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VARIATIONS IN FREQUENCY AND AMPLITUDE OF NONSPECIFIC ELECTRODERMAL RESPONSES

Dindar S. Bari
Research Center, University of Zakho, Zakho, Kurdistan Region, Iraq
Department of Physics, College of Science, University of Zakho, Zakho, Kurdistan Region, Iraq
Email: dindar.bari@uoz.edu.krd

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ABSTRACT:

Electrodermal activity (EDA) represents changes in the electrical properties of the skin due to the opening of sweat pores and sweat secretion. EDA responses are classified into specific and nonspecific responses. Nonspecific EDA responses (NS.EDRs) are EDA responses without external stimuli or motor activity and are shown to be a good measure of psychophysiological states and traits. Studies investigating NSEDRs are rare, especially on responses, which occur following specific responses at resting periods. This study aimed to investigate variations in NS.EDRs (in terms of frequency and amplitude) at a sequence of resting periods (pre and post of various stimuli). NS.EDRs parameters were recorded from 20 subjects simultaneously in the same skin area. They were computed at resting periods before and following specific responses due to five external stimuli. The study results indicated that there were differences in the frequency and amplitude of NS.EDRs recorded at different resting periods. Additionally, the frequency of NS.EDRs obtained before stimuli were more than those detected at other resting periods, whereas amplitudes of NS.EDRs following sound stimulus were higher than those computed before and after other stimuli; however, these results were statistically nonsignificant ($p>0.05$). This study suggests that nonspecific skin potential responses (NS.SPRs) are very sensitive to capture variations in the frequency and amplitude of NS.EDRs, whereas nonspecific skin susceptance responses (NS.SSRs) are the least sensitive compared to nonspecific skin conductance responses (NS.SCRs) and NS.SPRs. NS.EDRs may be an important indicator for tracking arousal, emotional behavior, psychophysiological variables, and goal-directed thinking in clinical applications due to their sensitivity to such responses.

KEYWORDS: Amplitude, electrodermal activity, frequency, nonspecific responses, specific responses.

1. INTRODUCTION

Nonspecific electrodermal responses (NS.EDRs) by definition, are those responses, which are occurred without any externally applied stimuli or motor activity. They are evoked due to the occurrence of some kind of internal or subliminal stimulus (Bari, 2019, Boucsein, 2012a). According to Boucsein et al., (Boucsein, 2012b) the amplitude for NS.EDRs can be defined as 0.01 µS for computerized scoring and 0.05 µS for hand-scoring NS.EDRs records. In contrast, electrodermal responses that are related to externally applied stimuli are called specific electrodermal responses (Boucsein, 2012b).

The number of occurrences of NS.EDRs is termed frequency of NS.EDRs. The frequency of NS.EDRs is appeared to be stable personality trait (Schell et al., 1988). In addition, it is suggested to be a reliable indicator of tonic activation. Moreover, the frequency of NS.EDRs is a significant psychophysiological variable that reflects individual differences, termed electrodermal lability (Vossel and Zimmer, 1990). Labiles are individuals who exhibit high NS.EDRs frequency, whereas stabiles are those individuals who show low NS.EDRs frequency (Crider and Lunn, 1971). This trait view of NS.EDRs frequency is supported by some evidences. Such evidences include counts of NS.EDRs, which have been shown to have moderate to high retest reliabilities over intervals of up to one year.

There is also a genetic contribution to the variance in NS.EDRs frequency. Finally, people who exhibit high NS.EDRs frequency have been found to differ from those who exhibit low NS.EDRs frequency in behavioral measures of attention and vigilance, as well as EEG (Boucsein, 2012a). Recently, it has been shown that, NS.EDRs are mainly used to investigate individual differences like personality,(Crider, 2008, Norris et al., 2007), health vulnerability,(El-Sheikh and Arsiwalla, 2011, El-Sheikh et al., 2007), and antisocial or aggressive behavior (Gatzke-Kopp et al., 2002).

Two quantitative parameters are important for analyzing NS.EDRs, which are frequency and amplitude. Both parameters are investigated for specific responses during the exposition of emotional or other specific stimuli, for example (Bari et al., 2018, Lipp et al., 1998, Turpin and Siddle, 1979, Goshvarpour et al., 2014). However, investigation of variations in frequency and amplitude of NS.EDRs before and after specific stimuli (responses) remain unclear. In addition, there are a limited number of studies on NS.EDRs. For instance, an increase in the frequency of NS.EDRs during mental load compared to rest was observed (Dawson et al., 2007, Nikula, 1991).

