Available online at : http://josi.ft.unand.ac.id/

Jurnal Optimasi Sistem Industri

| ISSN (Print) 2088-4842 |ISSN (Online) 2442-8795|

Research Article

The Influence of Stress on Industrial Operator's Physiology and Work Performance

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ARTICLE INFORMATION

Received : Juli 3, 2020
Revised : August 10, 2020
Available online : November 20, 20

KEWORDS

Stress, physiology, heart rate variability, work performance, cycle time

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A B S T R A C T

Elevated stress has been widely associated with physical and physiological threats as well as reduced work performance. However there is still lack of studies which investigate whether stress influences concurrently physiological and objective work performance. The purpose of this study is to examine whether workers' level of stress or negative emotional symptoms correlates with their physiological coherence and work performance. Eighteen female operators who reported high severity level of stress, assessed using Depression, Anxiety, and Stress Scale (DASS-42) were categorized as the risk group. A group of 18 participants from 99 female workers with significantly lower DASS scores were randomly chosen as a control group. Both groups were then asked to involve a five-day physiological measurement during which their work performance was measured in terms of a cycle time to complete the assembly task. The results showed that workers in the risk group obtained significantly lower coherence level and longer work cycle time than that of the control participants, implying that negative emotional symptoms were parallel with physiological coherence and work performance. However, the weak correlation was found between work performance and negative emotional symptoms and with physiological coherence. Despite the study limitations, our findings support evidence in a more complete picture of how stress affects female worker's physiology and work performance, suggesting a need to implement effective workplace stress intervention. Further study is needed for different group characteristics such as male, and in other occupational settings.

INTRODUCTION

Occupational stress has been well documented having adverse effects on workers physical, psychological, and productivity. Blue collar workers – occupational group that require manual labor (e.g. assembly line operators) – are population at high risk due to some factors such as lack of autonomy and control, low salaries, job conflict, lack of social support, skill underutilization, and poor physical environment [1]–[3]. However, there are very few studies investigating the influence of stress among line operators which are the largest working class in the Malaysian manufacturing sector. The neglected effect of blue collar worker's stress may lead to greater consequences of financial loss, cardiovascular diseases, and stress-induced deaths [4].

According to the classic concept of Yerkes and Dobson on an inverted U-shaped association between stress and performance efficiency [5], people need a small amount of stress to perform the task effectively Figure 1). However, excessive stress or distress is viewed as something that breaks the body's homeostatic (an internal stability and balance of autonomic nervous system (ANS)) relationship between human cognition and the environmental demand (the task). Performance deteriorates if an individual becomes too stressful, or even fails if the level of stress is extreme.

Human response to stress in three ways: physiological arousal (e.g. heart rate, blood pressure, temperature), psychological responses (e.g. anxiety, sleep problems, depression, irritation, etc.), and behavioral responses (e.g. work performance, eating disorders, aggression, drug abuse, poor relations) [6]. Monitoring one's heart rate variability (HRV) as physiological measure of stress is widely used in clinical and healthy populations [6] and [7]. However, related studies targeted for workers at operational level is still lacking.

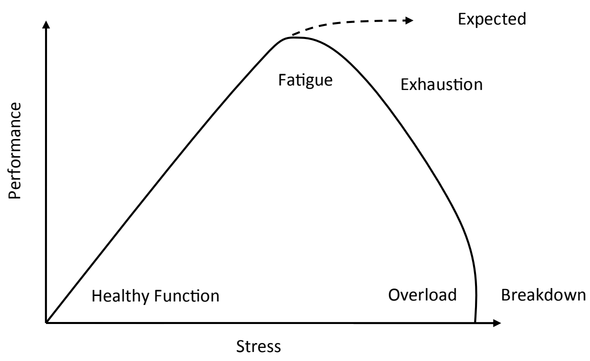

Figure 1. Human function curve –relationship between performance and stress (Yerkes-Dodson principle [5])

HRV and Physiology Coherence

HRV is the variation in the time interval between consecutive heartbeat (in milliseconds) used as an index for autonomic nervous system (ANS) [8]. In general, the heart rate is a reflection of ANS balance or imbalance in the body [9]. Higher HRV reflects ability to maintain homeostasis – an internal stability and balance of ANS system – which are related to better emotional self-regulation and increased cognitive performance [10]. On the opposite, individual who experiences high level negative emotional symptoms (depression, anxiety, stress) have been linked with lower HRV [11]–[13], and impaired some cognitive functions [14, 15].

