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Applying psychophysiological coherence training based on HRV-biofeedback to enhance pilots' resilience and wellbeing

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Abstract

Introduction. The COVID-19 pandemic not only limited pilots' proficiency in performing routine tasks, but also increased stress levels and operational risk due to new procedures in flight operations related to safety and health regulations. There is, therefore, an increasing need to improve pilots' mental and physical health to maintain aviation safety. **Research question.** (1) Does the practice of psychophysiological coherence using heart rate variability (HRV) biofeedback and the Quick Coherence Technique (QCT) improve pilots' resilience? (2) What effects does psychophysiological coherence practice have on pilots' resilience and wellbeing? **Method.** Eighteen commercial pilots' perceived stress and wellness were evaluated subjectively by the Perceived Stress Scale (PSS) and Ardell Wellness Self-Assessment (AWSA). They were taught the QCT for facilitating psychophysiological coherence, and their HRV data reflecting automatic nervous system (ANS) activities were collected as they practiced QCT via Inner Balance HRV sensors. **Results.** The QCT training improved pilots' AWSA scores ($t = -3.55$, $p = .002$) and decreased PSS scores ($t = 6.37$, $p < .001$). Pilots' post-training HRV were improved with SDNNs higher than pre-training, $t = -4.88$, $p < .001$; normalized low frequency (LF) power increased ($t = -10.91$, $p < .001$) and low-frequency to high-frequency (LF/HF) ratios increased ($t = -3.92$, $p = .001$). Additionally, pilots' post-training respiration rates were lower than pre-training, $t = -2{,}45$, $p = .025$. **Discussion.** Based on the empirical data analysis, HRV-biofeedback QCT can improve psychophysiological coherence and thereby increase pilots' resilience and wellbeing. Increased post-training SDNNs, normalized LF power, and LF/HF ratio indicate the improvement of ANS control and balance, and stress management capacity. These findings demonstrate the effectiveness of HRV-biofeedback QCT training in improving psychophysiological coherence, which confers real-time and post-practice benefits of optimal energy utility and self-regulation in challenging situations on flight operations and everyday life. **Conclusion.** This research demonstrates significant benefits of a short session of HRV-biofeedback QCT on pilots' resilience and cognitive process by improving psychophysiological coherence. HRV-biofeedback QCT training can be an effective intervention for aviation authorities and airline operators to develop peer support programs for pilots to increase psychological resilience and wellbeing. This may be particularly beneficial given the various challenges presented to pilots in their preparation for return to normal operations.

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1. Introduction

The COVID-19 pandemic has been posing sustained threats across typical daily life and entire global aviation industry since 2019. Pilots endurably go through maladaptive perception of multiple stressors and risks of emerging infection, social isolation, and career uncertainty, which are associated with general health decline, autonomic dysregulation, and cognitive process (Chrousos & Kino, 2005). Heart rate variability (HRV) changes are related to social threat and a variety of other peripheral responses to stressors (Wager et al., 2009). Recent studies have emphasized the usefulness of HRV as a global index of psychological heath in the general population during the COVID-19 related lock-down (Bourdillon et al., 2020). HRV-biofeedback practice based on breathing frequency regulation can improve efficiency in respiratory gas exchange and blood pressure control through baroreflex and automatic nervous system (ANS) activities to induce feelings of relaxation and well-being, as well as increase the flexibility and resilience when facing stressful situations (Gevirtz, 2013).