In another study, (Bari, 2019) both quantitative parameters of NS.EDRs were investigated only during two resting periods (before and after a stimulus), where a significant difference was obtained between parameters recorded at two resting periods. In

* Corresponding author

the current study, the experiment has been expanded to cover more resting periods and after five different types of stimuli, instead of only one stimulus. The target was to know the effects of each type of stimulus on NS.EDRs, particularly on the frequency and amplitude of NS.EDRs, which occurred at resting conditions after the specific responses recovered to the initial reading before the specific response. These continuous measurements of NS.EDRs parameters might be of physiological interest and be employed to examine the electrodermal processes in detail.

The main goal of this investigation was to obtain a better understanding of the NS.EDRs. The specific aim was to find out and analyze variations in the frequency and amplitude of the three parameters of NS.EDRs, which were NS.SCRs, NS.SPRs, and NS.SSRs at various resting periods (pre and post various external stimuli) simultaneously at the same skin site. To do that a non-invasive bioimpedance technique was utilized. The technique is dependent on recording the three EDA parameters, skin conductance (SC), skin potential (SP), and skin susceptance (SS) simultaneously at the same skin site.

2. RELATED WORKS

The studies conducted on NS.EDRs are rare. Only a few studies in the literature focused on the analysis of NS.EDRs. For example, Boucsein et al. (Boucsein, 2012b) noted that NS.EDRs are short-lasting changes in EDA, which might occur in the absence of obvious external stimuli. According to a study by Bernstein (1979), the frequency of NS.EDRs exhibited by a subject which can vary depending on the conditions or setting in which the frequency is measured. The interplay between the subject and the conditions or sessions can make changes in NS.EDRs frequency and this frequency may reflect a trait-like characteristic of the subject. Nikula (1991) investigated the association between cognitions and NS.EDRs. The author showed that NS.EDRs may reflect arousal in the service of increased cognitive capacity. Franz et al. (2003) recorded NS.SCRs and used to compare subjects with high alexithymic to normal or low alexithymics during stimuli presentation. Authors reported that, subjects with high alexithymic showed a decreased number of NS.SCRs under all load conditions in contrast to low alexithymics. According to Dawson et al. (2007), frequency of NS.EDRs increases during mental load compared to rest period. NS.SCRs were quantified in a study conducted by Rachow et al. (2011) to investigate differences between normal and patients with acute schizophrenia.

However, their results did not reveal a significant difference between patients and controls. Bari (2019) compared variations in NS.EDRs at two different resting phases, before and after a specific stimulus. The author found significant changes in NS.EDRs that were recorded in the resting period following the specific stimulus. Gertler et al. (2020) studied the neural correlates of NS.SCRs occurred during resting state fMRI scan. They showed that the NS.SCRs are regulated by a wide cortical network of brain regions that engage in a complex, seemingly biphasic manner. In a controlled laboratory study, NS.SCRs were examined by Van Der Mee et al. (2021) during various conditions including mental stressors or physical activities to predict changes in the sympathetic nervous system. Researchers suggested that NS.SCRs frequency is useful to predicate changes in sympathetic activity during daily life. Kurinec et al. (2022) examined NS.SCRs to predicate total sleep deprivation (TSD). Authors found that NS.SCRs were sensitive to TSD, with significant systematic inter-individual differences.

The above cited studies are focused on recording only one parameter (NS.SCRs) and one resting period. In the current study, variations in frequency and amplitude of three EDA (NS.SCRs, NS.SSRs and NS.SPRs) parameters at various resting periods before and after five different external stimuli are investigated with the aim of better understanding the waveforms of the NS.EDRs and electrodermal processes in general.

