STRESS
2024, VOL. 27, NO. 1, 2361253
https://doi.org/10.1080/10253890.2024.2361253

Taylor & Francis
Taylor & Francis Group

RESEARCH ARTICLE

OPEN ACCESS

Check for updates

Practice effects of a breathing technique on pilots' cognitive and stress associated heart rate variability during flight operations

Jingyi Zhang, Wen-Chin Li, Graham Braithwaite and James Blundell

Safety and Accident Investigation Centre, Cranfield University, Bedfordshire, UK

ABSTRACT

Commercial pilots endure multiple stressors in their daily and occupational lives which are detrimental to psychological well-being and cognitive functioning. The Quick coherence technique (QCT) is an effective intervention tool to improve stress resilience and psychophysiological balance based on a five-minute paced breathing exercise with heart rate variability (HRV) biofeedback. The current research reports on the application of QCT training within an international airline to improve commercial pilots' psychological health and support cognitive functions. Forty-four commercial pilots volunteered in a one-month training programme to practise self-regulated QCT in day-to-day life and flight operations. Pilots' stress index, HRV time-domain and frequency-domain parameters were collected to examine the influence of QCT practice on the stress resilience process. The results demonstrated that the QCT improved psychophysiological indicators associated with stress resilience and cognitive functions, in both day-to-day life and flight operation settings. HRV fluctuations, as measured through changes in RMSSD and LF/HF, revealed that the resilience processes were primarily controlled by the sympathetic nervous system activities that are important in promoting pilots' energy mobilization and cognitive functions, thus QCT has huge potential in facilitating flight performance and aviation safety. These findings provide scientific evidence for implementing QCT as an effective mental support programme and controlled rest strategy to improve pilots' psychological health, stress management, and operational performance.

ARTICLE HISTORY
Received 15 December 2023
Accepted 22 May 2024

KEYWORDS
Stress Resilience; Psychophysiological Intervention; Heart Rate Variability; Quick Coherence Technique; Aviation Safety Management

1. Introduction

Pilots' cognitive workload and psychological stress are regarded as determinant factors of flight performance and aviation safety, due to their detrimental impact on the pilot's cognitive functions and task performance (Marin et al., 2011). Therefore, airline pilots' mental health and psychological states have been brought to the forefront (BEA, 2016). The Federal Aviation Administration (FAA, 2021) introduced the consideration of psychological conditions and mental health in the medical certification of commercial pilots, whilst commercial airlines have focused on improving pilots' mental health through the lens of crew fatigue and alertness management (Cahill et al., 2021). However, psychological issues and well-being detriments related to chronic and accumulated stress are not properly addressed within existing airline safety management systems due to pilots' concerns about losing their medical certification and jobs (Vuorio & Bor, 2020). In this study, the implementation of a psychological intervention strategy within an international airline, based on the quick coherence technique (QCT), was investigated to determine its effects on commercial pilots' heart rate variability (HRV) biomarkers associated with stress resilience and cognitive function in both day-to-day life and flight operations.

QCT is a powerful technique based on heart-focused breathing to regulate individuals' respiration rate to approximately six to ten breaths per minute, thus improving the autonomic nervous system (ANS) balance for stress resilience and emotional regulation (Li et al., 2023a; McCraty & Zayas, 2014). Widdicombe and Sterling (1970) noted a direct association between breathing and the ANS activities that control complex psychophysiological interactive mechanisms. Previous research also examined the modification effects of paced breathing techniques on ANS activities related to psychological well-being and emotional regulation as a means to improve mental/physical health and stress resilience (Zaccaro et al., 2018). Psychological resilience is a dynamic regulation process in which individuals deal with traumatic events successfully and maintain cognitive function after exposure to severe stress (Bonanno et al., 2011). HRV serves as a promising biomarker of resilience to reflect the flexibility and efficiency of physiological, emotional, and cognitive responses to ANS-governed stressors (Perna et al., 2020; Sgoifo et al., 2021). According to the polyvagal theory, stress response and resilience are complex integrative processes supported by the ANS regulations, in which a sympathetic-adrenal system increases metabolic output and an inhibitory vagal system

CONTACT Wen-Chin Li wenchin.li@cranfield.ac.uk Safety and Accident Investigation Centre, Cranfield University, Martell House, Cranfield, Bedfordshire, MK43 0TR, UK

promotes immobilization behaviors (Porges, 2001). Therefore, to test the QCT training effect on commercial pilots' biomarkers associated with stress resilience and cognitive function, HRV measurements were applied as promising biomarkers to investigate the ANS regulation process. Three hypotheses are proposed as follows:

> H1: QCT significantly influences commercial pilots' stress index in day-to-day life and flight operations.
>
> H2: QCT significantly influences commercial pilots' time-domain HRV in day-to-day life and flight operations.
>
> H3: QCT significantly influences commercial pilots' frequency-domain HRV in day-to-day life and flight operations.

2. Materials and methods

2.1. Participants

Forty-four commercial pilots (6 females and 38 males) with various flight experiences between 3,000 and 20,000 hours ($M = 10{,}811.25, SD = 4{,}736.59$) were recruited. Their ages were between 29 to 60 years old ($M = 44.75, SD = 7.07$) and their service years in this international airline ranged from 2 to 32 years ($M = 14.41, SD = 8.26$). Participants required a validated commercial pilot license (CPL) and were excluded if they were currently on any medical issues either physical or mental that might interfere with the results of the study. Each participant was required to sign a consent form, which provided detailed information related to the experiment and the content of the data collection. Participants were also informed that they had the right to terminate and withdraw from the experiment at any stage, even after the data collection phase. This research followed the Data Protection Act under the UK's general data protection regulation (GDPR). The research ethical proposal was submitted and approved by the research ethics committee in advance (CURES/12817/2021 & CURES/15728/2022). All data and research materials were available at https://osf.io/ayvf2/?view_only=a0927a3d393d49a98184b133640a79e3.

2.2. Quick coherence technique

Psychophysiological coherence represented the degree of order, harmony and stability occurring in the ANS consisting of sympathetic and parasympathetic systems. A coherent HRV pattern indicated effective cognitive and physical functions, related to the ease of energy and information processing (McCraty & Zayas, 2014). QCT was based on a paced breathing exercise (six to ten cycles per minute) with real-time HRV biofeedback to alter participants' cardiac activities and visualize HRV moment-to-moment fluctuation. The Inner Balance device and the Inner Balance Application (APP) were used to carry out the HRV biofeedback QCT training. The Inner Balance device was a lightweight Bluetooth sensor that measures psychophysiological data and provides real-time HRV biofeedback information on the Inner Balance APP via connection with personal mobile devices (iOS/Android).