The normal variability in heart rate is due to the synergistic action of the two branches of the ANS, which operates in balance through neural, mechanical, humoral and other physiological mechanisms to maintain the optimality of cardiovascular parameters and to response properly to both internal and external conditions [16]. In a healthy individual, the heart rate estimated at any given time reflects the net effect of the parasympathetic (vagus) nerves which slow down the heart rate, and triggering the sympathetic nerves to accelerate it. This natual mechanism is influenced by emotions, thoughts and physical exercise. Changes in heart rhythms affect not only the heart but also the brain's ability to process information, including decision-making, problem-solving and creativity. They also directly affect the emotions. High vagal tone (activation of parasympathetic) is associated with the ability to self-regulate, and therefore to have results in greater behavioral flexibility and adaptability in a changing environment. On the other hand, low vagal tone is associated with poor self-regulation and a lack of behavioral flexibility [17].

It has been shown in previous studies that during mental or emotional stress, there is an increase in sympathetic activity and a decrease in parasympathetic activity, particularly in occupational settings [18]–[20]. A recent meta-analysis also showed that HRV can be employed as a bio-marker of top-down self-regulation [21]. Moreover, some researchers suggested that HRV is due to the interaction between the two branches of the nervous system and the afferent signals sent from the heart to the brain (baroreceptor network) [16] and [22]. Figure 2 illustrates the nervous system links between the heart and brain. Thus, the study of HRV is a powerful, objective, and noninvasive tool to measure neuro-cardiac function that reflects heart–brain interactions and ANS dynamics. The analysis of HRV can be used to explore the dynamic interactions between physiological, mental, emotional and behavioral processes [21], [23].

Meanwhile, numerous researches have also showed that stress affect individual work productivity in various organizations across countries such as interns in technical university, and correctional officers [15], [24], [25]. However, very few studies use objective outcome indicators on either work performance or physiological response [26]. Assessing to what extent the effect of stress on objective measure will provide more understanding about the stress consequences among assembly-line operators which can be used by the organization to design and implement an effective intervention strategy to improve productivity and worker's well-being.

This research is the first study to investigate the association between negative emotions states with physiological and objective work performance in assembly-line workers of a Malaysian manufacturing industry. Assembly line workers are more likely exposed to repetitive motion overload while their mental functions are underutilized [1]. Our hypothesis is that the group participant who experienced higher level of stress would have lower HRV and poorer work performance compared to those of the control group. Moreover, there would be a correlation between negative emotional symptoms, physiological index, and operators' performance.

METHODS

Participants

The study population consists of assembly line operators in an electronic manufacturing industry in Pahang, Malaysia. We conducted a preliminary screening of stress using depression, anxiety, and stress scale (DASS) among 321 workers. Inclusion criteria include female workers and at least one year of working experience, did not suffered from diabetes or took medication that could decrease physiological arousal. Eighteen female operators who have extremely severe level on each scale simultaneously were assigned as the high-risk group. We then formed the control group comprising the same number of participants and gender to ensure homogeneity of sample by choosing them randomly from 99 female respondents who reported normal to moderate severity of depression, anxiety, and stress. Table 1 displays the demographic characteristics of each group.

