Psychophysical Coherence Training Regulating Air Traffic Controller's Heart Rate Variability and Resilience to Fatigue

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Abstract. Heart Rate Variability (HRV) can reflect individuals' cognitive workload objectively. HRV measurement is a non-invasive method to evaluate relevant physiological changes in a human body. Physiological changes and cognitive processes are associated with the cardiac dynamic autonomic control, and thus to influence individuals' ability to cope with fatigue and achieve resilience. As a dynamic process to be learned, resilience can be formed and improved through Quick Coherence Training in a short time. To study the regulatory effects of coherence training on Air Traffic Controllers' (ATCOs) HRV and resilience ability, the HRV parameters of 34 qualified ATCOs before and after Quick Coherence Training (QCT) are collected and analysed by paired T-Test. Also, participants' HRV at rest are recorded as baseline. The results show that the coherence, mean RR interval, SDNN, and RMSSD after QCT are significantly higher than before. The mean heart rate after QCT is significantly lower than before. The findings demonstrate that coherence has effective and efficient regulatory effects on coherence, mean RR interval, SDNN, mean heart rate, and RMSSD. Psychological coherence training can be an efficient method for ensuring ATCOs recover from fatigue and achieve resilience quickly during the short break in long-time continuing monitoring and controlling. The findings in the current research can have potential to be further developed for Fatigue Risk Management System which is required by ICAO (International Civil Aviation Organization) to be applied for Air Navigation Services providers.

Keywords: Heart rate variability · Psychophysical resilience · Quick Coherence Training · Fatigue risk management

1 Introduction

Fatigue risk management is considered to be most effective when it is integrated into, or supported by, an SMS, thereby forming an FRMS [1]. Fatigue risk management system (FRMS) have been introduced on the basis that "better results (both in terms of safety and productivity) might be obtained from approaches that are more comprehensive, more flexible, and better tuned to current scientific understanding of key factors in fatigue

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prevention" [2]. In fact, the prescriptive approach has been under increased scrutiny as to its benefits in preventing fatigue. The main assumption is that regulations are not able to take into account the complexity of fatigue [1]. For instance, because of circadian rhythms, a break will not have the same recovery value depending on the time of the day, the timing of the break being more important than the duration of the break itself. This is the reason why alternatives to a prescriptive approach, such as FRMS, are becoming more popular [3].

Resilience refers to the ability for individuals to resist or recover from suffering negative experiences such as stress and fatigue [4]. Resilience has been proven to be associated with some inherent traits of individuals. There are significant correlations between psychological resilience and the big five personality traits: resilience is positively correlated with conscientiousness, agreeableness, openness to experience and extraversion, and negatively correlated with neuroticism [5]. Also, resilience is associated with social intelligence and coping styles related to task and emotion [6, 7]. Furthermore, there are some psychiatric illnesses or cognitive disorders which could influence the ability of resilience [7, 8]. On the other hand, the formation and improvement of resilience are considered as the dynamic process which could be learned at any period of life [9]. Resilience could be acquired over a period of time by using a process rather than coming all at once [10]. Intervention techniques based on cognitive behavioral therapy or mindfulness have been proven to have a positive impact on resilience [11].

Heart rate variability (HRV) can reflect a person's cognitive workload objectively [12, 13]. Healthy biological systems exhibit mathematically chaotic variations. HRV is composed of variations in the interval between successive heartbeats, known as the heartbeat interval (IBIs). A healthy heart is not a metronome. The oscillations of healthy hearts are not only complex but also varied. This enables the cardiovascular system to quickly adapt to any challenges for the homeostasis. Due to the influence of respiration, blood pressure and skin temperature on the heart control mechanism, the heart rate of normal people will undergo physiological changes. HRV index is the neurocardiac function, which is generated by the cardiac and brain interaction and the dynamic nonlinear Autonomic Nervous System (ANS) process. From a clinical perspective, the relationship between specific psychologic states and patterns of autonomic physiological responses is a particularly important issue for further research. HRV reflects the physiological changes in the human body by a non-invasive measure method [14, 15]. Mental states and processes can have an impact on cardiac dynamic autonomic control [16]. The HRV parameters including basal characteristics, time domain, frequency domain and non-linear are proved to be associated with fatigue and perceived workload [17, 18]. HRV basal characteristics include Coherence, Mean R-R interval, Mean HR and STDHR; Time-domain parameters include SDNN, RMSSD, NN50, and pNN50; Frequency domain measurements include LF, HF, Total Power, and Ratio LF/HF. The research aim is to develop FRMS for air navigation services providers by psychophysical coherence training.