2.3. Procedures

The QCT training programme was carried out in an international airline to improve commercial pilots' psychological health and stress management. During the one-month self-regulated practice, participants were encouraged to practise a five-minute QCT three times per day in everyday life, and as often as possible during controlled rest breaks in flight operations using the Inner Balance™ device. Before each five-minute practice of QCT, an additional five minutes of data was collected as a psychophysiological baseline. Pilots were instructed during baseline to follow their normal patterns of flight deck or daily life activity, respective to the environmental context of the current QCT practice being undertaken. The in-flight QCT practice was in accordance with the airline's safe operating practices of controlled rest policy to ensure that operational safety was always the priority.

2.4. Measures

2.4.1. Heart rate variability

HRV offered a unique window to observe the psychophysiological states related to stress resilience and cognitive functioning (Perna et al., 2020). HRV data were measured via the photoplethysmography (PPG) ear sensor of the Inner Balance device. The Inner Balance device had 80 hours of battery life and a 125-hertz sample rate to measure HRV data 125 times per second. This lightweight and compact device could be easily applied in any situation without additional processing on participants' skin or hair. In previous research, the Inner Balance device was widely utilized to investigate the neuro-cardiac function and ANS dynamics via HRV measurements in operational scenarios (Li et al., 2023a; 2023b; McCraty & Atkinson, 2012).

2.4.2. Data processing

Participants' baseline measures and QCT practice recordings were stored in the HeartCloud platform, which could be accessed by pre-registered usernames and passwords via the EmWave® software. The collected HRV data were processed by EmWave software to export as the raw moment-to-moment inter-beat interval (IBI) data (recorded every 500 milliseconds). The raw IBI data were further imported into Kubios software. The R-wave time instants were autonomically detected by the built-in QRS detection algorithm, which represented an advanced detection algorithm based on the Pan–Tompkins algorithm (Pan & Tompkins, 1985). For each beat, the quartile deviation of the 90 surrounding beats was calculated and multiplied by factor 5.2 (Tarvainen et al., 2021). Beats within this range covered 99.95% of all beats if the RR series is normally distributed. However, the RR interval series was not often normally distributed, and thus, also some of the normal beats exceeded the threshold. Therefore, the artifact beats in the IBI time series were detected and corrected by an accurate and robust algorithm proposed by Lipponen and Tarvainen (2019). Detected artifact beats, including missing, extra, misaligned, and ectopic beats, were corrected by replacing corrupted RR times with interpolated RR values;

missed beats were corrected by adding new R-wave occurrence time; extra beats were corrected by removing extra R-wave detection and recalculating the RR interval series. In this research, the corrected beats percentage was from 0 to 10.81.

2.4.3. HRV measurements

The effects of QCT training upon a global psychophysiological indicator (stress index), one HRV time-domain parameter (RMSSD), and one HRV frequency-domain parameter (LF/HF) were investigated. The stress index was the square root of Baevsky's stress index, which was a geometric measure of HRV reflecting cardiovascular system stress calculated by the variation scope of RR intervals (Baevsky & Chernikova, 2017). RMSSD was the square root of the mean squared differences between successive RR intervals, which was a robust measure of the PNS activation state (Otzenberger et al., 1998). LF/HF was the ratio of low-frequency (0.04–0.15 hertz) to high-frequency (0.15–0.4 hertz) power, which was widely used as an indicator of sympathetic nervous modulation (Pagani et al., 1986). However, LF/HF was becoming increasingly controversial because of its non-linear and ambiguous association with the SNS activation and sympathovagal balance psychophysiological state (Billman, 2013; Von Rosenberg et al., 2017).

2.5. Statistical analysis

Generalized linear mixed model (GLMM) analysis was conducted to interpret the effects of QCT practice, in day-to-day life and flight operation environments, upon commercial pilots' HRV measurements. GLMM analysis was conducted using *fitglme()* within the MATLAB (2022b) Statistical Toolbox, and followed the best-practice guidance by Meteyard and Davies (2020). All analyses included two fixed effects for *session type* (two levels: baseline measure vs QCT practice) and *practice location* (two levels: day-to-day life vs flight operation). The random effect structure for each analysis was determined by comparing Akaike's information criterion (AIC) values of candidate maximal models that contained varying complexities of random by-participant and by-session slopes (for each fixed effect) and intercepts (Diggle et al., 2002). The model containing the random effect structure with an AIC value equal to 0 was chosen as the model which subsequent fixed effect analyses were based upon. Including by-participant random intercepts and slopes in this way accounted for possible variation within HRV measurements that were associated with participant individual differences (gender, age, flight experience). All HRV required a natural logarithm transformation for GLMM analysis assumptions to be met (residuals normally distributed and exhibiting homoscedasticity). All models converged.

Likelihood ratio tests (LRT) tests were used to analyze fixed effects. Here, a Chi-Square ($\chi2$) approach of model comparison was implemented where interaction and main effect terms were verified by comparing models with and without relevant terms (Winter, 2013). The size and confidence of significant fixed effects were described using exponential converted (to account for previous logarithm transformation) model slope coefficients (β) and confidence interval (CI).

3. Results

3.1. Sample characteristics

During the one-month self-regulated QCT practice, 5193 sets of psychophysiological indicators and HRV parameters were collected from 44 commercial pilots. The quantity of practice session data contributed by individual participants ranged from between 11 to 226 (M = 98.26, SD = 52.73). This distribution was normal (Shapiro-Wilk test, p = .231), and the absence of outliers was observed in box plots. Thus, it is unlikely the results could be strongly influenced by a subset of participants providing either extreme (high or low) data contributions. There were 2410 baseline measures and 2469 QCT practices in day-to-day life; in flight operations, 143 baseline measures and 144 QCT practices were collected during controlled rest breaks in long-haul flights. Descriptive results of commercial pilots' HRV measurements of baseline measures and QCT practices in day-to-day life and flight operations are shown in Table 1.

3.2 Quick coherence technique practice effects on stress index in day-to-day life and flight operations

GLMM results of QCT practice effect on commercial pilots' stress index were based on a random effect structure containing *participant ID* random intercepts and slopes for both fixed effects, as described in Equation 1. The same random effect

Table 1. Descriptive results of commercial pilots' HRV measurements. Grouped by *practice location* (day-to-day life vs flight operation) and *session type* (baseline measure vs QCT practice).