3. MATERIALS AND METHOD

A new technique of recording the three EDA parameters simultaneously at the same skin site was used (Bari et al., 2018). The technique was dependent on the computerized system, which consisted of a small (matchbox-sized) front-end electronic box connected by using a National Instruments DAQ card- NI USB-6211 to a PC laptop running custom-written software in LabVIEW, v. 14. Bari et al.(2018) who used a three electrode setup, with one measuring electrode (M), one reference electrode (R), and a current-sink electrode (C) . The C and R electrodes were used for unipolar AC SC and SS measurements, whereas M and R electrodes were utilized for SP measurement. The employed electrodes were KendallTM KittyCatTM1050NPSM, which is shown to be reliable for EDA recordings (Tronstad et al., 2010).

2.1 Participants and Measurements

EDA measurements were done on 20 apparently healthy participants (10 males and 10 females, 21–39 years old, average age 29 yrs). All participants were recruited from the University of Zakho and gave written informed consent. During the data collection, the participants were sitting in an armchair in a silent laboratory with a temperature 22±2 ˚C. The electrodes were affixed five minutes before the EDA recordings started so that they would have time to stabilize. Also, this was done for the participants to relax in order to get steady EDA recordings when the measurement started. Then measurement of EDA parameters started and NS.SCRs, NS.SPRs and NS.SSRs were computed at resting periods before and after five (asking a mathematical question, exposing to unwarned sound, looking at a scary image, having a deep breath, and touching or mild clap on the test subject's shoulder) different stimuli. It should be noted that, the duration for each resting period was 60 seconds. Throughout the whole recordings, participants were asked to relax, and to keep the testing hand calm.

2.2 Data Analysis

The Statistical Package for Social Sciences (SPSS) was used for data analysis. The differences in the NS. EDRs were evaluated statistically in terms of different resting periods by utilizing one-way repeated analysis of variation (ANOVA) followed by post hoc multiple pairwise comparisons using Sidak correction.

Ethical approval

The protocol of this study has been complied with all the relevant national regulations, institutional policies and in

accordance with the tenets of the Helsinki Declaration (Carlson et al., 2004).

4. RESULTS

3.1 Frequency of Nonspecific Electrodermal Responses

3.1.1 Frequency of NS. SCRs

Table 1 shows the frequency of NS. SCRs obtained for each subject before and after five stimuli. It is clear that almost all participants gave a series of NS.SCRs. In addition, there is a high difference among participants with respect to the frequency of NS.SCRs. Moreover, Figure 1 indicates the frequency count of NS.SCRs for all subjects per resting periods. The highest frequency (141) is recorded at the first resting period (i.e. before stimuli), whereas the lowest responding frequency (89) is recorded at the final resting period (i.e. after the touch stimulus). Furthermore, it can be seen from the figure that the frequency of NS.SCRs are decreased with time (by comparing the first resting period with the rest of the periods).

Table 1: Frequency of subjects NS.SCRs before and after five stimuli

Subject	Before	A. Math	A. Sound	A. Image	A. Breath	A. Touch
	7.26±4.43	**6.52±3.95**	**5.84±3.33**	**4.89±3.71**	**4.89±3.24**	**4.26±3.21**
1	3	7	11	9	8	8
2	9	10	6	8	10	9
3	10	9	7	6	7	4
4	3	5	9	6	8	4
5	8	10	9	9	7	6
6	2	1	1	0	1	0
7	13	14	11	13	8	9
8	16	6	4	6	7	1
9	1	1	1	1	1	2
10	1	1	4	2	4	1
11	6	8	4	7	9	6
12	12	6	8	8	7	11
13	9	12	8	10	7	8
14	4	1	1	0	0	2
15	7	8	6	5	7	6
16	4	5	7	0	0	3
17	13	11	10	5	4	1
18	10	5	8	3	2	4
19	1	1	0	0	0	0
20	9	10	7	4	4	4

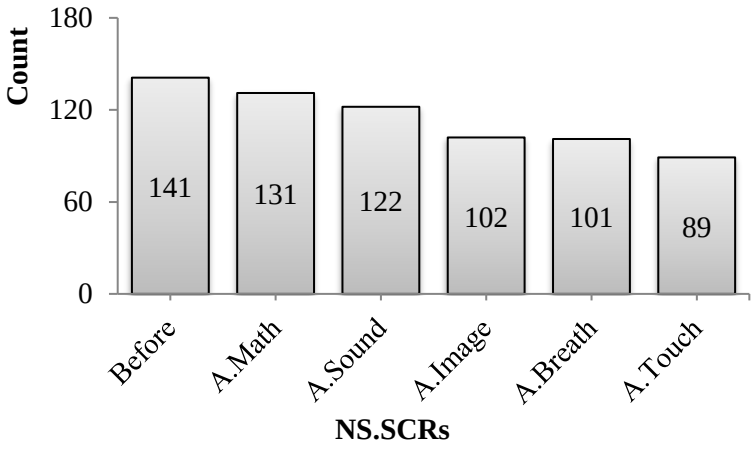

Figure 1: Histogram of the frequency count of NS. SCRs recorded at six different resting periods from all participants (n=20)