2 Method

2.1 Participants

Thirty-four qualified Air Traffic Controller Operators (ATCOs, 27 male and 7 female) participated in this research. The ages of participants ranged between 23 and 58 years of age (M = 41.21, SD = 7.49), and their work experience as air traffic controllers varied from 1 to 38 years (M = 17.28, SD = 9.38). The collected data was gathered from human subjects; therefore, the research proposal was submitted to the Cranfield University Research Ethics System for ethical approval. As stated in the consent form, participants have the right to terminate the experiment at any time and to withdraw their provided data at any moment even after the data collection.

2.2 Apparatus

HRV Measurement Device. The HeartMath emWave device was applied to collect HRV data while participants performed various tasks. The device is equipped with an ear sensor which can gather the Inter Beat Interval (IBI) parameters, and it is possible to connect it using Bluetooth and export HRV data to other mobile devices through Inner Balance application (Fig. 1). Kubios is an advanced tool for investigating the variability of heart-beat intervals. Due to the wide variety of different analysis options and easy-to-use interface, the software is suitable for researching various premises. The software is suitable for clinical and public health researchers working on human HRV. This research applied the latest version of Kubios HRV developed at University of Eastern Finland [17]. The Kubios software is used to analyze participants' HRV parameters including time domain, frequency domain and non-linear (Fig. 2).

Fig. 1. Inner Balance Bluetooth sensor for Android & iPhone

HeartMath Quick Coherence Technique. The Quick Coherence Training (QCT) proposed by HeartMath can shift from stress and frustration to balance and resilience in about one minute with simple, but powerful steps. Coherence refers to a state where thoughts

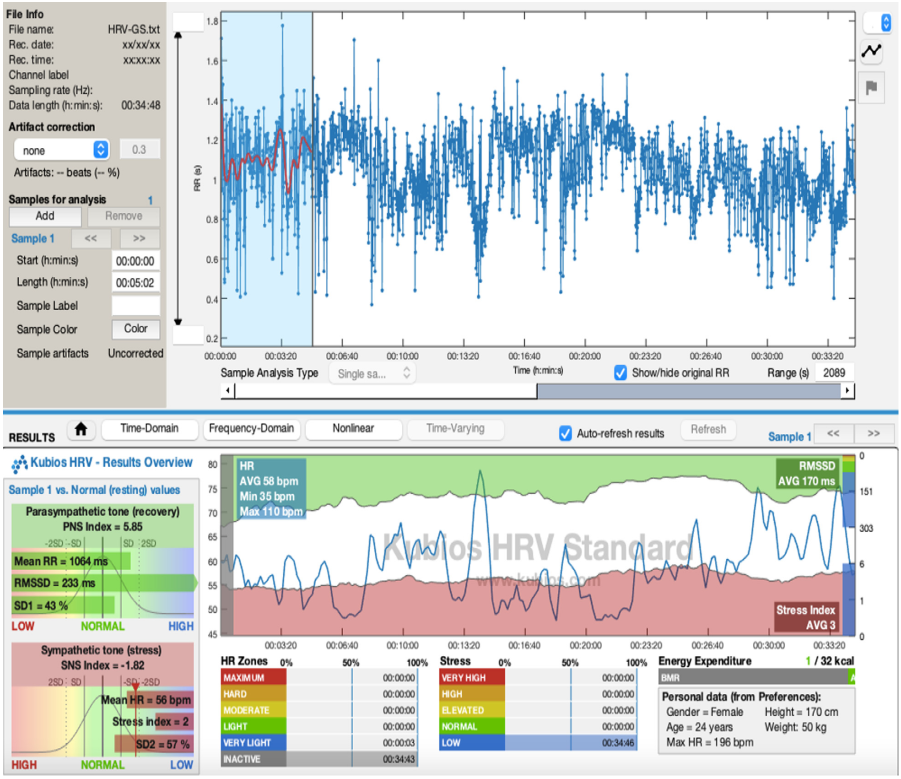

Fig. 2. Example of HRV parameters analysis by Kubios

and emotions are balanced, this is reflected in more balanced heart rhythms and it facilitates brain function and access to higher intelligence. The HeartMath Quick Coherence Training is an effective technique to achieve energy, mental clarity and resilience. There are two simple and quick steps for Coherence Training by the technique of heart-focused breathing.

2.3 Research Design

Each participant carries out the same procedures follows; (1) briefing the research aims (five minutes); (2) providing the demographical data including age, gender, qualifications, and working experience (five minutes); (3) wear Heart Math HRV measurement device for data collection on air traffic control working position (60 min); (4) conducting Quick Coherence Training (30 min); (5) Collecting post-training session of HRV (5 min).