	Location	Session	N	M	SD	Medians	Minimum	Maximum
Stress index	Day-to-day life	Baseline	2410	10.08	4.04	9.28	3.41	36.41
		QCT	2496	8.08	3.7	7.24	2.73	27.29
	Flight operation	Baseline	143	8.86	3.36	8.29	4.16	23.21
		QCT	144	7.19	2.79	6.8	2.92	17.41
RMSSD (ms)	Day-to-day life	Baseline	2410	50.75	25.03	45.35	11.83	195.49
		QCT	2496	52.88	28.98	45.3	8.61	241.95
	Flight operation	Baseline	143	57.02	25.13	53.12	12	128.54
		QCT	144	58.34	27.24	52.91	15.46	161.82
LF/HF	Day-to-day life	Baseline	2410	2.34	2.84	1.72	0.06	68.58
		QCT	2496	13.23	12.51	9.41	0.03	120.21
	Flight operation	Baseline	143	2.43	1.84	1.91	0.22	11.49
		QCT	144	11.75	11.37	8.53	0.35	60.37

structure was required for the time-domain HRV GLMM results presented in 3.3 below.

$$\begin{aligned} \mathit{Stress\ Index} \sim & \ \mathit{Session\ Type} * \mathit{Practice\ Location} \\ & + (\mathit{Practice\ Location} \,|\, \mathit{Participant\ ID}) \\ & + (\mathit{Session\ Type} \,|\, \mathit{Participants\ ID}) \end{aligned} \tag{1}$$

The model's total explanatory power was good, adjusted $R^2 = 0.56$. Main effects were found for *session type*, $\chi^2(1) = 46.01$, $p < .001$, and *practice location*, $\chi 2(1) = 4.81$, $p = .026$. The *session type* main effect represented a decrease in stress index during QCT practice compared to the baseline measure, $\beta = -2.4092$, 95%CI=−3.00 ~ −1.85. Therefore, '*H1: QCT significantly influences commercial pilots' stress index in day-to-day life and flight operations*' was supported. Furthermore, a smaller effect of *practice location* showed that stress index responses were lower during flight operations compared to day-to-day life, $\beta = -0.82$, 95%CI=−1.59 ~ −0.09. There was no significant interaction effect between *session type* and *practice location*, $\chi 2(1) = 2.40$, $p = .121$. GLMM model estimates for stress index were shown in Figure 1.

3.3. Quick coherence technique practice effects on time-domain heart rate variability in day-to-day life and flight operations

For RMSSD GLMM analysis the random effect structure was the same as the stress index analysis described in Equation 1. The RMSSD model, whilst exhibiting good explanatory power (adjusted R2 = 0.51) did not contain a main effect for session type, $\chi 2(1) = 0.65$, $p = .419$, or practice location, $\chi 2(1) = 2.81$, $p = .094$. Similarly, there was no significant interaction effect between session type and practice location, $\chi 2(1) = 1.75$, $p = .186$.

Therefore, '*H2: QCT significantly influences commercial pilots' time-domain HRV in day-to-day life and flight operations*' was rejected: the QCT practice had no significant influence on pilots' time-based HRV measured via RMSSD neither in day-to-day life nor flight operations. GLMM model estimates for the time-domain HRV analysis were shown in Figure 2.

3.4. Quick coherence technique practice effects on frequency-domain heart rate variability in day-to-day life and flight operations

The random effect structure of LF/HF GLMM analysis was the same as the stress index and HRV time-domain parameters analysis described in Equation 1. The selected model's total explanatory power was good, adjusted $R^2 = 0.61$. A main effect was found for *session type*, $\chi 2(1) = 81.39$, $p < .001$, which reflected an increase in LF/HF during QCT practice compared to the baseline measure, $\beta = 6.04$, 95%CI = 4.68 ~ 7.68. No significant main effect of *practice location* was found, $\chi 2(1) = 0.83$, $p = .363$. There was also no significant interaction effect between *session type* and *practice location*, $\chi 2(1) = 0.78$, $p = .376$.

Therefore, '*H3: QCT significantly influences commercial pilots' frequency-domain HRV in day-to-day life and flight operations*' was supported. GLMM model estimates for the frequency-domain HRV analysis were shown in Figure 3.

4. Discussion

QCT training as a practical intervention tool could improve the efficiency of respiratory gas exchange and blood pressure control through baroreflex and ANS activities, which could support psychological resilience and cognitive functioning processes when facing stressful situations (Gevirtz, 2013; Lehrer et al., 2020). In the current study, the effect of short-term QCT practice on HRV parameters as ANS activity biomarkers in day-to-day life and flight operations was investigated. The primary finding from a GLMM analysis was a significant effect of *session type* across a range of HRV and ANS biomarkers, alongside an absence of a *session type* by *practice*

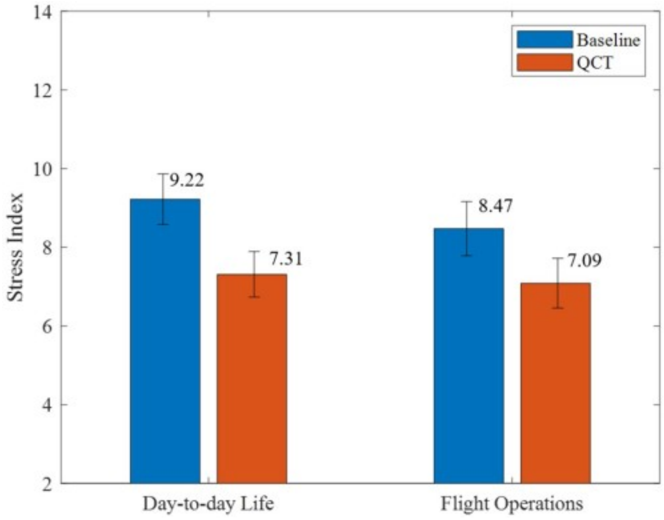

Figure 1. Comparisons of stress index between baseline measure and QCT practice in day-to-day life and flight operations based on GLMM model estimates (error bars present model estimate 95% CIs).

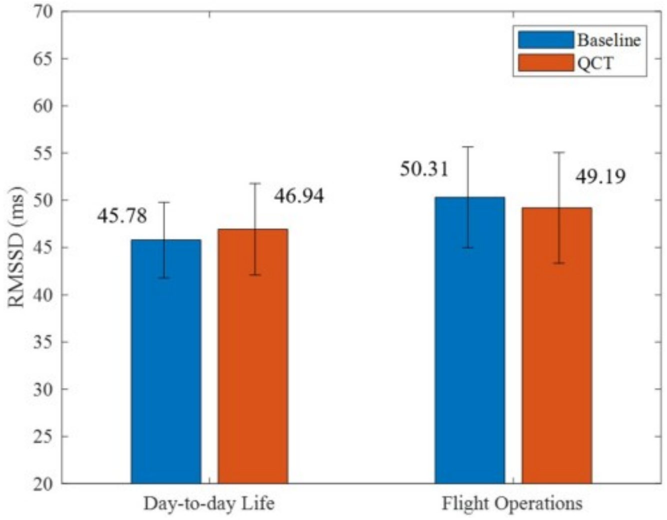

Figure 2. Comparisons of HRV time-domain parameter of RMSSD between baseline measure and QCT practice in day-to-day life and flight operations based on GLMM model estimates (error bars present model estimate 95% CIs).

