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Effects of Cognitive Load and State of Vigilance On Sympathetic

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ABSTRACT

The skin conductance response is one of the noninvasive peripheral markers of the activity of the sympathetic nervous system. Skin conductivity level monitorization during cognitive performance processes is used as a physiological indicator of task-related alertness and attention. This study is aimed to investigate the relationship between task-related sympathetic activity and reaction time in students 18–22 years of age. A total of 20 healthy male and female students were included in the study. Hand preference and color blindness tests were applied to the participants. Electrodermal activity recordings were recorded as tonic and phasic recordings during all tasks. Different colored 2-dimensional geometric objects were presented in fixed and random intervals through the computer system. The task performance of pressing the predefined button as soon as the stimulus appeared on the computer screen was investigated in relation to cognitive load and sympathetic stress response. Applying an increased amount of cognitive load increases sympathetic stress response ($p<0.001$). An increase in reaction time was observed with the increasing amount of cognitive load ($p<0.05$). The similar task levels, on the other hand, cause statistically higher mean skin conductivity levels when a visual stimulus is presented at a fixed interval rather than a random stimulus interval. Beyond the expectations, our novel findings highlight the importance of the internal timestamp processes of individuals. Therefore, we may suggest that time estimation processes play a critical role in the generation of the sympathetic stress response when compared to the vigilance state caused by simply waiting for random stimuli.

Keywords: Cognitive load, sympathetic skin response, reaction time

Introduction

The skin conductance response (SCR), also known as electrodermal activity (EDA) or galvanic skin response, is widely used in psychophysiological research as a noninvasive peripheral indicator of the sympathetic nervous system (1-3). Sweat glands are innervated with sudomotor cholinergic fibers and EDA evaluates changes in the ability to transmit electrical conductance of skin depending on the activity of the sweat glands (4). Therefore, skin conductance level (SCL) and skin conductance fluctuation rate (SCFr) are set as a physiological index of alertness (5). SCFr is the number of skin conductance response fluctuations during EDA recording (6,7) Increased alertness level increases skin conductivity as sympathetic stimulation to the sweat glands increases (8). Skin conductivity measurements are composed of two components: tonic and phasic. The tonic component of skin conductivity is measured by the level of skin conductivity and reflects resting skin conductivity. The phasic component is the response in which a few seconds of oscillation in skin conductivity are observed in response to environmental or emotional stimulation. It has been shown in brain imaging studies that the galvanic skin response measured during the cognitive performance is an indicator of task-related alertness (9). The tasks that need concentration, require the ability to suppress the perceptual effects or memory traces of previous stimuli to maintain cognitive focus. Therefore, managing attention requires the involvement of working memory and the use of special mental ability under cognitive load. Processing memory content to make it available also refers to working memory (10). Cognitive load is a complex concept that is often poorly defined. In the field of human-computer interaction, it is defined as the

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mental sources that a person must complete tasks in a certain time; it varies depending on the amount of information that needs to be processed simultaneously. The amount of cognitive load a person experiences is influenced by tasks and some other factors such as individual differences, and environmental and social environment (11). Classical research in information processing during problem-solving in the context of achieving goals reveals that short-term memory serves under managerial control. If schematic information is not available already, the information received is divided into quantities proper for the working memory capacity (12). In accordance with the classical cognitive load theory, these amounts show short-term memory and individual differences in processing capacities. High cognitive loads lead to cognitive choices that need attention, causing psychophysiological stress. This endeavor creates autonomic attention (13).

The reaction is a voluntary response to an external stimulus. There is an interval of time between the onset of external stimulus and the appropriate motor response that is known as reaction time (14). It reflects the speed of neurophysiological overall processes such as neural transmission and the response of motor acts (15). Sensation, perception, integration of the information in the sensory pathway, and decision-making combine to form cognitive functions that serve a crucial role in everyday social behavior (16). A literature review suggests that cognitive status is closely related to the sympathetic nervous system and has an impact on the galvanic skin response. However, there are still controversial points on the ways and patterns of sympathetic indicators of cognitive load and alertness. Therefore, this study, it was aimed to investigate the task-related changes in sympathetic activity. For this purpose, the changes in the sympathetic activity were evaluated through EDA recordings which are synchronized with various tasks. The tasks were designed in such a way that initiated the cognitive and vigilance processes in the participants.