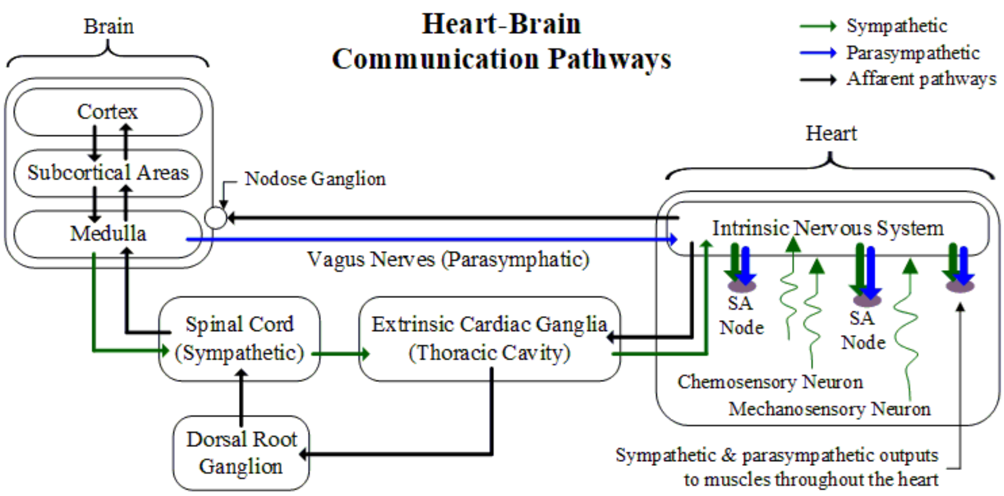

Figure 2. Relationship between Nervous System and the Heart and Brain [16]

Table 1. Demographic Characteristics of Participants

	Risk		Control	
	Mean	S.D	Mean	S.D
Age	35.1	9.20	25.9	3.15
Working experience	15.7	9.13	3.9	2.45

Table 2: Severity Label of DASS-42 Subscales Scores [27]

Category	Scale		
	Depression	Anxiety	Stress
Normal	0 – 9	0 – 7	0 – 14
Mild	10 – 13	8 – 9	15 – 18
Moderate	14 – 20	10 – 14	19 – 25
Severe	21 – 27	15 – 19	26 – 33
Extremely Severe	28 – 42	20 – 42	34 – 42

Instruments and Apparatus

Depression, Anxiety, and Stress Scale (DASS)

The negative emotional symptoms were assessed by Depression, Anxiety, and Stress Scale (DASS-42), a quantitative measure of three related negative emotional states of depression, anxiety and tension/stress which are suitable for non-clinical population [27]. Each of the scale consists of 14 items to measure the negative emotional states of depression, anxiety and stress. Subjects are asked to use a 4-point severity/ frequency scale (0 = Did not apply to me at all or never, 1 = Applied to me to some degree or sometimes, 2 = Applied to me to a considerable degree, or a good part of the time or often, and 3 = Applied to me very much, or most of the time, or always) to rate the extent to which they have experienced over the past weeks. Scores for Depression, Anxiety and Stress are calculated by summing the scores for the relevant items with severity label or categorization is displayed in Table 2. The Malaysian version of DAS42 has very good reliability of 0.84, 0.74 and 0.79, respectively, for depression, anxiety and stress [28]. For the purpose of testing the hypothesis, we used a composite measure of negative emotional symptoms by taking average of all three scale's scores [27].

Physiological Measurement

Physiological measurement was carried out using a set of computer and device program emWave Pro, developed by Institute of HeartMath. A sensor was placed in subject's earlobe which uses photoplethysmograph technology to collect real time HRV through the blood flow transmitted via infrared light. When connected to a laptop computer, the software provides values of low, medium, and high levels of HRV physiological coherence. Subjects receive visual feedback displayed as the coherence ratio bars of three color-coded red, blue and green which has accompanying audio signals (see Figure 3). The coherence ratio bars show how much time subjects have spent in low, medium and high coherence during recording session which is updated every five seconds in correlation with their heart rate rhythm. Numerous studies showed the validity and efficacy on the use of emWave Pro tool for HRV assessment in various settings [29]–[31].

Work Performance

The work performance criteria used in this study was the worker's cycle time, i.e. time required to accomplish task. Due to the possibility of high variation among individual, we have not determined the time standard of each participant which incorporated the performance rating and allowance. Figure 4 showed the product observed in this study: a part of an automotive product Toroidal Transformer model HA00—5587LFVT.

We performed direct time study technique using video recording to record the time taken to assembly a piece of product which is suitable to be used when there are repetitive work cycles with less variety of work elements [32]. The data were collected five sessions per day during five workdays: three sessions before lunch break and two sessions afterwards. Eight cycles were gathered per session, yielding a total of 200