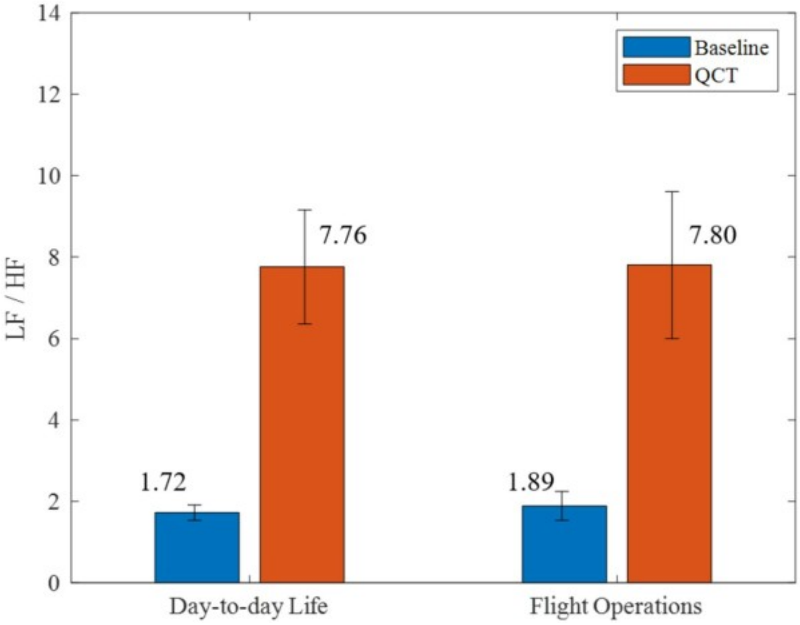

Figure 3. Comparisons of HRV frequency-domain parameter of LF/HF between baseline measure and QCT practice in day-to-day life and flight operations based on GLMM model estimates (error bars present model estimate 95% CIs).

location interaction. Thus, indicating the equal effectiveness of QCT training in facilitating pilots' stress resilience and cognitive functioning processes in day-to-day life and flight operations. Furthermore, the selection of random effect structures (based on AIC comparisons) demonstrated the requirement to include participant individual differences (which could characterize the effect of gender, age, and flight experience) as a random effect, in some form, for all HRV analyses. Suggesting the significant role individual differences have in influencing the QCT practice effects on HRV measurements. The different fluctuations of HRV time-domain and frequency-domain parameters also reflected the dynamic stress resilience process of cardiac autonomic nerve control, facilitated by the paced-breathing-based QCT training. The scientific evidence of developing QCT training as a peer support programme and controlled rest strategy to facilitate pilots' stress resilience and cognitive functioning was demonstrated here.

4.1. Quick coherence technique training supports commercial pilots' stress management

The heart-focused breathing technique was the key strategy of QCT to improve emotional and mental self-regulation. When performing QCT practice, pilots were recommended to direct their attention to the heart area and breathe deeply, around ten cycles in one minute. Previous research demonstrated that the 8-cycle paced breathing exercise could significantly decrease individuals' stress and anxiety (Clark & Hirschman, 1990). In the current study, the effects of the 12-cycle breathing-paced QCT training on commercial pilots' stress levels were also investigated: Baevsky's stress index showed a significant reduction after QCT practice in both day-to-day life and flight operations (Figure 1). Moreover, preliminary research has confirmed the long-term QCT training effects on decreasing commercial pilots' perceived stress and improving well-being (Li et al., 2023b). Naik et al. (2018) also indicated that a 12-week slow deep breathing exercise could effectively decrease perceived stress. This four-week self-regulated QCT training demonstrated consistent effectiveness in decreasing commercial pilots' perceived stress levels after regular practice, in which gradually increased resilience could be accumulated to address not only the daily stressors but also applicable task-relevant stress in flight operations with long-standing benefits.

4.2. Quick coherence technique practice promotes the sympathetic-controlled stress resilience process

Baevsky's stress index was calculated based on the changed proportion of HRV pulse fluctuation in the RR interval time series by electrocardiogram framework, and thus to objectively characterize the activities of individuals' cardiac autonomic functions and stress resilience (Baevsky & Chernikova, 2017; Sahoo et al., 2019). Through the baroreflex action and breathing regulation by QCT training, the brain controlled the heart directly through the sympathetic and parasympathetic branches of the ANS functions (Adjei et al., 2019). Based on the classical framework for short-term HRV interpretation: the power of the high-frequency HRV component and its surrogate indices RMSSD reflected PNS activity, while the relative power of the low-frequency component and LF/HF reflected SNS activity (Hayano et al., 1991; Hayano & Yuda, 2019). The GLMM fitting results indicated that the QCT practice could significantly increase commercial pilots' LF/HF, while no statistical change in RMMSD was found (Figures 2 & 3). These HRV parameters were observed to be a strong measure for stress detection in short-term analysis and closely associated with stress attenuation and psychophysiological resilience (Pereira et al., 2017; Roberto et al., 2018; Usui & Nishida, 2017). The fluctuation pattern of HRV indices indicated the QCT influence mechanism on ANS functions that mainly promotes the SNS activation to mobilize adequate cognitive resources in the dynamic resilience process but barely influences PNS activities for resting vagal control. By this means, pilots could effectively recover from the accumulated stress and workload while not causing sleepiness and mind wandering in further actions or tasks. In sum, these findings proved the effective regulation of QCT on SNS activation ANS balance for cognitive resources mobilization and allocation to promote the dynamic resilience process.

4.3. The controversy of LF/HF regarding stress response and resilience intervention

Previous research noted that heightened occupational stress is associated with reduced PNS activation and increased SNS activities, marked by an increase in LF/HF (Järvelin-Pasanen et al., 2018). However, in the current research, the LF/HF was found to be increased during the stress resilience process. Saboul et al. (2014) demonstrated that LF/HF is negatively correlated to respiration rate. Steffen et al. (2021) indicated that the paced breathing technique as a psychotherapy could significantly increase LF/HF and reduce negative emotional experiences. This point was further confirmed in the current study by higher LF/HF and lower stress index after the 5-minute QCT practice in both everyday life and flight deck. Hence, it can be proposed that LF/HF is a mediating factor in the dynamic resilience process regulated by the breathing technique that influences sympathetic activities and autonomic balance. Due to the complexity of the interaction mechanism of respiration regulation on cardiac autonomic activities, the association between LF/HF and ANS balance could be non-linear and ambiguous (Billman, 2013). Von Rosenberg et al. (2017) also noted that the ANS balance cannot be accurately revealed by LF/HF alone, as the correspondence between the LF/HF ratio and psychophysiological states was not constant. However, Usui and Nishida (2017) proposed that the LF/HF increased with SNS activities for a quick recovery from mental stress. These empirical pieces of evidence demonstrated the diverse fluctuation patterns of the LF/HF in stress response and resilience intervention processes regulated by complex ANS activation mechanisms: an increased LF/HF could occur in both coherence training practices based on paced breathing technique (Zhang et al., 2022), but also along with stressor/workload stimuli (Skibniewski et al., 2015).