3.1.2 Frequency of NS. SPRs

The frequency of NS. SPRs for all subjects are presented in Table 2. Based on the data indicated in Table 2, almost all subjects showed NS. SPRs at all resting periods. It is clear that SP is very sensitive to nonspecific responses by comparing NS.SPRs findings with NS.SCRs (Table 1 and Figure 1) and

NS.SSRs (Table 3 and Figure 3). Moreover, Figure 2 shows the frequency count of NS.SPRs for all subjects per resting periods. Again, like NS.SCRs, the highest frequency count (175) is obtained at the first resting period, whereas the lowest count (127) is obtained at the final resting period.

Table 2: Frequency of subjects NS.SPRs before and after five stimuli

Subject	Before	A. Math	A. Sound	A. Image	A. Breath	A. Touch
	8.75±4.25	**8.55±3.52**	**7.6±2.72**	**7.05±2.72**	**7±2.23**	**6.35±2.76**
1	3	7	11	9	8	8
2	9	10	6	8	10	9
3	10	9	7	6	7	4
4	3	5	7	6	8	4
5	8	10	9	9	7	6
6	2	1	1	2	2	1
7	14	14	10	12	8	9
8	16	7	8	6	10	2
9	1	2	3	2	3	6
10	6	8	7	4	4	3
11	7	12	6	8	11	7
12	14	10	9	11	7	12
13	9	12	6	8	7	7
14	11	9	11	12	7	11
15	9	6	6	5	9	8
16	12	12	12	9	8	7
17	10	13	11	9	5	4
18	12	8	8	6	5	7
19	5	4	5	4	7	5
20	14	12	9	5	7	7

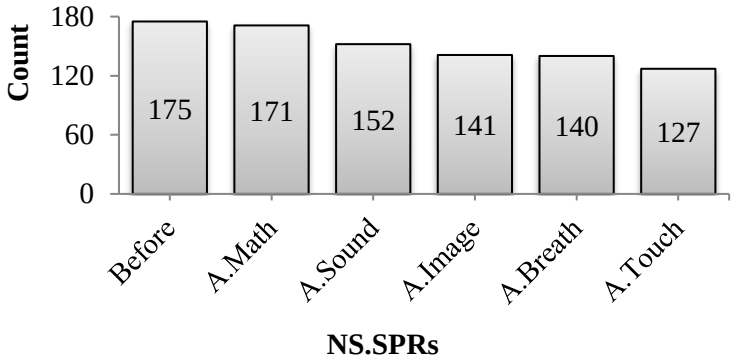

Figure 2: Histogram of the frequency count of NS.SPRs recorded at six different resting periods from all participants (n=20)

3.1.3 Frequency of NS. SSRs

The detected NS.SSRs from all subjects are displayed in Table 3 and Figure 3. The frequency count of NS.SSRs for all subjects are less than that of both NS.SCRs and NS.SPRs as indicated in Figure 3. In addition, no NS.SSRs were observed at all from some subjects such as subjects number 19 and 14. Moreover, frequency counts of NS.SSRs computed during the period before stimuli were more than those monitored during the rest of the periods (Figure 3).