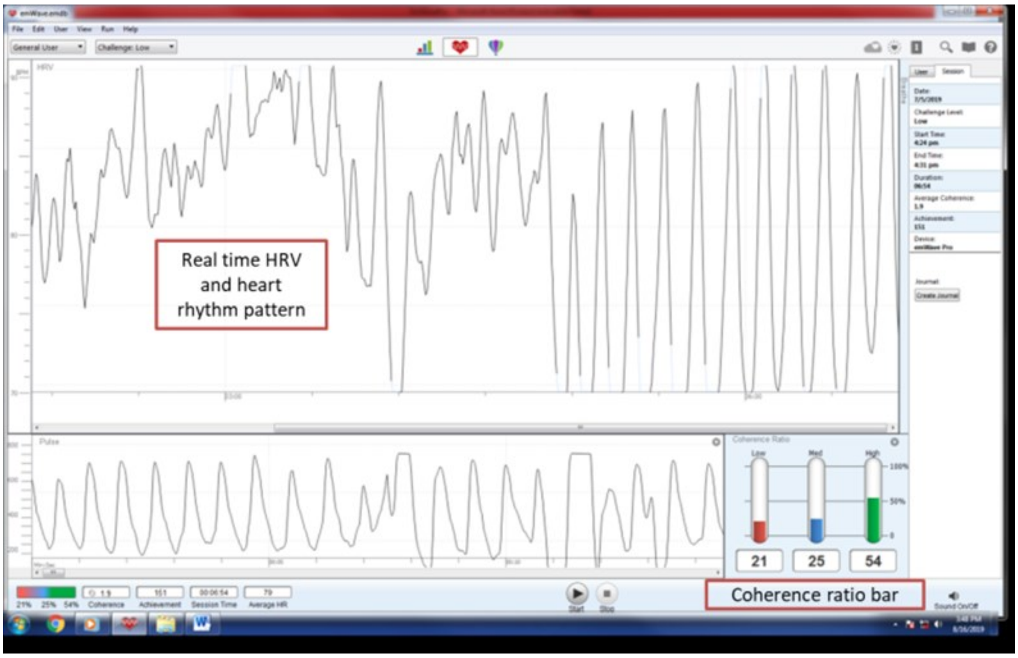

Figure 3. Feedback during Physiological Measurement. Coherence Ratio Bar Representing Percentage of Physiological Coherence by Color-code: red (low), blue (medium), green (high).

 DOI: 10.25077/josi.v19.n2.p82-90.2020

Figure 4. Assembled Product: Toroidal Transformer

Figure 5. Operators Performing Assembly Task

cycles for each participant. The final cycle times for each participant, measured in seconds, was calculated by taking the average of all 200 data. Figure 5 illustrates the workers performing the assembly task.

Experimental Procedure

All participants were provided informed consent containing a brief description about the study. No monetary rewards were given. The study was approved the Research Committee of University of Malaysia Pahang, Malaysia. Participants in both groups were asked to seat in in a well-controlled environment room. They were taught how to breathe in a slow paced and induce positive emotion. After that, the ear-clip sensor was placed and the session was started.

At the beginning of each session, the participant was asked to breathe normally for five minutes. After five minutes, the subject was instructed to follow the pacer displayed in the laptop monitor about five minutes–recommendation length of heart rate variability measurement [33] and [34], then the recording time was started. A smooth sine wave-like pattern represents high coherence, emotional well-being, while an irregular graphical pattern is an indication of low coherence, stress, and worry. The observations of workers' cycle time were conducted at different days of their physiological measurement time measurement.

Study Design and Analysis

Prior to testing the hypothesis, we checked the normality assumption of the data using Kolmogorov Smirnov statistics. To evaluate the difference between group on all outcome measures, we performed an independent sample t-test or Mann-Whitney non parametric test if data were later found non normal. To find the relationship between each variable, we used a bivariate Pearson correlation or Spearman rank analysis, an alternative to parametric test if data did not meet normality assumption. The analysis was carried out using SPSS 23.0 with significance level was set at $\alpha = 0.05$ (one-tailed).

RESULTS AND DISCUSSION

Results

The associate probability value of each Kolmogorov Smirnov statistics for checking normality distribution assumption is summarized in table 3. A low p-value (<0.05) indicating the respective data were not normally distributed. Table 4 displays the average cycle-time of 200 cycles, measured in seconds, for each participant in both group. The summary of descriptive statistics for all variables and results of statistical analysis are revealed in Table 5.