4.4. Quick coherence technique improves stress resilience and cognitive performance in flight operations

The equal practice effectiveness in daily life and flight operations indicated the huge potential for implementing QCT as an effective and efficient controlled rest strategy. QCT has been proven useful in coping with accumulated fatigue in air traffic control operations (Li et al., 2023b). In the current study, the improved HRV state demonstrated coherent neuro-cardiac functions and balanced ANS dynamics, thus reflecting higher cognitive performance and psychological resilience (Schubert et al., 2009; Thayer et al., 2010). When ANS activity creates oscillations through the cardiorespiratory neuronal network, causing periodic fluctuation in the HRV state, the cognitive process and stress response could be regulated by sympathetic energy mobilization and parasympathetic restorative function (Hernando et al., 2016; Spyer, 1994). Previous research indicated that a balanced autonomic reactivity -marked by increased SNS activation and deactivating PNS tone - allows individuals to achieve the best ‘fight or flight’ response and quick adaptive recovery for stress management and improved executive functioning, including decision-making skills in challenging situations (Alacreu-Crespo et al., 2018; Williams et al., 2009). Flight operations represented a ‘fight or flight’ scenario where pilots face multiple stressors in the form of time-limited safety-critical tasks. In the current study, a five-minute QCT practice on the flight deck provided pilots with more cognitive resources by triggering sympathetic activities to address their perceived stress and accumulated workload related to flight tasks (De Sampaio Barros et al., 2018). Furthermore, according to the coping competition model proposed by Salvador and Costa (2009), an active coping response pattern characterized by activated sympathetic functions was associated with positive emotional states and increasing success probability in performing challenging tasks. Therefore, the upregulated SNS activation and enhanced ANS balance via QCT practice during the controlled rest breaks in flight operations could not only facilitate pilots’ fatigue and stress resilience process but also improve the decision-making skills and flight performance to cope with the potential risks and emergencies encountered in flight operations.

4.5. Practical and theoretical implications

The current study carried several implications, both theoretically and practically. First, the current empirical research investigated the effects of QCT on commercial pilots’ stress/fatigue management through a five-minute quick practice and long-term self-regulated training method. The findings of this study were consistent with previous research, which demonstrated evidence of QCT’s long-standing benefits (Li et al., 2023a). The current empirical findings could support aviation authorities and airlines in developing effective pilot peer support programs based on regular QCT practice to cope with cumulative stress and distress, as well as improve well-being. Moreover, the significant influence of QCT practice on pilots’ stress resilience and cognitive-relevant biomarkers provided an innovative controlled rest strategy; Supporting pilots to manage task-relevant stressors and workload, as well as the replenishment of cognitive resources to improve flight performance during long-haul flights. Second, the investigation of the HRV fluctuation in the dynamic stress resilience process could supplement the framework of the ANS control mechanisms within stress response and resilience intervention processes. Neuro-cardiac responses to external stressor stimuli are a complex process varying with individual differences and slight environmental changes. The current study illustrated the HRV fluctuation pattern regulated by SNS activation primarily in an intervened resilience process by the paced breathing technique. Especially for the controversial LF/HF parameter, this study provided insight into the research of stress detection and intervention research in terms of HRV measurements and ANS dynamics.

4.6. Limitations and future work

The current study demonstrated that coherence training based on the breathing paced technique can facilitate pilots' sympathetic activities and improve stress resilience. However, there were still a few constraints that should be noted.

Firstly, there is a controversy related to the reliability of PPG-measured HRV: whether PPG can be an alternative to ECG in HRV analysis given the sensitivity to pulse transients and artifacts in the breathing interval of PPG (e.g., Hemon & Phillips, 2016). However, an increasing number of studies further investigated the agreement between HRV taken by ECG and PPG (e.g., Morelli et al., 2018; Schäfer & Vagedes, 2013); the results demonstrated sufficient accuracy of using PPG to measure short-term HRV reflecting coupling effects between respiration and the cardiovascular system for healthy subjects. In the current study, artifact beats were corrected by an accurate and robust algorithm to avoid the overestimation of PPG-measure HRV caused by artifacts. Future research would consider using electrocardiogram (ECG) for HRV measurement and analysis.

Secondly, this research consisted of an open-label, single-arm design. Hence, together with the voluntary sampling technique, a bias in the QCT training effect could be possibly due to different levels of participant motivation and engagement. Furthermore, the QCT practice and HRV measurements were during different time points, which might contribute to the fluctuation of psychophysiological data. The practice time and frequency should be regulated in future QCT training programmes. Also, a control group without any psychophysiological intervention should be involved in future studies to compare and investigate the effectiveness of QCT practice.

Thirdly, based on 44 commercial pilots as participants, there were only 185 datasets of baseline and QCT practice collected while pilots were on duty in the flight deck compared to 2722 in day-to-day life. The unequal sample size might reduce the statistical power and skew the results. Larger samples and a larger collection of flight deck data would be considered in further studies to improve the validity of research findings.

Fourthly, the LF/HF was a controversial indicator to reflect the purely ANS balance. The complexity and ambiguity of the LF/HF ratio also lie in its close association with personality traits, and its effectiveness as a stress biomarker can be influenced by the differential application of stress-coping strategies as well as the different stressor types (Kim et al., 2014; Schubert et al., 2009). Further studies would categorize different stressors and flight phases to investigate the stress resilience effects of QCT training on specific stressor types and flight tasks. The fluctuation of HRV indices, especially the LF/HF in a dynamic stress resilience process, as well as its complex association with ANS balance, could be further investigated.

Furthermore, although short-term measures of frequency-domain HRV via a 5-minute recording have been widely used in recent research for investigating cognitive- and stress-relevant responses (e.g., Liu et al., 2013; May et al., 2021; Yang et al., 2018), there were still arguments related to the reliability of 5-minute HRV measurements on the frequency domain (Malik, 1996). Thus, the interpretation of the frequency-based measures required caution, and it was recommended that the longer-term studies of QCT upon frequency-domain HRV be conducted in the future.

Finally, the in-flight QCT practice sessions were collected during the controlled rest breaks in which pilots can implement work break strategies to recover from fatigue/stress and sustain alertness during long-haul flights (Caldwell, 2005). There was qualitative feedback confirming the superior fatigue management effects of QCT practice compared to the traditionally controlled rest strategies, such as chatting and walking around in the flight deck (Li et al., 2023a). A quantitative study should compare the effectiveness of conventional short-term break strategies and QCT practice on pilots' stress and fatigue resilience in flight operations.