Table 3: Frequency of subjects NS. SSRs before and after five stimuli

Subject	Before	A. Math	A. Sound	A. Image	A. Breath	A. Touch
	5.15±4.36	**4.4±2.83**	**4±3**	**3±2.32**	**3.25±2.84**	**2.8±2.62**
1	0	0	0	0	0	0
2	9	7	4	7	8	5
3	10	5	3	3	3	3
4	3	5	8	5	7	4
5	6	7	7	6	5	4
6	0	0	1	1	0	0
7	9	6	8	3	3	2
8	9	5	2	5	6	1
9	0	0	0	0	0	0
10	1	1	2	1	3	3
11	4	8	4	7	8	6
12	14	7	9	4	6	11
13	3	6	4	4	7	5
14	0	0	0	0	0	0
15	4	5	3	4	3	3
16	1	5	5	0	0	2
17	11	7	9	4	3	1
18	9	5	6	2	2	3
19	1	1	0	0	0	0
20	9	8	5	4	1	3

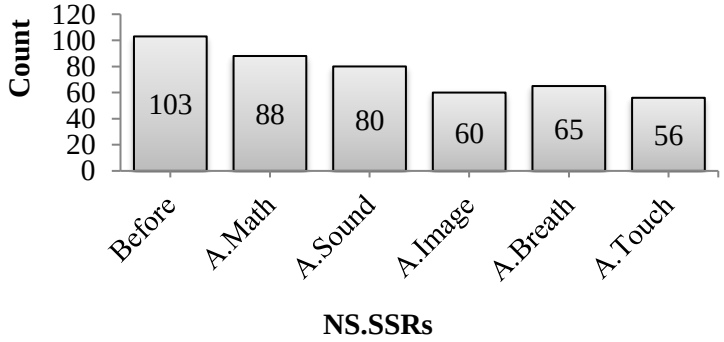

Figure 3: Histogram of the frequency count of NS.SSRs recorded at six different resting periods from all participants (n=20)

4.1 Amplitude of NS.EDRs

4.1.1 Amplitude of NS.SCRs

Figure 4 shows the box plot of the amplitude of NS.SCRs at six different relaxation periods for test subjects. It is clear that there are distinctions among amplitudes of NS.SCRs. In addition, the amplitude of NS.SCRs computed after the sound stimulus is higher than amplitudes of NS.SCRs obtained from other resting periods. However, these findings were statistically nonsignificant (p>0.05).

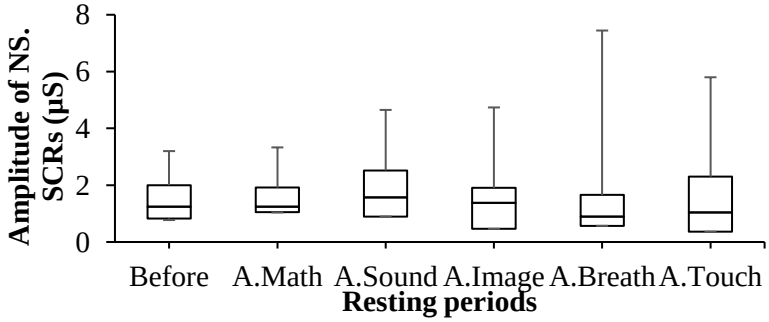

Figure 4: Box-plot shows mean value of amplitude of NS.SCRs at six different relaxation periods for all volunteers.

4.1.1 Amplitude of NS.SPRs

The mean amplitude of NS.SPRs recorded at various resting periods are presented in the box plot shown in Figure 5. It can be noted that the median amplitude of NS.SPRs of those measured after the sound stimulus is higher than the median amplitudes of NS.SPRs of those recorded at other resting times. However, when the ANOVA tests were carried out, insignificant (p >0.05) differences were obtained.

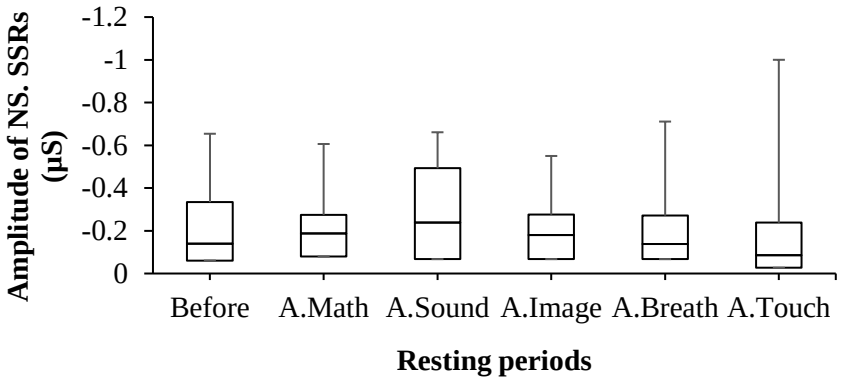

Figure 5: Box-plot shows mean value of amplitude of NS.SPRs at six different relaxation periods for all volunteers.