Material and Methods

A total of 20 healthy male and female right-handed students (18-22 years of age), from the Faculty of Medicine and Dentistry at Başkent University, participated in this study. The volunteers were informed before the experiment and an informed volunteer consent form was signed. The exclusion criteria included smoking/alcohol consumption, sleeping less than 5 hours the night before the test, consumption of more than 1 cup of coffee or more than 2 cups of tea, color blindness, and exercising or strenuous activity before the test. The inclusion criteria in the study were being at the age of 18-22, having no visual disturbances, no neurological disturbances, having slept at least 8 hours the night before, and having passed 2 hours after eating (17).

Determining Hand Preference: The Turkish version of the "Edinburgh Oldfield Inventory" was used to determine the dominant hand (18). The inventory included questions regarding writing, drawing, throwing a stone or ball, using scissors, using a toothbrush, using a knife without a fork, using a fork, using a broom, striking a match, and opening the lid of a bottle. The results were analyzed according to the Geschwind score (19).

Determining Color Blindness: The Color Blindness Mass Screening Test described by Gundogan et al was used to determine color blindness. The test consisted of 24 plates, which the participants were asked to read and then close their eyes for 4 seconds to relax them between plate readings. The subjects who read all plates correctly were considered normal and those who had four or more mistakes as color blind.

EDA Recordings: The participants taken to the recording room were let rest for 10 min. Participants were seated comfortably in an armchair 50 cm away from the computer screen with a sport for their wrists (20). All measurements were performed in the same period of the day. The participants were informed about the experiment and asked to be in a normal resting position, to be as still as possible, and not to breathe too deeply during the test. EDA was recorded continuously using 0.8 cm diameter Ag/AgCl biopotential electrodes attached to the distal phalanges of the first and second fingers of the non-dominant hand. Electrode paste, which contains saline (0.05 M) was placed between the skin and the electrodes to minimize the resistance between electrodes and skin then the electrodes were connected to the recording system (Biopac, MP36, USA) (21). The skin conductance was expressed as SCL [ln (μmho)/cm2 per electrode area]. EDA recording system was synchronized with the visual stimulus system. The input signals were digitized and stored in the system for future analysis. After the system calibration experiments were conducted in two stages as described below;

Stage 1 (Tonic recording): Tonic parameters were recorded for 2 minutes without any stimuli which

Table 1. Tasks Applied in Stage 2 (Phasic SCLs)

Tasks	Visual Stimulus	Stimulus Exposure Time (sec)	Number of Stimuli	Inter Stimulus Interval (sec)	Descriptions
Task1	Simple RED	0.5	10	2 Fixed	Participant was asked to press on Button-1 as quick as possible upon the onset of visual stimulus with index finger of the dominant hand
Task2	Simple RED	0.5	10	2-5 Random	Participant was asked to press on Button-1 as quick as possible upon the onset of visual stimulus with the index finger of the dominant hand
Task3	Cognitive 5 Color (Red, Black, Green, Yellow, Blue)	0.5	10	2 Fixed	Participant was asked to press on Button-1 as quick as possible if the stimulus is red colored object (target) otherwise Button-2 with the index finger of dominant hand
Task4	Cognitive 5 Color (Red, Black, Green, Yellow, Blue)	0.5	10	2-5 Random	Participant was asked to press on Button-1 as quick as possible if the stimulus is red colored object (target) otherwise Button-2 with the index finger of dominant hand

are also called resting recordings (tonic skin conductance level-tonic SCL) (3). Stage 2 (Phasic recording): Sequential visual stimuli were applied to generate skin conductance responses in the participants who have already completed Stage 1.

