EFFECT OF MENTAL WORK LOAD ON AUTONOMIC CARDIOVASCULAR CONTROL

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Summary. Psychophysiological and occupational medicine determination of mental work load of air traffic controllers (ATC) reveal that ATC are exposed to increased level of work load. The purpose of the study is to determine the effect of mental work load on autonomic cardiovascular control assessed with Heart Rate Variability (HRV) measures in air traffic controllers from Sofia airport. Results of our study indicate that the effect of mental work load in ATC might accelerate the ageing process and induces changes in autonomic cardiovascular control – decrease of parasympathetic activity and increase of sympathetic activity. The level of work load of ATC working at the airport control might induce change of the pattern of autonomic cardiovascular control with prevalence of the sympathetic activity. The results of our study indicate that HRV measures might be a useful tool for the assessment of the effect of work load on autonomic cardiovascular control.

Key words: *mental work load, autonomic cardiovascular control, heart rate variability, air traffic controllers*

INTRODUCTION

The issue of measuring mental work load, mental effort and fatigue has been an important topic in the field of psychophysiology and occupational medicine. Automation and industrialization have significant influence on work process and working conditions but in many cases mental work load of operators and associated shift from physical to mental load is not associated with real decrease of mental demands.

Mental work load induces changes in autonomic cardiovascular control measured with heart rate variability, and respiratory sinus arrhythmia which are sensi-

tive indicators of cognitive activity [1]. Indices of cardiac activity, heart rate and heart rate variability (HRV) are reliable occupational medicine and psychophysiological measures for assessing the effect of mental work load and stress on operator's functional state [2-6]. These measures reflect changes in the level of operator's mental work load and mental effort. HRV measures reveal the extent of mental effort required of the operator to sustain the required level of cognitive performance [7]. Performance of effortful mental tasks was related to a significant reduction in HRV in laboratory and field conditions, and it was hypothesized to be a result of the defence reaction which was associated with a decrease in baroreflex sensitivity [8].

Psychophysiological and occupational medicine determination of mental work load of air traffic controller (ATC) reveal that ATC are exposed to increased level of work load [9-12]. ATC perform several tasks at once: scanning radar and other displays; giving instructions to pilots; annotating flight strips; calling down information onto tabular displays; planing ahead and anticipating future tasks; liaising; updating or removing out-of-date information, etc. There is considerable evidence in traffic control that replacing routine functions might enable ATC to devote more time to decision making and problem solving [13]. Mental tasks are associated with considerable cognitive and perceptive functions which might exert stress effect, and induce mental strain and distress. Stress response might exert the influence of following factors: the working place; the working process – the intensity of work load, information processing; the working task – scanning radars, planning, anticipating; the association between tolerance to stress and mental strain; the operator-system interaction. Stress response of ATC is dependent on the frequency and number of planes to handle.

Air traffic control is considered a stressful occupation. Psychophysiological studies of analysis of ATC tasks with measurements of heart rate, and heart rate variability reveal that ATC task is emotionally stressing, and that ATC job is a stressful occupation [14-21]. Rose and Fogg, 1993 [15], Lille and Burnod, 1983 [22] found increase of heart rate and systolic and diastolic blood pressure responses in ATC with the increasing of the number of planes to handle and increase of mental load. Henderson et al., 1990 [23] reveal that during exposure to mental load in ATC the task demand induces increase of heart rate and decrease of the interval between R wave and the pulse at the ear. Metzger and Parasuraman, 2001 [24] show the sensitivity of heart rate variability for the study of mental work load in ATC. Health analysis of ATC occupation shows high morbidity rate of diseases related to dysfunction of the autonomic nervous system – hypertension, heart rhythm disturbances, ulcer diseases [25].

The purpose of the study is to investigate the effect of mental work load on autonomic cardiovascular control assessed with heart rate variability measures in air traffic controllers from Sofia airport.

METHOD

Fifty seven ATC participated in this study. ATC were divided into three groups: 25 ATC working at the airport control (AC); 27 ATC working at the flight control (FC), and 5 ATC working at the airport tower main visual control point (TC).