1.1. COVID-19 pandemic influences pilots' psychological wellbeing

This unprecedented challenge and disruption caused by COVID-19 pandemic led to a range of negative stressors to pilots, which induces further downstream consequences of psychological health and cognitive functioning impairments. Metin et al. (2021) found a significant decrease in the psychological wellbeing and resilience of people from almost all countries and industries during COVID-19 pandemic. Recent research also noted that the stress-related declines in cognitive functioning are inevitable for even the most resilient individuals, leading to frequent mind wandering with negative emotions, poor performance on sustained attention tasks, and decreased situational awareness (Boals & Banks, 2020). The risk to safe operations is that the COVID-19 pandemic presents additional stressors and can reduce human capacity and ability to perform or monitor themselves as effectively as would usually be (CAA, 2020). The forecasts for air transportation recovery also increased pilots' stress as global flight restrictions were foreseen to run through the post-pandemic (Miani et al., 2021). According to a survey targeted at all aviation workers, 47% of participants indicated that their job motivation had deteriorated since the COVID 19 pandemic, and around 15% were concerned that they will not be fit to return to work post pandemic (Cahill et al., 2021). Therefore, it is vital to recognise and monitor pilots' psychological problems and cognitive declines arising from the COVID-19 pandemic in order to avoid the adverse consequences of underperforming flight operations. Effective intervention tools for improving pilots' resilience from these negative impacts are also in pressing need for the aviation industry to be fully prepared to return to normal operations in this post-pandemic era.

1.2. Heart rate variability biofeedback technique improves resilience

HRV is closely associated with the functions of Sympathetic Nervous System (SNS) and Parasympathetic Nervous System (PNS) for cognitive process. Furthermore, HRV serves as a biomarker of emotional regulation and stress resilience in the COVID-19 pandemic context (Makovac et al., 2021). The intervention based on HRV-biofeedback requires individuals to breathe in a low frequency (around 10 breaths per minute) effectively lengthening and balancing both the inhalation and exhalation period to increase the amplitude of HRV. This technique can effectively train people in the voluntary control of psychophysiological parameters through audio-visual feedback mechanisms to increase psychophysiological coherence and resilience (Shaffer & Ginsberg, 2017). Psychophysical coherence is associated with the alignment of physical and mental functions which can facilitate a well-established relationship between cognitive information processing and task performance (Bradley et al., 2010). Resilience is the ability to cope with a crisis and return to pre-crisis status quickly using mental processes and behaviours in promoting personal assets and protecting self from the potential negative effects of stressors. Therefore, HRV-biofeedback training has been widely used by military pilots for preventing loss of consciousness when facing prolonged hypoxia and hyperventilation conditions for decades (Kloudova et al., 2019). The Quick Coherence technique (QCT) based on biofeedback breathing training has also been demonstrated as an effective method to increase air traffic controllers' fatigue resilience and operational risk management (Li et al. 2022). In consequence, there are huge potentials to develop intervention programmes based on HRV-biofeedback training to improve pilots' psychological wellbeing and resilience in the current pandemic context.

This research is to evaluate the effectiveness of the QCT training based on HRV-biofeedback technique on moderating pilots' psychophysiological coherence, psychological resilience, wellness, and cognitive process during the COVID-19 pandemic. There are two research questions to be investigated as follows:

(1) Does the practice of psychophysiological coherence using HRV-biofeedback and the QCT improve pilots' resilience?

(2) What effects does psychophysiological coherence practice have on pilots' resilience and wellbeing?

2. Methodology

2.1. Participants

Eighteen commercial pilots who are working for an international airline volunteered to participate in this research. The participants' ages ranged from 30 to 58 years old (M=45.1, SD=7.5) with different aircraft type ratings and flight hours (M=11597.2, SD=5496.8). Participants' service years are between 3 years and 26 years (M=14.7, SD=7.8). The research ethical approval was granted in advance of the research taking place. All participants were informed that this research is evaluating the effectiveness of HRV biofeedback using QCT on stress and fatigue risk management as related to the impacts of the COVID-19 pandemic. Participants were guaranteed their right to withdraw from this research at any stage and provided their signed consent form. All collected data is managed in accordance with the United Kingdom Ethical Code and the General Data Protection Regulation (GDPR).