Applying Visual Stimulus: Visual stimuli were applied through a separate custom-made computer-based test battery and synchronized with the EDA recording system (22). The task protocols assigned to the participants are given in detail in Table 1. Participants were having rest for 5 min in between each task. Participants were asked to give the fastest response to the successive stimuli of each task by pressing the predefined button. Inaccurate button pressing (faulty response) was evaluated as a false answer. The onset time of the stimulus and the time of the response were input to one channel of the EDA recording system as the time marker. The task and the presented stimulus with the answers given were saved into the computer's hard drive for further analysis. At least 1% changes in skin conductance within the first 0.5-3 seconds of presenting the visual stimulus were accepted as the skin conductivity response (2).

Results

The mean age of the participants was (19.6 ± 2.5) and the sexual distributions in the groups were found to be comparable ($p > 0.05$)

EDA parameters

Effects of Tasks Difference on SCR: "As shown in Table 2" mean values of SCL and SCFr for all tasks are given compared with the tonic recording values. Phasic SCL values for task 1 and task 3 were found to be higher than the tonic recording. These statistically significant differences ($p<0.001$, for both cases) indicate that tasks with fixed-ITI have an increasing effect on skin conductance. However, the increase in SCL values recorded during the tasks with random-ITI (task 2 and task 4) compared with tonic recording was not statistically significant. There was also a statistically significant difference between SCL values of the tasks where fixed-ITI and random-ITI used. This result traced by comparing task 1 with task 2 ($p = 0.017$) and task 3 with task 4 ($p = 0.006$). This also suggests the impact of using fixed-ITI during the task is higher than random-ITI.

Table 2. Measured SCL and SCFr Values During Tonic and Phasic Recordings. Phasic Recording Consists of 4 Different Tasks

n=20	SCL (mean±std), μmho	SCFr (min-max) Peak/min
Tonic recording [a]	8.70 ± 3.0. [b,d]	13.0 (2-24)
Phasic recording		
Task 1[b]	12.11 ± 4.4 [a,c]	12.5 (4-25)
Task 2[c]	10.04 ± 4.6 [b,d]	11.0 (2-27)
Task 3[d]	12.61± 4.9 [a,c,e]	11.5 (2-23)
Task 4[e]	10.49 ±4.4 [d]	12.0 (4-24)
p	<0.001*	0.724**

*: Repeated Measures ANOVA; Groups with significant differences as a result of multiple comparisons are shown with letters; Mean ± SD. **: Friedman test; Median (Min-Max)

Table 3. Median SCL values of the participant with (w) and without (w/o) faulty response in task-3 and task-4. The SCL ranges are given in parenthesis. (n) denotes the number of participants who had either faulty or no faulty responses

	Task 3		Task 4	
	Participants w (n=17)	Participants w/o (n=3)	Participants w (n=14)	Participants w/o (n=6)
SCL, μmho	22.63 (10.02 – 24.16)	11.85 (4.82 – 17.73)	10.19 (7.54 – 22.72)	8.79 (4.32- 19.27)
p	0.125*		0.322*	

*: Mann-Whitney U test; median (min-max)

"As shown in Figure 1" skin conductivities during task 1 and task 3 were comparable and therefore there is no significant difference. This is also true for tasks 2 and task 4, which suggests that the impact of cognitive load is negligible.

No significant difference was found in mean SCFr values for all tasks compared with Tonic recordings ($p = 0.724$).

Evaluation of Skin Conductance Response During Cognitive Tasks: The results show no statistically significant difference in median values of SCL of the participants in task 3 and task 4 ($p = 0.125$ and $p = 0.322$, respectively) (Table 3). One of the reasons for this result may be due to the limited number of participants and it should be repeated with more participants.

Reaction Time and Task Content Relation: Reaction times of the participants in response to the tasks are given in Table 4". Table also includes responses to the target and the non-target stimulus.

As seen in the Table 4, while the reaction time was the shortest in task 1, it was found to be the longest in task 4 where the participants were under a higher cognitive load and in a higher vigilance state.