1. Heart Rate Variability.

A computerized diagnostic system for the study of cardiovascular function was applied [26]. Individuals were investigated for a period of 12 minutes between 9 a.m. and 11 a.m in sitting position after two hours monitoring of ATC radar task. Following indices were analyzed: 1. Time-domain HRV measures associated with the time characteristics of consecutive series of cardiointervals (RR intervals): mean cardiointerval (RR interval) (X) (msec); standard deviation (SD) (msec); mean difference of successive cardiointervals (V) (msec); total positive successive difference (S) (sec); number of the waves in the cardiotachogram (N) (number). 2. HRV measures associated with RR intervals histogram distribution: mode (Mo) (msec); amplitude of the mode (AMo) (%); homeostatic index (HI = AMo / Mo * SD) defined as ratio of the AMo to the product of most frequent duration of RR intervals (Mo) and standard deviation (SD) (s^{-2}). 3. Frequency-domain measure of HRV (Index of Autonomic Balance – IAB = PT / P_{RSA}) (s/Hz2) – ratio of spectral power of RR intervals in the temperature band (0.01-0.05 Hz) (PT) to the spectral power of RR intervals in the respiratory sinus arrhythmia (RSA) band (0.15-0.50 Hz) (P_{RSA}). 4. Classification Index (CI). CI is the sume of main components of HRV multiplied by their coefficients of weight) (arb. un.). CI value determines the functional state and reflects the level of stress reaction. HRV measures are mediated by the activity of two branches of the autonomic nervous system.

2. Mean values (X) and standard errors (Sx) of HRV measures were calculated. Student's t-test for independent variables was used to determine the significance of differences between examined groups. A p value < 0.05 was considered statistically significant.

RESULTS

Results might be summarized as follows:

1. There exists an age-related difference in comparing ATC divided into three age groups: 20-29 (N = 21); 30-39 (N = 28); and 40-49 (N = 8). CI value in the first age group was 31.3; in the second age group 5.5; and in third – 37.9 (Table 1).

Table 1. HRV indices in different age groups

HRV Indices	GROUP 1 20-29 yr N = 21	GROUP 2 30-39 yr N = 28	GROUP 3 40-49yr N = 8	P-value		
	X±Sx	X±Sx	X±Sx	1-2	1-3	2-3
1. X (msec)	815.2±23.2	786.1±18.7	777.6±35.8	0.67	0.5	0.8
2. SD (msec)	59.1±4.0	54.0±3.0	48.3±9.1	0.3	0.2	0.5
3. V (msec)	30.3±2.7	25.0±1.7	20.5±3.7	0.08	0.05	0.2
4. S (sec)	10.9±0.7	9.7±0.5	8.1±1.2	0.5	0.04	0.1
5. N (number)	320.8±10.9	333.1±13.1	355.6±27.2	0.5	0.1	0.5
6. Mo (msec)	806.4±24.7	784.1±21.7	773.9±38.2	0.5	0.5	0.8
7. AMo (%)	15.8±1.1	17.7±0.9	23.3±2.2	0.1	0.002	0.01
8. HI (s-2)	0.45±0.07	0.57±0.08	0.91±0.1	0.2	0.005	0.06
9. IAB (s/Hz2)	0.75±0.04	0.73±0.03	0.77±0.1	0.6	0.7	0.5
10. CI (arb. un.)	31.3±5.2	5.5±2.2	-37.9±8.6	0.1	0.01	0.08

2. As far as work-related distress may be evaluated through HRV parameters, AC group seems to be exposed to more severe strain conditions in comparing with FC and TC groups. ATC working in AC show lowest value of CI than ATC working in FC and TC: CI_AC = 1.52; CI_FC = 12.7; CI_TC = 26.2) although the differences are not statistically significant (Table 2).

Table 2. HRV indices in ATC groups

HRV Indices	GROUP 1 AC N = 25	GROUP 2 FC N = 27	GROUP 3 TC N = 5	P-value		
	X±Sx	X±Sx	X±Sx	1-2	1-3	2-3
1. X (msec)	796.6±19.7	794.2±21.9	800.4±28.7	0.89	0.89	0.87
2. SD (msec)	51.8±3.2	55.2±3.7	60.4±5.8	0.5	0.27	0.57
3. V (msec)	24.0±1.7	27.7±2.3	32.3±6.1	0.21	0.08	0.53
4. S (sec)	9.1±0.4	10.4±0.6	12.2±1.8	0.1	0.01	0.27
5. N (number)	325.3±11.0	339.2±14.4	324.4±17.7	0.5	0.92	0.72
6. Mo (msec)	796.9±23.2	787.4±22.9	789.4±29.9	0.76	0.86	0.92
7. AMo (%)	18.1±0.98	18.2±1.2	14.2±1.5	0.92	0.09	0.18
8. HI (s-2)	0.58±0.07	0.64±0.1	0.36±0.1	0.64	0.2	0.24
9. IAB (s/Hz2)	0.74±0.07	0.8±0.04	0.65±0.05	0.29	0.21	0.16
10. CI (arb.un.)	1.52±1.3	12.7±1.7	26.2±2.1	0.57	0.59	0.7

3. In comparing morning and afternoon shifts, it is not evident that the values of HRV measures in afternoon shift show greater level of work-related strain than HRV values in morning shift.