5. Conclusion

The psychological health and stress management of commercial pilots have been brought to the forefront of attention due to their significant influence on aviation operational safety. Commercial pilots are suffering from physical, mental, and social health difficulties, which can contribute to decreased well-being and increased risk of aircraft-assisted suicide (Cullen et al., 2021; Kioulepoglou et al., 2024; Kioulepoglou & Blundell, 2022). Therefore, the QCT training based on HRV biofeedback and paced breathing technique is proposed in the current study to improve commercial pilots' stress resilience. This empirical research demonstrated that QCT practice in both day-to-day life and flight deck effectively reduces stress index measurements through the heart-focused breathing technique. The HRV fluctuation reflects a dynamic stress resilience process regulated by sympathetic activities to facilitate energy mobilization and attention reservation. These benefits not only improve emotional regulation to cope with daily stressors but also have huge potential to promote cognitive function and flight performance to ensure aviation safety. By understanding the full implications of QCT training, the aviation industry can move forward by developing effective peer support programmes and training syllabus to improve pilots' psychological well-being, stress management, and aviation safety. Furthermore, the positive effects of in-flight QCT practice demonstrate a potential application of a five-minute QCT session as an efficiently controlled rest strategy to improve pilots' stress resilience and operational performance in long-haul flights.

Acknowledgements

The corresponding author of this research was supported by the Higher Education Innovation Fund (HEIF 2021-2022). The authors would like to express special thanks to Captain Ben Whitworth, and his team for their participation and contribution to this research. Their support and the enthusiasm of practicing quick coherence technique in the flight deck and day-to-day life were invaluable in facilitating the authors' research efforts.

Disclosure statement

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

Notes on contributors

Jingyi Zhang, PhD, Research and Teaching Fellow, Safety and Accident Investigation Center, Cranfield University, UK. PhD in Transport System, Safety and Accident Investigation Center, Cranfield University, UK.

Wen-Chin Li, PhD C.ErgHF FCIEHF, Senior Lecturer, Safety and Accident Investigation Center, Cranfield University, UK. PhD in Aviation Human Factors, College of Aeronautics, Cranfield University, UK.

Graham Braithwaite, PhD FRAeS, Professor and Head of Transport Theme, Cranfield University, United Kingdom. PhD in Aviation Safety Management, Loughborough University, United Kingdom

James Blundell, PhD, Senior Lecturer, Safety and Accident Investigation Center, Cranfield University, UK. PhD in Cognitive Psychology, School of Psychology, Birmingham University, UK.

ORCID

Jingyi Zhang http://orcid.org/0000-0001-7600-7119
Wen-Chin Li http://orcid.org/0000-0002-8825-3701
Graham Braithwaite http://orcid.org/0000-0002-5120-755X
James Blundell http://orcid.org/0000-0002-4029-0773

Data availability statement

Data supporting this study are openly available from the Cranfield Online Research Data (CORD) repository at: doi:10.17862/cranfield.rd.24494665

References

Adjei, T., Von Rosenberg, W., Nakamura, T., Chanwimalueang, T., & Mandic, D. P. (2019). The classA framework: HRV based assessment of SNS and PNS dynamics without LF-HF controversies. *Frontiers in Physiology*, *10*, 1. https://doi.org/10.3389/fphys.2019.00505

Alacreu-Crespo, A., Costa, R., Abad-Tortosa, D., Salvador, A., & Serrano, M. Á. (2018). Good decision-making is associated with an adaptive cardiovascular response to social competitive stress. *Stress (Amsterdam, Netherlands)*, *21*(6), 528–11. https://doi.org/10.1080/10253890.2018.1483329

Baevsky, R. M., & Chernikova, A. G. (2017). Heart rate variability analysis: physiological foundations and main methods. *Cardiometry*, *10*, 66–76. https://doi.org/10.12710/cardiometry.2017.6676

BEA. (2016). Final report: accident on 24 March 2015 at Prads-Haute-Bléone (Alpes-de-Haute-Provence, France) to the Airbus A320-211 registered D-AIPX operated by Germanwings, French Civil Aviation Safety Investigation Authority, Le Bourget Cedex, France. Retrieved from https://bea.aero/uploads/tx_elydbrapports/BEA2015-0125.en-LR.pdf

Billman, G. E. (2013). The LF/HF ratio does not accurately measure cardiac sympatho-vagal balance. *Frontiers in Physiology*, *4*, 26. https://doi.org/10.3389/fphys.2013.00026

Bonanno, G. A., Westphal, M., & Mancini, A. D. (2011). Resilience to loss and potential trauma. *Annual Review of Clinical Psychology*, *7*(1), 511–535. https://doi.org/10.1146/annurev-clinpsy-032210-104526

Cahill, J., Cullen, P., Anwer, S., Wilson, S., & Gaynor, K. (2021). Pilot work related stress (WRS), effects on wellbeing and mental health, and coping methods. *The International Journal of Aerospace Psychology*, *31*(2), 87–109. https://doi.org/10.1080/24721840.2020.1858714

Caldwell, J. A. (2005). Fatigue in aviation. *Travel Medicine and Infectious Disease*, *3*(2), 85–96. https://doi.org/10.1016/j.tmaid.2004.07.008

Clark, M. E., & Hirschman, R. (1990). Effects of paced respiration on anxiety reduction in a clinical population. *Biofeedback and Self-Regulation*, *15*(3), 273–284. https://doi.org/10.1007/BF01011109

Cullen, P., Cahill, J., & Gaynor, K. (2021). A qualitative study exploring well-being and the potential impact of work-related stress among commercial airline pilots. *Aviation Psychology and Applied Human Factors*, *11*(1), 1–12. https://doi.org/10.1027/2192-0923/a000199

De Sampaio Barros, M. F., Araújo-Moreira, F. M., Trevelin, L. C., & Radel, R. (2018). Flow experience and the mobilization of attentional resources. *Cognitive, Affective & Behavioral Neuroscience*, *18*(4), 810–823. https://doi.org/10.3758/s13415-018-0606-4

Diggle, P., Heagerty, P., Liang, K.-Y., & Zeger, S. (2002). *Analysis of longitudinal data* (2nd ed.). Oxford University Press.

FAA. (2021). Guide for Aviation Medical Examiners: Decision Considerations – Aerospace Medical Dispositions. Federal Aviation Administration (FAA), Washington, DC, USA. Retrieved from https://www.faa.gov/about/office_org/headquarters_offices/avs/offices/aam/ame/guide/app_process/exam_tech/item48/amd/gd/

Gevirtz, R. (2013). The promise of heart rate variability biofeedback: evidence-based applications. *Biofeedback*, *41*(3), 110–120. https://doi.org/10.5298/1081-5937-41.3.01

Hayano, J., & Yuda, E. (2019). Pitfalls of assessment of autonomic function by heart rate variability. *Journal of Physiological Anthropology*, *38*(1), 3. https://doi.org/10.1186/s40101-019-0193-2

Hayano, J., Sakakibara, Y., Yamada, A., Yamada, M., Mukai, S., Fujinami, T., Yokoyama, K., Watanabe, Y., & Takata, K. (1991). Accuracy of assessment of cardiac vagal tone by heart rate variability in normal subjects. *The American Journal of Cardiology*, *67*(2), 199–204. https://doi.org/10.1016/0002-9149(91)90445-Q