A significant difference was found between the tasks in terms of reaction times ($p < 0.05$). There were statistically significant differences between reaction times in task 1 and task 3 ($p < 0.001$), task 1 and task 4 ($p < 0.001$), task 2 and task 4 ($p < 0.001$) reflecting the task difficulty.

A statistically significant difference was also found between reaction times of target (0.7 ± 0.6 sec) and non-target (0.6 ± 0.5 sec) stimuli ($p = 0.046$) for task 3 and between target (0.71 ± 0.1 sec) and non-target (0.67 ± 0.1 sec) stimuli ($p = 0.046$) for task 4 ($p = 0.049$).

Correlation Between SCL, SCFr, and Reaction Times: There was no linear relationship between the tasks by using the mean values of SCL, SCFr, and reaction times of the tasks.

Discussion

In this study, it was investigated the relationship between sympathetic stress response and various levels of cognitive tasks. For this purpose, we used 4 different tasks from simple to complex each with fixed and random ITI. EDA was initially recorded during rest without any stimulus (tonic recordings) and then during the tasks with

Table 4. Reaction Times of Participants as Second for All Tasks in Terms of Median, Maximum and Minimum

	Median (Min-Max), sec
Task-1	0.54 (0.48 – 0.75)
Task-2	0.58 (0.48 – 0.75)
Task-3 (Target stimuli)	0.66 (0.56 – 0.80)
Task-3 (Non target stimuli)	0.63 (0.51 – 0.78)
Task-4 (Target stimuli)	0.71 (0.58 – 0.88)
Task-4 (Non target stimuli)	0.66 (0.58 – 0.90)
p	<0.05

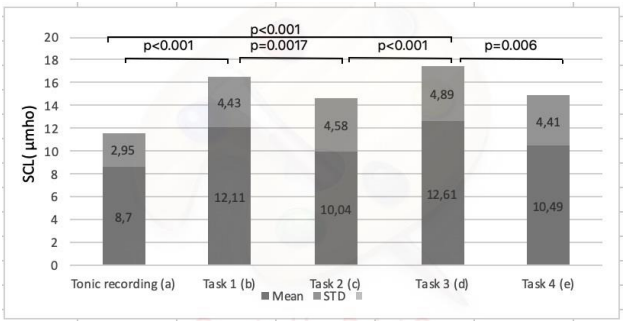

Fig. 1. Comparison of SCL Values in Different Task

varying cognitive load (phasic recordings). The results indicate that the mean values of SCL were significantly different in all tasks and emphases on the impacts of the task on triggering the sympathetic response. The mean SCL value of phasic recordings was found to be higher in task 1 and task 3 compared to task 2 and task 4, this result suggests that cognitive load causes an increase in sympathetic stress response, which is in accordance with the studies suggesting also an increase in sympathetic activity with the increased mental load (23, 24). In another study by Visnovcova et al., galvanic skin response was used as an indicator of stress initiated with the cognitive load in young healthy people (1).

In contrast to task-1 and task-3 we had not that much increase in SCL values during task-2 and task-4. The latter two tasks with their random ITIs were expected to force the participants into going a further vigilance state and therefore, cause a further increase in cognitive load.