2.2. Apparatus and materials

2.2.1. Inner Balance

The Inner Balance device with ear sensor (left top on figure 1) is a lightweight Bluetooth photoplethysmographic (PPG) sensor with 125hz sample rate and 80 hours of battery life which is optimized to ensure accurate HRV and psychophysiological coherence measurement. It can be easily connected with personal mobile devices (Android or Apple smartphone or tablet) for training purpose (left bottom on figure 1). The visual feedback on coherence status includes coloured indicators comprised of red (low), blue (medium) and green (high) with percentage indicators summed up as 100% (right top on figure 1). This study uses high percentage (green) as psychophysiological coherence indicator for data analysis, which indicates the degree of harmony and stability occurring in the ANS reflecting the optimal cognitive functions and optimisation of energy resources (HeartMath, 2014). Furthermore, the collected data are examined by Kubios software to analyse participants' HRV, which reflects variations between consecutive inter-beat-intervals. The respiration rate is an important psychophysiological parameter for HRV analysis which can be computed from the beat-to-beat RR interval time series data. Respiration rate has been used in a wide range of clinical settings for the identifying abnormalities since it is a strong biomarker to respond rapidly to variations in both physiological state and psychological workload. This research also analyses time-domain HRV parameters including SDNN and RMMSD, as well as frequency-domain parameters including normalized LF power and LF/HF ratio. SDNN is the standard deviation of RR intervals; RMSSD is the square root of the mean squared differences between successive RR intervals. The normalized LF power is the relative power of the low-frequency band (0.04–0.15 Hz) in normal units; LF/HF is the ratio of low-frequency (0.04–0.15 Hz) to high-frequency (0.15–0.4 Hz) power.

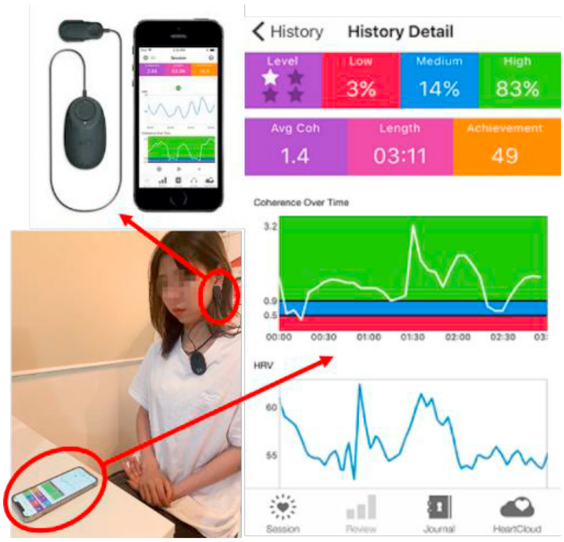

Fig. 1. Inner Balance device for HRV-biofeedback training

2.2.2. Perceived Stress Scale

Perceived Stress Scale (PSS) is a self-reported subjective questionnaire which was developed to measure the degree to ten scenarios in individual's life considered as stressful. The PSS has become one of the most widely used psychological instruments for measuring perceived stress. It has been used in studies assessing the stressfulness of situations and the effectiveness of stress-reducing interventions. The PSS has consisted of ten items (including four reversing questions) evaluating the degree to which individuals believe their life has been unpredictable, uncontrollable, and overloaded. The score of each item of PSS is from 0 to 4 (five-point). Individuals' perceived stress can be categorized into three level (low, moderate, and high) based on the PSS total score.

2.2.3. Ardell Wellness Self-Assessment

Ardell Wellness Self-Assessment (AWSA) is often applied to diagnose participants' state of wellness and stress index using a seven-point Likert scale (from +3 to -3) that measures individual wellbeing. Ardell Wellness test consists of 25 questions incorporating physical, mental, emotional, and social aspects of health which offer a balanced assessment of varied stress sources. The AWSA test results can be further interpretated as six levels of wellbeing status according to the total score. Where the higher the total score, the higher level of wellness, the higher the happiness of that participant, and vice versa.

2.3. Research procedures

Participants voluntarily attended a two-day psychophysiological coherence training program. All participants went through the same procedures as follows, (1) briefing the research objectives and two-day training syllabus; (2) participants provide their signed consent form with agreed data management plan; (3) participants conduct pre-training subjective assessments on AWSA and PSS; (4) participants provide pre-training biofeedback for 5 minutes using Inner Balance connected to his/her personal device (Android or Apple smartphone or tablet); (5) participants attend two-day coherence training which includes practicing QCT and information about physiology, emotions and stress management; (6) participants perform their post-training assessments using AWSA, PSS and Inner Balance for psychophysiological coherence after training completed; (7) Debriefing and response to participants' comments. All participants' coherence data was stored on the HeartCloud which can only be accessed by the project leader using encrypted username and passwords to follow GDPR requirements.