3 Results

The HRV parameters of 34 participants before and after QCT are collected. Also, participants' HRV data at rest was recorded as baseline. For the convenience of statistical analysis and based on the research goals, five parameters: Coherence, Mean RR, SDNN, Mean HR, and RMSSD are involved in the statistical analysis in the current study. Mean RR is the heart inter-beat (R-R) interval; SDNN is the standard deviation of normal to normal (N-N) R-R intervals, reflecting the sympathetic and parasympathetic activity influencing HRV; Mean HR is the mean heart rate in beats per minute; and RMSSD is the square root of the mean of the sum of the squares of differences between adjacent NN intervals. Paired T-Test was applied for data analysis. Cohen's d was calculated as the effect size metric. The sample characteristics and T-Test results of HRV parameters on three phrases are shown as Table 1.

Table 1. The means and standard deviation of HRV parameters and paired T-Test results between before and after QCT

HRV parameters (Baseline)	QCT	M	SD	N	T-Test			
					t	df	p	Cohen's d
Coherence (27.01)	Before	25.74	5.22	34	29.14	33	.000	5.00
	After	70.56	9.19					
Mean RR (ms) (796.20)	Before	814.53	105.54	34	4.05	33	.000	0.69
	After	922.65	105.10					
SDNN (ms) (85.10)	Before	71.15	39.83	34	2.87	33	.007	0.49
	After	101.43	46.45					
Mean HR (bpm) (76.48)	Before	74.91	9.98	34	− 4.22	33	.000	-0.72
	After	65.85	7.45					
RMSSD (ms) (88.94)	Before	76.08	51.79	34	2.60	33	.014	0.45
	After	109.62	53.91					

The T-Test results show that the Coherence after QCT ($M = 70.56$, $SD = 9.19$) is significantly higher than before ($M = 25.74$, $SD = 5.22$), $t = 29.14$, $p < .001$, $d = 5.00$. The Mean RR after QCT ($M = 922.65$, $SD = 105.10$) is significantly higher than before ($M = 814.53$, $SD = 105.54$), $t = 4.05$, $p < .001$, $d = 0.69$. The SDNNs after QCT ($M = 101.43$, $SD = 7.96$) is significantly higher than before ($M = 39.82$, $SD = 6.83$), $t = 2.87$, $p < .01$, $d = 0.49$. The Mean HR after QCT ($M = 65.85$, $SD = 7.50$) is significantly lower than before ($M = 74.90$, $SD = 9.98$), $t = -4.22$, $p < .001$, $d = -0.72$. The RMSSD after QCT ($M = 109.62$, $SD = 53.91$) is significantly higher than before ($M = 76.08$, $SD = 51.79$), $t = 2.60$, $p < .05$, $d = 0.45$.

4 Discussion

The T-Test results demonstrated that coherence training has significant regulatory effects on coherence, mean RR, SDNN, mean HR, and RMSSD. Coherence is the state when the heart, mind and emotions are in energetic alignment and cooperation. Gaining coherence is a strategy to build resilience and accumulate personal energy, recovering and keeping more energy for positive outcomes. A QCT program or training which increases sense of coherence could contribute to decrease stress and fatigue, as well as improve resilience [19]. Furthermore, compared to various complicated physiological parameters, coherence could be considered as a simple and quick indicator for evaluating individuals' general mental workload. The correlational and causative relationships between coherence and HRV as well as various other physiological systems have been revealed [20]. Therefore, it is effective and efficient as a means of fatigue management to monitor ATCOs' coherence level. If used during break times it should permit ATCO's to achieve resilience throughout their working day.

In terms of the fluctuation of HRV parameters, the statistical analysis reveals that coherence training could help ATCOs make a good recovery from Air Traffic Control tasks to a parallel or even better level with baseline HRV in a short time. The coherence increased significantly indicating participants have built a good resilience via coherence training. Moreover, the increased mean RR interval, SDNN, and RMSSD indicates the recovery from work pressure and mental stress [21–23]. Heart rate could increase with higher workload and complexity of tasks [24]. The decreasing heart rate of participants indicates effective relaxation and recovery from workload and fatigue. Through coherence training, participants are in a relatively relaxed state and able to embrace further ATC tasks and mental challenges.