When the tasks are designed in such a way that from simple to complicated form the sympathetic stress response increases. However, as the participant becomes familiar with the task and related timing issues of the task then the sympathetic stress is expected to decrease during the rest of tasks although the tasks get complicated with their random ITIs. This is verified in task-2 and task-4. While the mean SCL values of task 2 and task 4 are above the level of tonic SCL they are slightly lower than in task 1 and task 3. These results are consistent with the study of Steptoe and Greer in 1980 that confirms the lower levels of autonomic arousal as the training progressed (25). It is possible that the internal timing processes for estimating the occurrence of a particular event that is the case when repetitive stimuli come with fixed-ITI cause more sympathetic stress on participants than when the stimuli come with random-ITI. Therefore, we may suggest that internal timestamp estimation is more important and play a critical role in sympathetic stress response than simply waiting for random stimuli. We conclude that rather than the expectancy of random events, the process related to estimating and processing the internal time calculations of the onset time of events with fixed-ITI may better trigger cognitive load (26-28). This is our novel finding, which relates the sympathetic stress response to repetitive stimuli with either fixed- or random-ITI. However, this conclusion needs to be proven by further studies evaluating the impacts of additional sympathetic indicators in response to the stimuli with fixed- and random-it (29-32). When the reaction times measured for all tasks were compared with each other we observed as expected, an increase in reaction time along with the task difficulty. This result is in parallel with the results of the study of Parrington et al. and the study of Fan et al (33, 34). Evaluation of the difference between the reaction times for target and non-target stimuli in task 3 and task 4 indicates that reaction to a target stimulus takes a significantly longer time than non-target stimuli in both tasks. In our procedure, the occurrence frequencies of target stimuli were at least 4 times lower than non-target stimuli. Since the higher occurrence frequency of target stimuli activates (or facilitates) the decision-making processes in the brain. Therefore, relatively lower occurrence frequency in this study results in increased reaction time. This result is supported by the study of Lucci et al., which suggests that the higher frequency of target stimuli is associated with faster reaction times (35). One

of the limitations of our study is the low sample size, which may need to be considered in future studies. In a conclusion, this study suggests that EDA measurements still need to be studied further before its routine use as an indicator of sympathetic stress. Therefore, the impacts of several variables on the development of sympathetic stress such as decision-making processes, perceptual learning, internal time clock, and characteristics of stimuli are the possible subjects of future studies.

Conflict of Interest: The authors declare no conflict of interest.

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References

1. Visnovcova Z, Mestanik M, Gala M, Mestanikova A, Tonhajzerova I. The complexity of electrodermal activity is altered in mental cognitive stressors. Comput Biol Med 2016; 79: 123 - 129.
2. Dolu N, Acer H, Kara AY. Investigation of dose-related effects of carnosine on anxiety with sympathetic skin response and T-maze. Acta Med 2014; 57: 112 - 118.
3. Dolu N, Keloglan S, Bitiktas S, Cug S. The effects of the enriched environment on sympathetic skin response in pentylenetetrazol-kindled rats. Biomed Environ Sci 2013; 26: 394 - 397.
4. Boucsein W, Fowles DC, Grimnes S, et al. Society for psychophysiological research ad hoc committee on electrodermal measures. publication recommendations for electrodermal measurements. Psychophysiology 2012; 49: 1017 - 1034.
5. Bach DR, Friston KJ, Dolan RJ. Analytic measures for quantification of arousal from spontaneous skin conductance fluctuations. Int J Psychophysiol 2010; 76: 52 - 55.
6. Dolu N, Ozesmi C, Comu N, Süer C, Gölgeli A. Effect of hyperglycemia on electrodermal activity in diabetic rats. Int J Neurosci 2006; 116: 715 - 729.
7. Schumann A, Kietzer S, Ebel J, Bär KJ. Sympathetic and Parasympathetic Modulation of Pupillary Unrest. Front Neurosci. 2020; 14: 178.
8. Naqvi NH, Bechara A. Skin conductance: A psychophysiological approach to the study of decision making. Methods in mind 2006; 103 - 122.
9. Williams LM, Das P, Liddell B, et al. BOLD, sweat and fears: fMRI and skin conductance distinguish facial fear signals. Neuroreport 2005; 16: 49 - 52.
10. Lemche E, Sierra- Siegert M, David AS, et al. Cognitive load and autonomic response patterns under negative priming demand in depersonalization- derealization disorder. Eur J Neurosci 2016; 43: 971 - 978.
11. Ferreira E, Ferreira D, Kim S, et al. Assessing real-time cognitive load based on psycho-physiological measures for younger and older adults. IEEE; 2014: 39 - 48.
12. Sweller J. Cognitive load during problem solving: Effects on learning. Cognitive science. 1988; 12: 257 - 285.
13. Gazzaniga MS. Handbook of psychobiology. Elsevier; 2012.
14. Batra A, Vyas S, Jeph D. Color difference on simple visual reaction time in young volunteers. Int. j. clin. exp. physiol 2014; 1: 311.
15. Baayen RH, Milin P. Analyzing reaction times. Int J Psychol 2010; 3: 12 - 28.
16. Nouchi R, Taki Y, Takeuchi H, et al. Four weeks of combination exercise training improved executive functions, episodic memory, and processing speed in healthy elderly people: evidence from a randomized controlled trial. Age 2014; 36: 787 - 799.
17. Aydin L, Gundogan NU, Kiziltan E, et al. A Simple Sensitive Method for Measuring Borderline Mental Fatigue. J Adv Med Med Res 2016; 1 - 8.
18. Tan Ü. The distribution of hand preference in normal men and women. Int J Neurosci 1988; 41: 35 - 55.
19. Guendogan NU, Yazici AC, Oegues E, Simsek A. An original study for evaluating the correlation between handedness and eye dominance by different methods. Turkiye Klinikleri J Med Sci 2007; 27: 155 - 163.
20. Patston LL, Hogg SL, Tippett LJ. Attention in musicians is more bilateral than in non-musicians. Laterality 2007; 12: 262 - 272.
21. Zhang S, Hu S, Chao HH, Luo X, Farr OM, Chiang-shan RL. Cerebral correlates of skin conductance responses in a cognitive task. Neuroimage 2012; 62: 1489 - 1498.
22. Kiziltan E, Barut C, Gelir E. A high-precision, low cost system for evaluating finger-tapping tasks. Int J Neurosci 2006; 116: 1471 - 1480.