3. Results

Paired t-test analysis was applied to investigate the training effects on pilots' wellness, perceived stress, percentage of high coherence, respiration rate, and HRV indices between pre-training and post-training of QCT. There was no outlier observed by boxplots. The assumption of normality was verified by Q-Q plots. The effect sizes of samples were quantified by Cohen's d.

The t-test analysis showed that there is a significant difference in pilots' wellness by AWSA score between pre-training and post-training of QCT, $t(17) = -3.55$, $p = .002$, $d = -0.84$. A significant difference on pilots' perceived stress by PSS score between pre-training and post-training of QCT is also found, $t(17) = 6.37$, $p < .001$, $d = 1.50$. There is a significant difference on pilots' percentage of high coherence between pre-training and post-training of QCT, $t(17) = -12.04$, $p < .001$, $d = -2.84$. A significant difference between QCT pre-training and post-training on pilots' respiration rate is also found, $t(17) = 2.45$, $p = .025$, $d = 0.58$. For HRV parameters, there is a significant difference on pilots' SDNN between pre-training and post-training of QCT, $t(17) = -4.88$, $p < .001$, $d = -1.15$; Pilots' RMSSD has no significant difference between QCT pre-training and post-training, $t(17) = -1.16$, $p = .264$, $d = -0.27$; A significant difference is found on normalized LF power, between QCT pre-training and post-training, $t(17) = -10.91$, $p < .001$, $d = -2.57$; There is a significant difference between pre-training and post-training on pilots' LF/HF ratio, $t(17) = -3.92$, $p = .001$, $d = -0.92$. The descriptive statistics and t-test results are shown as Table 1.

Table 1. Mean, Standard deviation, and t-test results of pilots' wellness, perceived stress, psychological coherence and HRV indices between pre-training and post-training of QCT

	QCT	M	SD	N	SE	t	df	p	Cohen's d
Wellness	Pre-training	18.67	14.75	18	2.62	-3.55	17	.002	-0.84
	Post-training	27.94	11.13	18					
Perceived workload	Pre-training	19.33	6.41	18	1.33	6.37	17	.000	1.50
	Post-training	10.83	4.41	18					
Percentage of high coherence (%)	Pre-training	38.44	24.22	18	4.73	-11.38	17	.000	-2.68
	Post-training	92.22	10.02	18					
Respiration rate (Hz)	Pre-training	0.28	0.04	18	0.02	2.45	17	.025	0.58
	Post-training	0.23	0.09	18					
SDNN (ms)	Pre-training	47.39	16.27	18	5.77	-4.88	17	.000	-1.15
	Post-training	75.54	32.60	18					
RMSSD (ms)	Pre-training	55.20	25.05	18	4.91	-1.16	17	.264	-0.27
	Post-training	60.87	29.94	18					
Normalized LF power	Pre-training	53.11	18.52	18	3.11	-10.91	17	.000	-2.57
	Post-training	87.04	9.03	18					
LF/HF ratio	Pre-training	1.71	2.00	18	2.53	-3.92	17	.001	-0.92
	Post-training	11.64	11.18	18					