4.1.2 Amplitude of NS.SSRs

The amplitudes of NS.SSRs for all participants are shown with box-plot in Figure 6. The figure displays that the median value of amplitudes of NS.SSRs is changed as a result of different resting periods. Again, same as the amplitudes of NS.SCRs and NS.SPRs, the median amplitude of NS.SSRs that are detected after the sound stimulus is higher than the values measured at other resting periods. However, when statistical analyses were performed insignificant (p > 0.05) differences among the data recorded at different resting periods were observed.

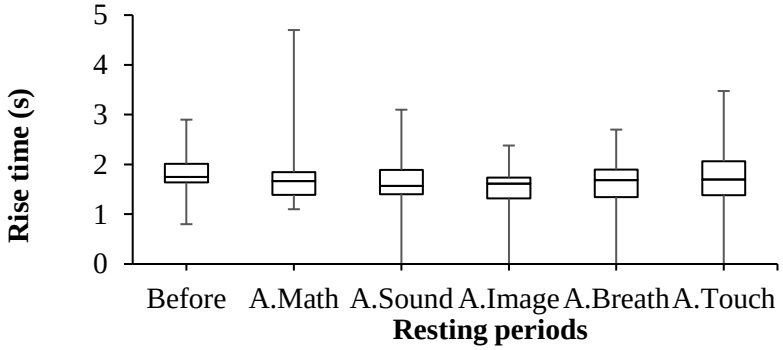

Figure 6: Box-plot shows average value of amplitude of NS. SSRs at six different relaxation periods for all volunteers.

4.1.1 Rise Time of NS.SCRs

The rise time of NS.SCRs also showed differences among resting periods and the highest values are recorded after the sound stimulus (see Figure 7). However, ANOVA tests showed insignificant (p > 0.05) differences among data from different resting periods.

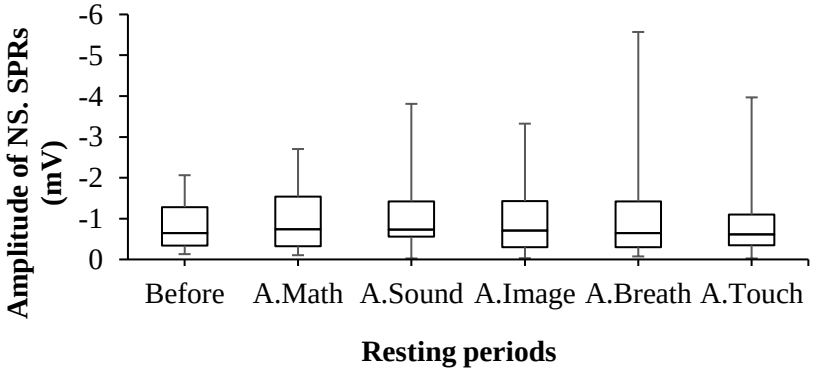

Figure 7: Box-plot mean average value of rise time of NS.SCRs at six different relaxation periods for all volunteers.

5. DISCUSSION

The present study was designed to examine changes in the frequency and amplitude of NS.EDRs during a fixed sequence of resting periods, which were administered to all subjects. This study demonstrated that the frequency of NS.EDRs (NS.SCRs, NS.SPRs, and NS.SSRs) recorded at the first resting period (i.e. before stimuli) were more than those recorded at the periods after stimuli. Based on the above results, the frequency counts gradually decreased to the lowest value at the last resting period, which was after the final stimulus (touch). On the other hand, there were fluctuations in the amplitude of NS.SCRs, NS.SPRs, and NS.SSRs recorded before and after stimuli.

Based on the findings of this study, NS.SCRs, NS.SPRs, and NS.SSRs were highly sensitive to observe variations in the frequency of NS.EDRs and accordingly changes in sympathetic system and individuals' differences (labiles and stabiles). There was a great variation among the participants according to the frequency of NS.SCRs, NS.SPRs, and NS.SSRs. The high frequency of NS.SCRs, NS.SPRs, and NS.SSRs of some subjects may be due to the high existence and intensity of personally significant thoughts. On the other hand, the low frequency of NS.SCRs, NS.SPRs, and NS.SSRs in other subjects may be due to a general disengagement of goal-oriented cognitions (Nikula, 1991).