23. Nepal O, Jha R, Bhattarai A, Khadka P, Kapoor B. Galvanic skin response as a simple physiology lab teaching tool-an alternative indicator of sympathetic arousal. Kathmandu Univ Med J 2018; 16: 156 - 160.
24. Steptoe A, Greer K. Relaxation and skin conductance feedback in the control of reactions to cognitive tasks. Biol Psychol.1980; 10: 127 - 138.
25. Setz C, Arnrich B, Schumm J, La Marca R, Tröster G, Ehlert U. Discriminating stress from cognitive load using a wearable EDA device. IEEE Trans Inf Technol Biomed 2010; 14:410 - 417.
26. Starr A, Sandroni P, Michalewski HJ. Readiness to respond in a target detection task: pre- and post-stimulus event-related potentials in normal subjects. Electroencephalogr Clin Neurophysiol 1995; 96: 76 - 92.
27. Golob E, Starr A. Effects of stimulus sequence on event-related potentials and reaction time during target detection in Alzheimer's disease. Clin Neurophysiol 2000; 111: 1438 - 1449.
28. Dolu N, Gölgeli A, Süer C, Ascioglu M, Özesmi Ç, Sahin Ö. Sex-related differences in time estimation and the role of expectancy. Int J Neurosci 2004; 114: 805 - 815.
29. Ranganathan G, Rangarajan R, Bindhu V. Estimation of heart rate signals for mental stress assessment using neuro fuzzy technique. Appl Soft Comput 2012; 12: 1978 - 1984.
30. Salvia E, Guillot A, Collet C. Autonomic nervous system correlates to readiness state and negative outcome during visual discrimination tasks. Int J Psychophysiol 2012; 84: 211- 218.
31. Paxion J, Galy E, Berthelon C. Mental workload and driving. Front Psychol 2014; 5: 1344.
32. Chandra S, Sharma G, Sharma M, Jha D, Mittal AP. Workload regulation by Sudarshan Kriya: an EEG and ECG perspective. Brain Inform 2017; 4: 13 - 25.
33. Parrington L, MacMahon C, Ball K. How task complexity and stimulus modality affect motor execution: target accuracy, response timing and hesitations. J Mot Behav 2015; 47: 343 - 351.
34. Fan X, Zhao C, Zhang X, Luo H, Zhang W. Assessment of mental workload based on multi-physiological signals. Technol Health Care 2020; 28: 67 - 80.
35. Lucci G, Berchicci M, Perri R, Spinelli D, Di Russo F. Effect of target probability on pre-stimulus brain activity. Neuroscience 2016; 322: 121 - 128.