4. Discussion

The t-test results demonstrated that pilots' high percentage of coherence significantly increased from 38.44% to 92.22% by a short-term HRV-biofeedback QCT training program (table 1 & figure 2a). This finding revealed the effectiveness of QCT training on improving the psychophysiological coherence and cognitive information process (Bradley et al., 2010). Furthermore, by QCT practice, pilots' perceived stress decreased from 19.33 to 10.83 and wellness increased from 18.67 to 27.94 (table 1 & figure 2b). This point demonstrated that HRV-biofeedback technique can significantly facilitate pilots' resilience and psychological wellbeing through the moderation effects on psychophysiological coherence, which is consistent with previous research that proposed QCT training improved air traffic controllers' fatigue resilience related to rotating shift works (Li et al., 2022). Therefore, the first research question: “Does the practice of psychophysiological coherence using HRV-biofeedback technique improve pilots’ resilience?” was supported. Furthermore, resilience as a key factor of cognitive functioning can be crucial to the piloting abilities such as situation awareness and decision-making, and thus to influence the flight performance (Causse et al., 2011). The improvements on pilots’ resilience and cognitive information process by HRV-biofeedback training would bring long-standing benefits to pilots’ fatigue management and task performance in flight operation. A five-minute QCT practice session during the controlled rest in flight deck can be an effective strategy of taking breaks at work to help pilots re-charge their mental and physical resources during long-haul flights. The increased psychophysiological coherence and resilience facilitate pilots’ cognitive functioning and energy mobilization, contributing to concentrate on the current flight situation with calmer attitude. Thus, the flight performance and aviation safety can also be improved. In sum, the QCT training program based on HRV biofeedback technique can increase pilots’ psychophysiological coherence to cope with the negative impacts by pandemic, which is also able to further improve their psychological wellbeing and resilience in both day-to-day life and flight operation.

Based on the empirical data analysis, pilots’ respiration rate significantly decreased from 0.28 Hz to 0.23 Hz by HRV biofeedback QCT training program (table 1 & figure 2c). According to the close association of the respiratory system with emotional regulation and cognitive processes, respiration rate can serve as an index of ANS activity and change in psychological state (Stevenson & Ripley, 1952). The occurrence of over breathing was also found to be in conjunction with various psychophysiological negative changes such as anxiety and stress (Suess et al., 1980). Therefore, the decreasing respiration rate demonstrated the stress resilience and emotional self-adaption process of pilots with practicing QCT training. Furthermore, the SDNN of time-domain HRV significantly increased from 47.39ms to 75.54ms (table 1 & figure 2d), which indicates a decreased stress level and improved resilience by HRV-biofeedback QCT (Boutcher & Stocker, 1996). However, there is no significant difference on pilots’ RMSSD between QCT pre-training and post-training (table 1 & figure 2d). While SDNN primarily reflects PNS activities but also partly SNS influences on heart, RMSSD reflects PNS functions mainly (Otzenberger et al., 1998). As two major dynamic-balanced branches of ANS, the SNS is associated with energy mobilization, and the PNS is associated with vegetative and restorative functions (Thayer et al., 2010). This finding demonstrated that HRV-biofeedback QCT has significantly direct moderation on the SNS activities to alleviate mental workload and perceived stress by improving the energy mobilization. Furthermore, previous study mentioned that not all indices of HRV are equally affected by respiration: RMSSD is especially less affected by changes in breathing frequency (Penttila et al, 2001). This can be an alternative plausible explanation for the unchanged RMSSD with QCT practice. In frequency-domain HRV analysis, the normalized LF power increased from 53.11% to 87.04% (table 1 & figure 2d), which represents the activation influence on SNS activities via baroreflex action and breathing regulation by HRV-biofeedback QCT practice (Adjei et al., 2019). This finding can further confirm that the QCT training would mainly influence pilots’ SNS activities in a proactive and direct way to facilitate pilots’ self-regulated capacity and psychological resilience. Furthermore, there is a dramatical increase from 1.71 to 11.64 of the LF to HF ratio (table 1 & figure 2d). The LF/HF ratio is considered as a quantitative marker of sympatho/vagal balance to reflect SNS modulations (Heathers & Goodwin, 2017). Previous research indicated that the psychological stress was significantly associated with an increase in the LF/HF ratio (Kim et al., 2018), which is obviously not in line with the finding of current study. A plausible explanation is that the LF/HF ratio show the complexity and ambiguity in reflecting different stressor sources (Schubert et al., 2009). Pilots are vulnerable to multiple dimensions of stressors in the context of the combination of COVID-19 pandemic and the nature of flight operation tasks. Based on the two-dimensional analysis framework proposed by Von Rosenberg et al. (2017), the high LF/HF ratio also represents a state of low mental stress and physical stress. Furthermore, the increased LF power and LF/HF also demonstrated a direct association with the manipulated intervention of baroreflex modulation on cardiac autonomic outflows (Goldstein et al., 2011). This perspective further confirmed the effectiveness of QCT training on facilitating pilots’ psychophysiological state through baroreflex regulation. Therefore, the research question 2: “What effects does psychophysiological coherence practice have on pilots’ resilience and wellbeing?” was solved. HRV-biofeedback QCT can improve psychophysiological coherence and thereby increase pilots’ resilience and wellbeing. Increased post-training SDNNs, normalized LF power, and LF/HF ratio indicate significant improvement of stress management capacity and SNS activities via ANS control and baroreflex modulation. These findings demonstrate the effectiveness of HRV-biofeedback QCT training in improving psychophysiological coherence, which confers real-time and post-practice benefits of optimal energy utility and self-regulation in challenging situations during pandemic.