4. The results obtained were also compared with data from other occupational groups (operators from electrical power stations). This comparison indicated that the air traffic control is rather difficult occupation.

DISCUSSION

Changes in the values of HRV measures are valuable tool for comparing the effect of work load on autonomic cardiovascular control. HRV indices may detect changes in work load which do not result in any variation of the pulse. HRV indices are more sensitive measure of mental work load than heart rate.

Results of our study reveal that age differences are better pronounced in comparing HRV measures based on pulse variability: V, S, AMo, HI, CI (see Table 1). The effect of mental work load in ATC might accelerate the ageing process and induces changes in autonomic cardiovascular control – decrease of parasympathetic activity and increase of sympathetic activity. We observed significant decrease when comparing mean differences of successive cardiointervals (V), total positive successive difference (S) and classification index (CI) between age groups: 20-29 and 40-49 yr. We observed also significant increase of mean values of amplitude of the mode (AMo) and homeostatic index (HI) when compared 20-29 and 40-49 groups. The results of our study reveal that work load might accelerate aging process and change the pattern of autonomic cardiovascular control with sympathetic predominance. The existence of real "functional" age difference was confirmed by the results of psychosomatic complaints. Psychosomatic complaints increase with the increasing of chronological age.

CI is an indicator of work-related stress. CI is mediated by the activity of the two branches of autonomic nervous system. ATC working in AC show lowest value of CI than ATC working in FC and TC although the difference is not statistically significant. The level of work load of ATC working in AC might induce change of the pattern of autonomic cardiovascular control with prevalence of the sympathetic activity. ATC working in airport control might be exposed to a higher level of mental work load and stress than FC and TC groups.

Changed autonomic cardiovascular control assessed with HRV indices indicate the influence of cognitive functions on cardiovascular functional state and the extent of mental effort of the operator to sustain the required level of cognitive performance [7, 27]. Change of the pattern of autonomic cardiovascular control with prevalence of the sympathetic activity reveal the invested level of mental effort and the effect of mental work load on cardiovascular functional state. Similar results are reported in the study of Backs et al., 2000 [18] who observed that autonomic modes of control change as a function of the level of work load – high and medium workload elicited significant reciprocally-coupled sympathetic activation and parasympathetic withdrawal, whereas low workload did not elicit significant change from baseline.

The results of this study indicate that HRV measures might be a useful tool for the assessment of the effect of work load on autonomic cardiovascular control. Results of our study of analysis of mental tasks of ATC with measurements of heart rate variability reveal that ATC job is a stressful occupation. Similar results are reported in the studies of [14, 18-21]. Stress does not only depend on the difficulties

of the task but also on the physical components of the working process, psychosocial stress, etc. Some of these parameters were carefully studied, and the results obtained brought similar findings to the study of the effect of mental work load on autonomic cardiovascular control assessed with heart rate variability measures.