Hemon, M. C., & Phillips, J. P. (2016). Comparison of foot finding methods for deriving instantaneous pulse rates from photoplethysmographic signals. *Journal of Clinical Monitoring and Computing*, *30*(2), 157–168. https://doi.org/10.1007/s10877-015-9695-6

Hernando, A., Lazaro, J., Gil, E., Arza, A., Garzon, J. M., Lopez-Anton, R., de la Camara, C., Laguna, P., Aguilo, J., & Bailon, R. (2016). Inclusion of respiratory frequency information in heart rate variability analysis for stress assessment. *IEEE Journal of Biomedical and Health Informatics*, *20*(4), 1016–1025. https://doi.org/10.1109/JBHI.2016.2553578

Järvelin-Pasanen, S., Sinikallio, S., & Tarvainen, M. P. (2018). Heart rate variability and occupational stress—systematic review. *Industrial Health*, *56*(6), 500–511. https://doi.org/10.2486/indhealth.2017-0190

Kim, D., Koo, H., Lee, W., & Kim, M. (2014). Application and limitation of frequency domain, LF/HF component in heart rate variability as an acute stress index. *Proceedings of the International Conference on Biomedical Engineering and Systems (No. 128,* pp. 1–4). Prague, Czech Republic, 2014.

Kioulepoglou, P., & Blundell, J. (2022). Impact of COVID-19 on job satisfaction: The case of military and airline pilots. *The International Journal of Aerospace Psychology*, *32*(4), 183–202. https://doi.org/10.1080/24721840.2022.2071714

Kioulepoglou, P., Chazapis, S., & Blundell, J. (2024). A comparative analysis of job satisfaction among military and airline pilots: During, and post COVID-19. *Research in Transportation Business & Management*, *53*, 101103. https://doi.org/10.1016/j.rtbm.2024.101103

Lehrer, P., Kaur, K., Sharma, A., Shah, K., Huseby, R., Bhavsar, J., Sgobba, P., & Zhang, Y. (2020). Heart rate variability biofeedback improves emotional and physical health and performance: A systematic review and meta analysis. *Applied Psychophysiology and Biofeedback*, *45*(3), 109–129. https://doi.org/10.1007/s10484-020-09466-z

Li, W. C., Zhang, J., Braithwaite, G., & Kearney, P. (2023a). Quick coherence technique facilitating commercial pilots' psychophysiological resilience to the impact of COVID-19. *Ergonomics*, *66*(8), 1176–1189. https://doi.org/10.1080/00140139.2022.2139416

Li, W. C., Zhang, J., & Kearney, P. (2023b). Psychophysiological coherence training to moderate air traffic controllers' fatigue on rotating roster. *Risk Analysis: An Official Publication of the Society for Risk Analysis*, *43*(2), 391–404. https://doi.org/10.1111/risa.13899

Lipponen, J. A., & Tarvainen, M. P. (2019). A robust algorithm for heart rate variability time series artefact correction using novel beat classification. *Journal of Medical Engineering & Technology*, *43*(3), 173–181. https://doi.org/10.1080/03091902.2019.1640306

Liu, Q., Zhou, R., Oei, T. P., Wang, Q., Zhao, Y., & Liu, Y. (2013). Variation in the stress response between high-and low-neuroticism female undergraduates across the menstrual cycle. *Stress (Amsterdam, Netherlands)*, *16*(5), 503–509. https://doi.org/10.3109/10253890.2013.797958

Malik, M. (1996). Heart rate variability: Standards of measurement, physiological interpretation, and clinical use: Task force of the European Society of Cardiology and the North American Society for Pacing and Electrophysiology. *Annals of Noninvasive Electrocardiology*, *1*(2), 151–181. https://doi.org/10.1161/01.CIR.93.5.1043

Marin, M. F., Lord, C., Andrews, J., Juster, R. P., Sindi, S., Arsenault-Lapierre, G., Fiocco, A. J., & Lupien, S. J. (2011). Chronic stress, cognitive functioning and mental health. *Neurobiology of Learning and Memory*, *96*(4), 583–595. https://doi.org/10.1016/j.nlm.2011.02.016

May, R. W., Fincham, F. D., Sanchez-Gonzalez, M. A., & Firulescu, L. (2021). Forgiveness: protecting medical residents from the detrimental relationship between workplace bullying and wellness. *Stress (Amsterdam, Netherlands)*, *24*(1), 19–28. https://doi.org/10.1080/10253890.2020.1729733

McCraty, R., & Atkinson, M. (2012). Resilience training program reduces physiological and psychological stress in police officers. *Global Advances in Health and Medicine*, *1*(5), 44–66. https://doi.org/10.7453/gahmj.2012.1.5.013

McCraty, R., & Zayas, M. A. (2014). Cardiac coherence, self-regulation, autonomic stability, and psychosocial well-being. *Frontiers in Psychology*, *5*, 1090. https://doi.org/10.3389/fpsyg.2014.01090

Meteyard, L., & Davies, R. A. (2020). Best practice guidance for linear mixed-effects models in psychological science. *Journal of Memory and Language*, *112*, 104092. https://doi.org/10.1016/j.jml.2020.104092

Morelli, D., Bartoloni, L., Colombo, M., Plans, D., & Clifton, D. A. (2018). Profiling the propagation of error from PPG to HRV features in a wearable physiological-monitoring device. *Healthcare Technology Letters*, *5*(2), 59–64. https://doi.org/10.1049/htl.2017.0039

Naik, G. S., Gaur, G. S., & Pal, G. K. (2018). Effect of modified slow breathing exercise on perceived stress and basal cardiovascular parameters. *International Journal of Yoga*, *11*(1), 53–58. https://doi.org/10.4103/ijoy.IJOY_41_16

Otzenberger, H., Gronfier, C., Simon, C., Charloux, A., Ehrhart, J., Piquard, F., & Brandenberger, G. (1998). Dynamic heart rate variability: A tool for exploring sympathovagal balance continuously during sleep in men. *The American Journal of Physiology*, *275*(3), H946–950. https://doi.org/10.1152/ajpheart.1998.275.3.H946

Pagani, M., Lombardi, F., Guzzetti, S., Rimoldi, O., Furlan, R., Pizzinelli, P., Sandrone, G., Malfatto, G., Dell'Orto, S., & Piccaluga, E. (1986). Power spectral analysis of heart rate and arterial pressure variabilities as a marker of sympatho-vagal interaction in man and conscious dog. *Circulation Research*, *59*(2), 178–193. https://doi.org/10.1161/01.RES.59.2.178

Pan, J., & Tompkins, W. J. (1985). A real-time QRS detection algorithm. *IEEE Transactions on Bio-Medical Engineering*, *32*(3), 230–236. https://doi.org/10.1109/TBME.1985.325532