However, participants' coherence and HRV parameters did not simply return to baseline state at rest, especially for the mean RR interval and heart rate (Fig. 3). On the one hand, this finding confirms the effectiveness of coherence training for resilience and recovery. On the other hand, it is uncertain that the baseline HRV parameters demonstrate the optimum state for more ATC tasks. It is noted that mean RR interval increase and heart rate decrease during work, which means less stress and mental workload. This phenomenon could be attributed to the influence of passive fatigue, which might be caused by boredom, task underload or monotony [25]. Therefore, it is essential to find proper points to initiate coherence training and engage in tasks without passive fatigue.

Table 1 demonstrated that ATCOs' mean RR had significantly increased from 814.53 ms to 922.65 ms with SDNN increasing from 71.15 ms to 101.43 ms by practicing quick coherence training compared not using QRT on the working position. While the HeartMath tools are intentionally designed to be easily learned and used in day-today life, professionals suggest that these techniques often facilitate profound shifts in perception, emotion and awareness. Moreover, extensive laboratory research performed at HMI has shown that the physiological changes accompanying such shifts are dramatic. Several studies using various combinations of these QCT techniques have found significant correlations between psychophysical coherence and improvements in cognitive function. For example, a study of school students with Attentional Deficit Hyperactivity Disorder (ADHD) showed a wide range of significant improvements in short and long-term memory, ability to focus and significant improvements in behaviours both at home and in school [26]. A study of 41 fighter pilots engaging in flight simulator tasks found a significant correlation between higher levels of performance and heart coherence as well as lower levels of frustration [27]. A study of patients diagnosed with Post-Traumatic

Stress Disorder (PTSD) found that relatively brief periods of HRV coherence training combined with practicing the Quick Coherence Technique resulted in significant improvements in the ability to self-regulation along with a wide range of cognitive functions [28]. McCraty et al. concluded that psychologically the coherence state promotes a calm, emotionally balanced, yet alert and responsive state with a sense of enhanced subjective well-being, which is conducive to cognitive function and task performance, including problem-solving, decision-making, and activities requiring perceptual acuity, attentional focus, coordination, and discrimination [29]. Edwards evaluated the influence coherence training both quantitatively and qualitatively. The findings indicated significant improvements in health, mindfulness, and spirituality perceptions, as well as meaningful learning experiences and positive evaluations of the coherence training feedback for health, sport, exercise, performance, meditation, and daily life contexts [30]. Field et al. also provided consistent evidence that the coherence training program is both feasible and effective in improving heart rate variability, physiological relaxation and mindfulness [31]. The technique of quick coherence did increase ATCOs' resilience to fatigue and improve ATCOs' health and well beings.

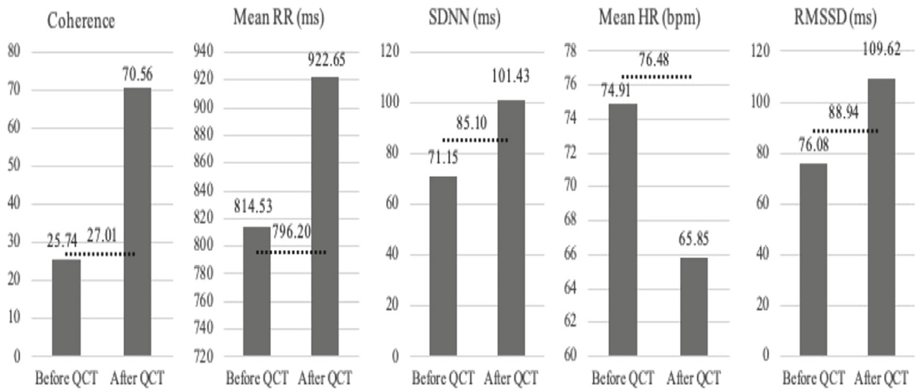

Fig. 3. Participant' coherence, mean RR, SDNN, mean HR and RMSSD before QCT and after QCT, and at rest as baseline (dotted lines)

5 Conclusion

The statistical results demonstrated that coherence training could regulate ATCOs' HRV parameters effectively and efficiently. Psychological coherence training could contribute to recovery from heavy workload and achieve resilience to cope with fatigue. However, the proper initial state and optimum outcomes of HRV parameters for coherence training are still uncertain. The negative influence on ATCOs HRV parameters and resilience ability of passive fatigue should be confirmed and would benefit from further research. QCT could be an efficient method for ensuring ATCOs' recovery and resiliency in a short break form long-time shift work. In summary, the current research could have the potential to be further developed for Fatigue Risk Management System which is required by ICAO (International Civil Aviation Organization) to be applied for Air Navigation Services providers.

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