REFERENCES

1. B o u c s e i n , W. et R. Backs. The psychophysiology of emotion, arousal and personality: Methods and models. – In: Handbook of Digital Human Modeling (Ed. V. Duffy). New York, CRC Press, Taylor and Francis Group, 2009, 35-1–35-18.
2. F a h r e n b e r g , J. et C. Wientjes. Recording methods in applied environments. - In: Engineering Psychophysiology. Issues and applications (Eds. R. Backs, W. Boucsein). Mahwah, N. J., Lawrence Erlbaum Associates, 2000, 111-136.
3. G a i l l a r d , A. et A. Kramer. Theoretical and methodological issues in psychophysiological research. – In: Engineering Psychophysiology. Issues and applications (Eds. R. Backs, W. Boucsein). Mahwah, N. J., Lawrence Erlbaum Associates, 2000, 31-58.
4. W i e n t j e s , C., H. Veltman et A. Gaillard. Cardiovascular and respiratory processes during a complex decision-making task under prolonged isolation. – In: Advances in space biology and medicine, JAI Press Inc., 1996, 5, 133-155.
5. V e l t m a n , J. et A. Gaillard. Physiological workload reactions to increasing levels of task difficulty. – Ergonomics, **41**, 1998, 656-669.
6. M i y a k e , S. Multivariate workload evaluation combining physiological and subjective measures. – Int. J. Psychophysiol., **40**, 2001, № 3, 233-238.
7. M i l l e r , J. et S. Rokicki. Psychophysiological test methods and procedures. – In: Handbook of human factors testing and evaluation (Ed. S. Charlton). Mahwah, N. J., Lawrence Erlbaum Associates, 1996, 135-155.
8. B a c k s , R. et W. Boucsein. Engineering Psychophysiology. Issues and Applications. Mahwah, N. J., Lawrence Erlbaum Associates, 2000, 385 p.
9. E n d s l e y , M. et M. Rodgers. Distribution of attention, situation awareness in a passive air traffic control task: Implications for operational errors and automation. – Air Traffic Control Q., **6**, 1998, № 1, 21-44.
10. G a l s t e r , S. et al. Air traffic controller performance and workload under mature free flight: Conflict detection and resolution of aircraft self-separation. – Int. J. Aviation Psychol., **11**, 2001, 71-93.
11. R e m i n g t o n , R. et al. Visual search in complex displays: Factors affecting conflict detection by air traffic controllers. – Human Factors, **42**, 2000, 349-366.
12. W i c k e n s , C. et al. The future of air traffic control: Human operators and automation. Washington, National Academy, 1998.
13. T r a c k r a y , R., J. Bailey et R. Touchstone. Physiological, subjective, and performance correlates of reported boredom and monotony while performing a simulated radar control task. – FAA Office Aviation Med. Rep., **7**, 1975, 75-89.
14. W i l s o n , G. et C. Russell. Operator functional state classification using multiple psychophysiological features in an air traffic control task. – Human Factors, **45**, 2003, № 3, 381-389.
15. R o s e , R. et L. Fogg. Definition of a responder: analysis of behavioral, cardiovascular, and endocrine responses to varied workload in air traffic controllers. – Psychosom. Med. **55**, 1993, № 4, 325-338.
16. B r o o k i n g s , J., G. F. Wilson et C. Swain. Psychophysiological responses to changes in workload during simulated air traffic control. – Biol. Psychol., **42**, 1996, № 3, 361-377.

17. R o w e , D., J. Sibert et D. Irwin D. Heart rate variability: indicator of user state as an aid to human-computer interaction. – Proc. of the SIGCHI conference on Human factors in computing systems, New York, 1998.
18. B a c k s , R., T. Navidzadeh et X. Xidong. Cardiorespiratory indices of mental workload during simulated air traffic control. human factors and ergonomics society annual meeting proceedings, Proceedings 3. – Aerospace Systems , 2000, 89-92.
19. M e t z g e r , U. et R. Parasuraman. Automation in future airt management: effects of decision aid reliability on controller performance and mental workload. – Human Factors. **47**, 2005, № 1, 35-49.
20. C o l l e t , C., P. Averty et A. Dittmar. Autonomic nervous system and subjective ratings of strain in air-traffic control. – Applied Ergonomics, **40**, 2009, № 1, 23-32.
21. H o o v e r , A. et E. Muth. A Real-Time index of vagal activity. – Int. J. Human-Computer Interaction, **17**, 2004, № 2, 197-209.
22. L i l l e F. et Y. Burnod. Professional activity and physiological rhythms. – Adv. Biol. Psyciatr., **11**, 1983, 64-71.
23. H e n d e r s o n , P., D. Bakal et B. Dunn. Cardiovascular response patterns and speech: A study of air traffic controllers. – Psychosom. Med., **52**, 1990, 27-41.
24. M e t z g e r , U. et R. Parasuraman. The role of the air traffic controller in future air traffic management: An empirical study of active control versus passive monitoring. – Human Factors, **43**, 2001, № 4, 519-528.
25. C o b b , S. et R. Rose. Hypertension, peptic ulcer and diabetes in air traffic controllers. – J. Am. Med. Assoc., **224**, 1973, 489-492.
26. D a n e v , S. [Informativeness of heart rhythm in occupational physiological aspect.] (D. Sc. Thesis) Sofia, National Institute of Hygiene, Medical Ecology and Nutrition, 1989 (in Bulgarian).
27. V e r n e t - M a u r y , E. et al. Autonomic Nervous System activity and mental workload. – In: Psychophysiology of Mental Workload. Munich, Bundesanstalt fur Arbeitsmedizin Verlag, 1993, 42-49.

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