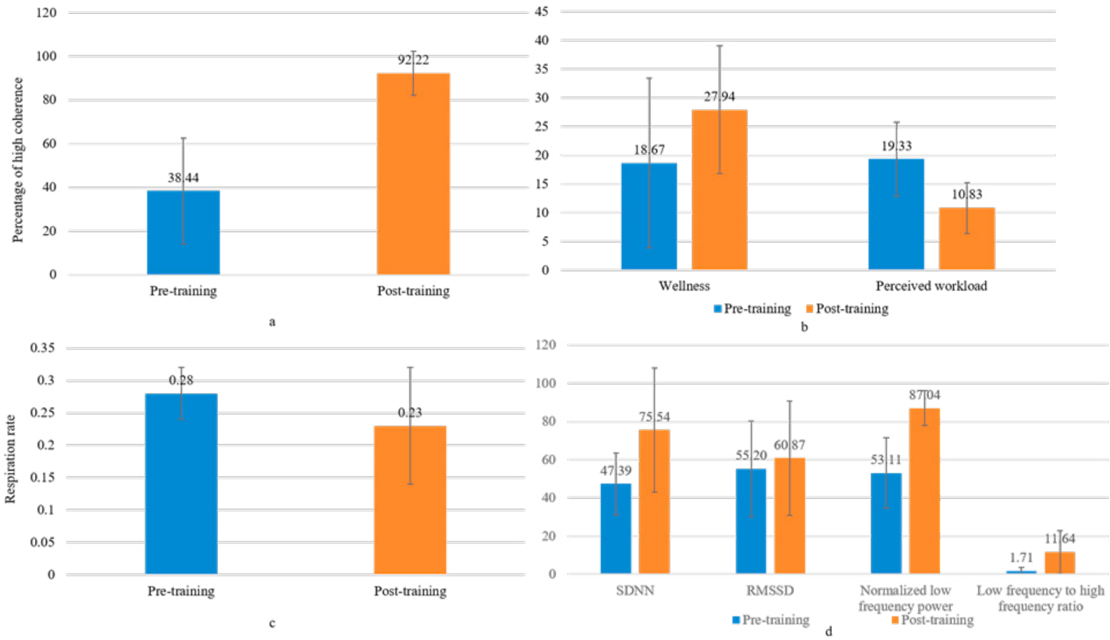

Fig. 2. The differences of psychophysiological coherence, perceived stress, wellness, respiration rate, and HRV parameters between pre-training and post-training of QCT based on HRV-biofeedback technique

5. Conclusion

The outbreak of COVID-19 pandemic induced multiple risks to commercial pilots including both psychological and physical health issues, presenting as threats affecting pilots' perceived stress and wellbeing. This research applied QCT biofeedback as an intervention to increase pilots' resilience and wellbeing, as well as facilitate cognitive process to cope with the negative influence caused by pandemic. The findings of empirical study demonstrated significant benefits of a short session of QCT based on HRV-biofeedback technique on pilots' cognitive functioning and psychological resilience by improving their psychophysiological coherence. HRV-biofeedback QCT training can be an effective intervention for aviation authorities and airline operators to develop peer support programs for pilots to increase psychophysiological resilience and wellbeing. This may be particularly beneficial given the various challenges presented to pilots on the preparation for return to normal operations.

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Declaration of Interest

The authors declared that they have no commercial or associative interest that represents a conflict of interest in connection with the work submitted.

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