Table 3. Normality Check Assumption

	Variable	Group	*p value*
Negative emotional symptoms	Depression	Risk	0.05
		Control	$<0.01^*$
	Anxiety	Risk	0.20
		Control	0.71
	Stress	Risk	0.11
		Control	0.02^*
	Composite scores of DASS	Risk	0.10
		Control	0.16
Physiological	Low	Risk	0.10
		Control	0.20
	Medium	Risk	0.20
		Control	0.20
	High	Risk	0.08
		Control	0.20
Work Performance	Cycle time	Risk	0.20
		Control	0.20

Table 4. Average Cycle-time of Each Subject in Risk and Control Group

No.	Cycle-time (sec.)		No.	Cycle-time (sec.)	
	Risk	Control		Risk	Control
1	7.25	5.2	10	16.25	10.46
2	9.75	7.2	11	31.55	22.95
3	6.55	5.15	12	20.75	15.55
4	28.25	18.2	13	18.25	14.58
5	18.25	9.25	14	12.85	8.25
6	5.25	4.55	15	20.75	14.25
7	6.25	4.85	16	25.55	21.85
8	15.25	9.58	17	17.75	13.75
9	19.55	11.25	18	20.75	14.05

Table 5. Summary of Descriptive Statistics, Mann-Whitney *U*-statistics, *t*-statistics of Negative Emotional Symptoms, Physiological Coherence, and Work Performance for Risk and Control groups

Variables		**Group**	**Mean**	**SD**	**Statistics**
Negative Emotional Symptoms	Depression	Risk	41.2	13.71	$U = -5.18^{**}$
		Control	39.6	10.21	
	Anxiety	Risk	45.9	8.85	$U = -5.15^{**}$
		Control	3.9	2.11	
	Stress	Risk	5.3	2.52	$U = -5.16^{**}$
		Control	4.9	3.00	
	Composite DASS scores	Risk	42.2	6.80	$t = 10.58^{**}$
		Control	14.1	2.59	
Physiological Coherence	Low	Risk	52.61	17.38	$t = 4.26^{**}$
		Control	26.89	18.83	
	Medium	Risk	24.28	14.50	$t = 0.52$
		Control	21.89	13.23	
	High	Risk	23.11	13.21	$t = -4.65^{**}$
		Control	51.39	22.16	
Work Performance	Cycle time	Risk	16.7	7.6	$t = 2.23^{*}$
		Control	11.72	5.63	

Table 6. Spearman Correlation Coefficients (*r*) Indicating Degree of Relationship between All Variables

	Low	**Medium**	**High**	**DASS**	**Cycle time**
Low	1.00				
Medium	-0.32*	1.00			
High	-0.77*	-0.36	1.00		
DASS	0.50*	0.13	-0.60*	1.00	
Cycle time	0.31*	-0.36*	-0.18	0.18	1.00

*significant at $p < 0.05$ (one-tailed)

The independent *t*-test showed that subjects in the risk group performed significantly different on the percentage of high and low coherence than the control group. The percentage of time spent in low and high physiological coherence between two groups differed significantly but not in medium coherence ($p = 0.61$) (see also Figure 6). Moreover, an independent t-test revealed that they also performed slower on assembly tasks when being compared to the control group ($p < 0.05$).

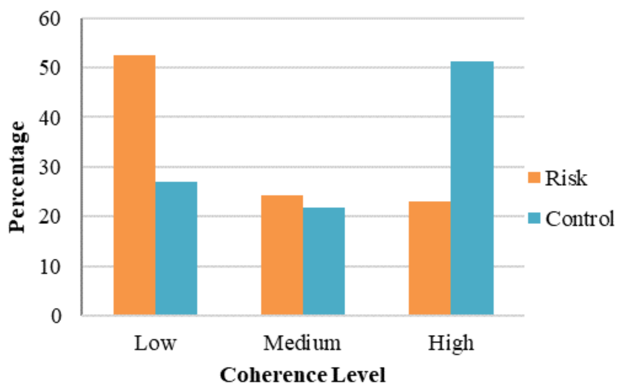

Figure 6. Percentage of Physiological Coherence Level between Risk and Control Group

Table 6 refers to Spearman correlation coefficients (*r*) for all measures while Figure 7 displays scatter plot of all correlations. High physiological coherence level was strongly correlated with low coherence in the opposite direction (-0.77). The weak negative correlation between medium coherence and other coherence levels (-0.32 and -0.36) were also found. Furthermore, negative emotional symptoms significantly correlated positively with low coherence(0.50) and negatively with high coherence level (-0.60). The work performance, measured by cycle time, was associated significantly with medium coherence level (-0.36) but not with low and high coherence as well as the emotional states (0.31, -0.18, and 0.18, respectively).