Notably, as mentioned above, the frequency of NS.SCRs, NS.SPRs, and NS.SSRs at the resting period before stimuli were more (see Tables 1,2, and 3, and Figures 1, 2, and 3) than the frequency detected after stimuli for the three parameters. This difference may be due to the fact that, at the beginning of the experiment the participants were under a higher level of stress than the rest periods of the experiments. In addition, with time, the level of stress decreased for all participants, which led to a noticeable reduction in the frequency of NS.SCRs, NS.SPRs, and NS.SSRs at the last resting period (after touch stimulus). According to Bernstein, (1973) , the status of an individual in terms of NS.EDRs frequency is dependent on the occasion or conditions under which the frequency index is recorded, then the interaction of individuals and condition (e.g. stressful) or individuals and session should be extensive contributors to variations in NS.EDRs frequency, and this frequency might reflect a trait-like characteristic of subjects.

According to the study findings, there were differences among the detected frequencies of the three parameters (NS.SCRs, NS.SPRs, and NS.SSRs). By comparing the results shown in Figures 1, 2, and 3, it is evident that the number of detected NS.SPRs was higher than both NS.SCRs and NS.SSRs. This suggests that SP is more sensitive than both SC and SS for detecting NS.EDRs. In addition, the frequency counts of NS.SSRs recorded from all the test subjects were very small compared to both NS.SCRs and NS.SPRs, and even NS.SSRs were not seen from some participants at all as revealed in Table 3. This suggests that NS.SSRs are not sensitive to detect variations in NS.EDRs in particular small responses, indicating that the role of SS is less crucial in the analysis of NS.EDRs compared to the SC and SP (Bari, 2019).

Variations in amplitudes of NS.SCRs, NS.SPRs, and NS.SSRs were also observed during different resting periods. In addition, amplitudes of NS.SCRs, NS.SPRs, and NS.SSRs decreased during resting periods after all stimuli (as seen in Figures 4, 5, and 6) in line with (Bari, 2019); except after sound stimuli, which were higher before stimuli. The occurrence of higher amplitudes of NS.SCRs, NS.SPRs, and NS.SSRs after sound stimulus could be due to the prior level of sweat in the duct as a result of the high intensity of sound. Also, it might be due to sympathetic overactivity throughout resting periods meaning a potential delayed inhibitory process of sympathetic activity (Visnovcova et al., 2016). The inhibitory and excitatory influences of sympathetic nervous system activity, which affect the central regulation of EDA arise in different structures of the central nervous system. Boucsein et al. (2012a) explained two relatively independent pathways which affected the production of sweat and accordingly EDA: Cortical level- central regulation of EDA associated with the affection of basal ganglia and cortical centers as brain structures, (Sequeira and Roy, 1993) and subcortical level-EDA regulation involves influences from the limbic system and hypothalamus connected with thermoregulatory sweating. Moreover, the amygdala mediates the excitatory influences of EDA, while the hippocampus affects the inhibitory influence (Visnovcova et al., 2016).

The rise time or time parameter of NS.SCRs is also changed in resting periods. Figure 7 shows that rise time of NS.SCRs decreased in the resting periods following the five external stimuli. The shorter rise time is associated with the weaker NS.SCRs, which is attributed to the same reasons discussed above. These findings are in agreement with Bari (20219), who also showed that the rise time of the NS.SCRs decreased in the resting time after an external stimulus.

CONCLUSION

The three parameters of NS.EDRs (NS.SCRs, NS.SPRs, and NS.SSRs) showed variations in the frequency and amplitude of NS.EDRs. NS.SPRs were more sensitive to detect or respond to slight changes in EDA waveforms compared to other two parameters. On average subjects showed a higher frequency and lower amplitude of NS.EDRs at the first resting period (i.e. before stimuli), than those recorded at resting times after the stimuli. This suggests that prior level of sweat in the duct due to external stimuli has impacts on the frequency and amplitude of NS.EDRs. NS.EDRs due to their sensitivity may be used in clinical applications for monitoring arousal, emotional behavior, psychophysiological variables, and goal-directed thinking.
In future studies, a wider age range can be targeted with a larger sample size to further investigate NS.EDRs.

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