measures at the functional level.

DISCUSSION AND SUMMARY

The results showed that within each participant there was a positive correlation between PATV and HR. However, across participants there was a negative correlation between the two measures. The results thus demonstrate the emergence of Individual Response Specificity. This can be interpreted as due to differences in people's arousal system with different individuals scoring higher on a particular index, or to different individuals using different arousal strategies.

A result that is more consistent with the second explanation is the change in these measures across time. The generalized measure (HR) stabilized faster than the sympathetic measure (PATV) throughout the task. This suggests that the processes tapped by these two measures may also have different dynamics. Examining the functional significance of the two measures supports their distinction because they correlated differently with performance. One possibility for the low association between HR and performance is that the task involved too little active effort with only two No-Go trials. Another possibility is that the task was too long to maintain high arousal.

	PATV		HR	
	Before	**After**	**Before**	**After**
Misses	-0.23^{+}	-0.25*	0.17	0.17
False Alarms	-0.06	-0.06	0.14	0.13

Table 1: Spearman Correlation between PATV and HR from 5 seconds pre- and post-stimuli type with measures of performance; $^{+}$ = p < 0.1; * = p < 0.05.

Previous studies have shown that PAT, an autonomic measure of sympathetic activation, is a better predictor of performance in cognitive tasks than HR [5]. This was argued to be due to the greater sensitivity of the PAT to fast paced changes in cognitive load [6]. The current findings suggest a complementary explanation, showing that in fact PAT and HR are not measures of the same construct. Rather, within participants, the two measures are positively correlated but only to a limited extent (about 0.2). Moreover, across performers the two measures are negatively associated. This negative association is also accompanied by different functional significance of the two measures, which suggests that the two measures represent different cognitive/physiological arousal strategies.

The current findings are somewhat consistent with the few previous studies examining correlations between general and sympathetic arousal. Consistent with the negative association between measures ***across participants,*** [9] found that during an auditory odd-ball and mental arithmetic task, HR reactivity was associated with minimal GSR while HR non-reactive subjects showed more skin conductance. For example, [7] reported a low positive correlation within participants however this was not statistically significant.

However, our results contrast [12] who reported a positive correlation between PEP and HR ***across*** participants during a delayed matching task. A possible explanation for the contradiction between results of the current study and those of [12] is that they did not examine the outcome of a particular strategy but studied the gross effect of effort on a simple task where effort improves performance. It may be that in this situation the two arousal subsystems work complimentarily. Still, this does not contradict the idea that the parasympathetic and sympathetic systems are associated with different cognitive strategies.

An explanation for the dissociation and even tradeoff between these measures must consider energetic differences between the measures. What PATV represents is a change in the allocation of bodily resources, mediated by the flow of blood, from the periphery to the center, thus enabling a re-organization of resources more effectively according to the task. In contrast, HR increases represent an increase in the bodily resources in general. It appears that individuals can exhibit both reactions, a re-organization and a general increase, simultaneously. However, some individuals responded to a novel task by increasing their resources, whereas others respond by re-organizing them. In other words general arousal (HR) is a gross performance enhancing mechanism. By increasing HR, more oxygenated blood is available to the brain than at lower HR values. In contrast, sympathetic arousal is a more strategic performance enhancing mechanism. Similar to general arousal increases, by constricting peripheral arteries, more oxygenated blood is available to the brain. However general arousal increases oxygenated blood flow throughout the body, whereas sympathetic arousal increases oxygenated blood flow to specific parts of the body (e.g. the brain). Sympathetic arousal thus appears a more efficient arousal mechanism for increasing task performance over the long term. Evidence for this claim is that participants in the current studies tended to exhibit an increase in either HR or PAT. For the task used, general arousal increases may be sufficient for maintaining performance at a target rate for the duration of the task. However, the gradual decrease in HR across trials suggests that maintaining higher levels of general arousal is challenging. Contrasting this, sympathetic arousal appeared to maintain steady (or increase slightly) during task completion. Thus for the tasks examined, a more efficient strategy appears to increase sympathetic activity rather than general arousal. For short duration tasks, either general or sympathetic activation is sufficient for increasing oxygenated blood flow. For long duration tasks, however, ANS activation is less efficient and more difficult to sustain than sympathetic arousal.