Discussion

Our data suggest that negative emotional symptoms states are parallel with physiological coherence and work performance. Participants who experienced high levels of stress could not obtain higher scores on physiological measurement as indicated by their higher percentage of low coherence and lower percentage of high coherence, as compared with the control group. Participants in the risk group achieved more than 50% of low coherence, indicating that they did not meet the health physiological criteria (as suggested in the emWave practitioner's guide) [35]. The risk group also performed slower on the assembly tasks as measured by their respective cycle time (see Table 5). These findings support our hypothesis and are aligned with prior studies regarding HRV and stress in occupational settings [11], [36], [37]. The HRV coherence levels are associated with positive emotions, thus workers who feel more stressed are incapable to shift into higher physiological coherent state [31], [38]. Vaschillo et al [39], Appelhans and Luecken [13], and Fujimura and Okanoya [40] suggest that HRV correlates with physical health and emotional flexibility with greater HRV being linked to better health and emotional regulation.

Although there are still few studies on the simultaneous effect

DOI: 10.25077/josi.v19.n2.p82-90.2020

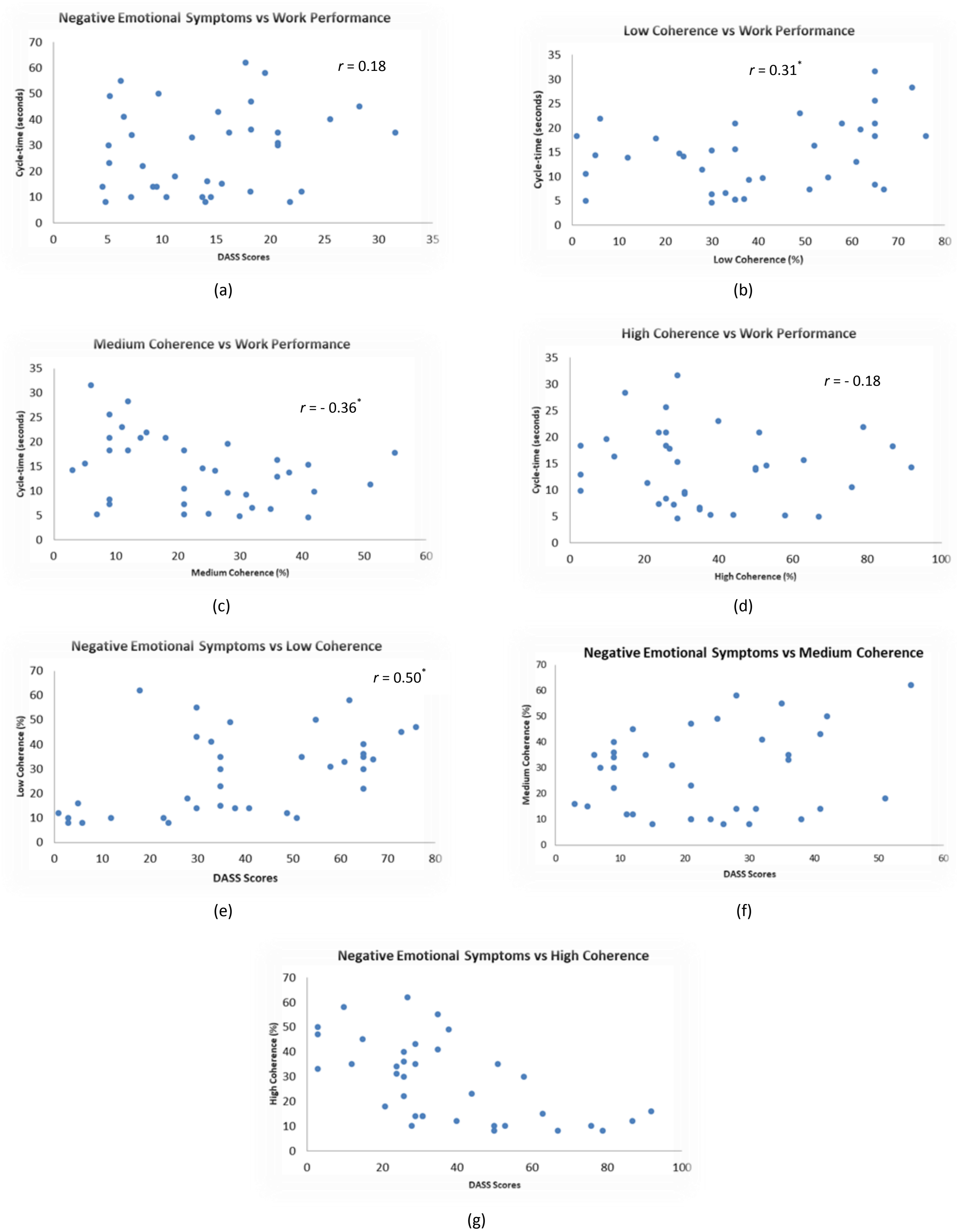

Figure 6. Scatter Plot of All Pair Correlation with Respective Spearman's Coefficient (r). *Correlation is significant at the 0.05 level (one-tailed)

of stress on HRV and work performance, the concept of physiological coherence (also referred to as HRV coherence, resonance, cardiac coherence) proposed by McCraty [16] might explain our results. This concept related to aforementioned neuro-cardiac term that reflects the synchronization of physiological rhythms from some body's regulatory system (respiratory, blood pressure, and heart rhythm) which occurs when they coordinate in harmony. The physiological coherent is assessed by calculating coherence ratio which is derived using specific formula of power spectral density analysis of

HRV as described in McCraty (2017). Higher coherent state is related to a shift in the increased heart-brain and different physiological systems synchronization. The coherent state has been linked with overall well-being and enhanced cognitive and physical performance. Some studies have demonstrated the association between HRV coherence and improvements in some cognitive functions and self-regulatory capacity [41]–[42].

Despite the parallel results of all measures, the correlation between work performance and stress level as well as physiological coherence were insignificant as displayed in table 6. This might be attributed to lack of the sensitivity of work performance measure. It also seems that the worker's stress level did not influence work performance to a great extent. To confirm these findings, replicating the study with larger sample size and more sensitive measures is required.