Despite the internal and external consistency of the results reported, there are several limitations. The lack of correlation between physiological measures and performance may be because the task involved few opportunities for variability; only two No-Go stimuli were presented. Future studies would benefit from more data points; however, [12] reported a correlation between measures of arousal and performance on early but not later trials of an attention task suggesting that arousal-performance correlations may be found with few data points. Given the argument presented above relating to the use of superior coping strategies by some participants as defined by differences in the physiological recordings suggests that the PAT may be used as a biofeedback training tool to improve performance. Recent research by [13] showed that ANS components can be controlled by directed training involving both internal cognitive and physiological monitoring. This is a recommended area of future research.

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REFERENCES

1. Cacioppo, J.T., and Tassinary, L.G. Inferring psychological significance from physiological signals. ***American Psychologist, 24***, 1 (1990), 16-28.
2. Cacioppo, J.T., Tassinary, L.G., and Berntson, G.G. ***Handbook of Psychophysiology*** (2nd ed.). Cambridge: Cambridge University Press, 2000.
3. Heponiemi, T., Ravaja, N., Elovainio, M., Näätänen, P., and Keltikangas-Järvinen, L. Experiencing positive affect and negative affect during stress: Relationships to cardiac reactivity and to facial expressions. ***Scandinavian Journal of Psychology, 47*** (2006), 327-337.
4. Hochman, G., Glockner, A., & Yechiam E. (in press). Physiological measures in identifying decision strategies. In A. Glockner and C.Witteman (Eds.), ***Foundations for Tracing intuitions, challenges, and methods***. London: Psychology Press & Routledge.
5. Iani, C., Gopher, D., Grunwald, A.J., and Lavie, P. Peripheral arterial tone as an on-line measure of load in a simulated flight task. ***Ergonomics***, ***7*** (2007), 1026-1035.
6. Iani, C., Gopher, D., and Lavie, P. Effects of task difficulty and invested mental effort on peripheral vasoconstriction. ***Psychophysiology, 4*** (2004), 789-798**.**
7. Kettunen, J., Ravaja, N., Näätänen, P., Keskivaara., and Keltikangas-Järvinen, L. The synchronization of electrodermal activity and heart rate and its relationship to energetic arousal: A time series approach. ***Biological Psychology, 48*** (1998), 209-225.
8. Lavie, P., Schnall, R.P., Sheffy, J., and Shlitner, A. Peripheral vasoconstriction during REM sleep detected by a new plethysmographic method. ***Nature Medicine, 6*** (2000), 606**.**
9. Lawler, E.E. ***Strategic Pay***, Jossey-Bass, San Francisco, CA, 1990.
10. Löw, A., Lang, P.J., Smith, J.C., and Bradley, M.M. Both predator and prey: Emotional arousal in threat and reward. ***Psychological Science***, ***19*** (2008), 865-873.
11. Marwitz, M., and Stemmler, G. On the status of individual response specificity. ***Psychophysiology, 35*** (1998), 1-15.
12. Richter, M., and Gendolla, G.H.E. The heart contracts to reward: Monetary incentives and pre-ejection period. ***Psychophysiology***, ***46*** (2009), 451-457.
13. Tang, Y., ***et al***. Central and autonomic nervous system interaction is altered by short-term meditation. ***Proc. Nat. Acad. Sci. USA, 106***, 22 (2009), 8865-8870.
14. Wallin, B.G. Sympathetic nerve activity underlying electrodermal and cardiovascular reactions in man. ***Psychophysiology, 18*** (1981), 470–476.