In the context of practical implication, our findings suggest that individual risk stress assessment using effective tools is needed to measure and monitor stress at workplace both subjectively and objectively. It is also recommended that the organization ought to implement a stress management intervention which may have beneficial outcomes for both individual and organizational.

This study presents some limitations that require further examination and additional research in the stress assessment. First, our relatively small sample size and sample characteristics (female workers in electronic manufacturing industries) limit the generalizability of findings. As the literature has well documented the gender difference while responding to stress-related problems, further study is needed to replicate the study among male workers. It would also be beneficial to determine if comparable effects can be observed across different occupational setting and work performance criteria. Although worker's cycle time is a widely accepted performance criteria in work study studies, but it is also necessary to add other performance criteria such as absenteeism, presenteeism, health-related lost productivity, and job satisfaction which provide more complete picture of an individual productivity as well as increase its sensitivity. Second, the measure of physiological index using HRV physiological coherence was generated by a specific device (emWave Pro) which limited us to make the comparison with other studies. Accordingly, there is a need to use more standardized HRV norms either time-domain indices or frequency-domain parameters, derived from HRV power spectral analysis [33].

CONCLUSIONS

These findings are integrated evidence in partial supporting our hypothesis that the higher level of negative emotional symptoms would be parallel with reduced physiological coherence and lower work performance among female blue-collar workers. Therefore, it is worthwhile to include objective measurements while conducting stress assessment which are independent of workers' interpretation. Future studies with larger sample size and different groups (e.g. male workforce, occupational settings) as well as employing more standardized objective measurement are required. This study shows a potential opportunity to gain more understanding of how stress affects work performance which in turn may be useful to design an effective stress management intervention for workplace health promotion.

ACKNOWLEDGMENT

We would like to thank the staffs in the participants, the production supervisor, and head of department in providing assistance in this study. This study was supported by research grants from the University Malaysia Pahang and BI Technologies Corporation Sdn Bhd under grant RDU192404.

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