Pereira, J. A., Barkham, M., Kellett, S., & Saxon, D. (2017). The role of practitioner resilience and mindfulness in effective practice: A practice-based feasibility study. *Administration and Policy in Mental Health*, *44*(5), 691–704. https://doi.org/10.1007/s10488-016-0747-0

Perna, G., Riva, A., Defillo, A., Sangiorgio, E., Nobile, M., & Caldirola, D. (2020). Heart rate variability: Can it serve as a marker of mental health resilience? *Journal of Affective Disorders*, *263*, 754–761. https://doi.org/10.1016/j.jad.2019.10.017

Porges, S. W. (2001). The polyvagal theory: phylogenetic substrates of a social nervous system. *International Journal of Psychophysiology: Official Journal of the International Organization of Psychophysiology*, *42*(2), 123–146. https://doi.org/10.1016/S0167-8760(01)00162-3

Roberto, C., Giuseppe, D. I., & Attilio, C. (2018). Heart rate variability: an overview and a few immediate/short-term assessments. *Heart and Mind*, *2*(4), 111–118. https://doi.org/10.4103/hm.hm_27_19

Saboul, D., Pialoux, V., & Hautier, C. (2014). The breathing effect of the LF/HF ratio in the heart rate variability measurements of athletes. *European Journal of Sport Science*, *14 Suppl 1*(1), S282–S288. https://doi.org/10.1080/17461391.2012.691116

Sahoo, T. K., Mahapatra, A., & Ruban, N. (2019). Stress index calculation and analysis based on heart rate variability of ECG signal with arrhythmia. *Proceedings of the 2019 Innovations in Power and Advanced Computing Technologies (pp. 1–7),* Vellore, India. https://doi.org/10.1109/i-PACT44901.2019.8959524

Salvador, A., & Costa, R. (2009). Coping with competition: neuroendocrine responses and cognitive variables. *Neuroscience and Biobehavioral Reviews*, *33*(2), 160–170. https://doi.org/10.1016/j.neubiorev.2008.09.005

Schäfer, A., & Vagedes, J. (2013). How accurate is pulse rate variability as an estimate of heart rate variability?: A review on studies comparing photoplethysmographic technology with an electrocardiogram. *International Journal of Cardiology*, *166*(1), 15–29. https://doi.org/10.1016/j.ijcard.2012.03.119

Schubert, C., Lambertz, M., Nelesen, R. A., Bardwell, W., Choi, J. B., & Dimsdale, J. E. (2009). Effects of stress on heart rate complexity—A comparison between short-term and chronic stress. *Biological Psychology*, *80*(3), 325–332. https://doi.org/10.1016/j.biopsycho.2008.11.005

Sgoifo, A., Carnevali, L., Pattini, E., Carandina, A., Tanzi, G., Del Canale, C., Goi, P., De Felici Del Giudice, M. B., De Carne, B., Fornari, M., Gavazzoli, B., Poisa, L., Manzoni, D., & Bollati, D. (2021). Psychobiological evidence of the stress resilience fostering properties of a cosmetic routine. *Stress (Amsterdam, Netherlands)*, *24*(1), 53–63. https://doi.org/10.1080/10253890.2020.1750590

Skibniewski, F. W., Dziuda, Ł., Baran, P. M., Krej, M. K., Guzowski, S., Piotrowski, M. A., & Truszczyński, O. E. (2015). Preliminary results of the LF/HF ratio as an indicator for estimating difficulty level of flight tasks. *Aerospace Medicine and Human Performance*, *86*(6), 518–523. https://doi.org/10.3357/AMHP.4087.2015

Steffen, P. R., Bartlett, D., Channell, R. M., Jackman, K., Cressman, M., Bills, J., & Pescatello, M. (2021). Integrating breathing techniques into psychotherapy to improve HRV: Which approach is best? *Frontiers in Psychology*, *12*, 624254. https://doi.org/10.3389/fpsyg.2021.624254

Spyer, K. M. (1994). Annual review prize lecture. Central nervous mechanisms contributing to cardiovascular control. *The Journal of Physiology*, *474*(1), 1–19. https://doi.org/10.1113/jphysiol.1994.sp019997

Tarvainen, M. P., Lipponen, J., Niskanen, J., & Ranta-Aho, P. O. (2021). Kubios HRV Software User's Guide (version 3.5). Retrieved from https://www.kubios.com/downloads/Kubios_HRV_Users_Guide.pdf

Thayer, J. F., Hansen, A. L., & Johnsen, B. H. (2010). The Non-invasive Assessment of Autonomic Influences on the Heart Using Impedance Cardiography and Heart Rate Variability. In: Steptoe, A. (eds) *Handbook of Behavioral Medicine (pp. 723–740)*. Springer, New York, NY. https://doi.org/10.1007/978-0-387-09488-5_47

Usui, H., & Nishida, Y. (2017). The very low-frequency band of heart rate variability represents the slow recovery component after a mental stress task. *PloS One*, *12*(8), e0182611. https://doi.org/10.1371/journal.pone.0182611

Von Rosenberg, W., Chanwimalueang, T., Adjei, T., Jaffer, U., Goverdovsky, V., & Mandic, D. P. (2017). Resolving ambiguities in the LF/HF ratio: LF-HF scatter plots for the categorization of mental and physical stress from HRV. *Frontiers in Physiology*, *8*, 360. https://doi.org/10.3389/fphys.2017.00360

Vuorio, A., & Bor, R. (2020). Black swan pandemic and the risk of pilot suicide. *Frontiers in Public Health*, *8*, 573006. https://doi.org/10.3389/fpubh.2020.573006

Widdicombe, J. G., & Sterling, G. M. (1970). The autonomic nervous system and breathing. *Archives of Internal Medicine*, *126*(2), 311–329. https://doi.org/10.1001/archinte.1970.00310080117020

Williams, P. G., Suchy, Y., & Rau, H. K. (2009). Individual differences in executive functioning: Implications for stress regulation. *Annals of Behavioral Medicine: A Publication of the Society of Behavioral Medicine*, *37*(2), 126–140. https://doi.org/10.1007/s12160-009-9100-0

Winter, B. (2013). Linear models and linear mixed effects models in R with linguistic applications. arXiv:1308.5499. Retrieved from http://arxiv.org/pdf/1308.5499.pdf

Yang, Y. N., Liu, Y. P., Hsieh, M. T., Lin, Y. C., & Tung, C. S. (2018). Effects of prolonged paradoxical sleep deprivation with or without acute cold stress on hemodynamic perturbations in rats. *Stress (Amsterdam, Netherlands)*, *21*(6), 520–527. https://doi.org/10.1080/10253890.2018.1483328

Zaccaro, A., Piarulli, A., Laurino, M., Garbella, E., Menicucci, D., Neri, B., & Gemignani, A. (2018). How breath-control can change your life: A systematic review on psycho-physiological correlates of slow breathing. *Frontiers in Human Neuroscience*, *12*, 353. https://doi.org/10.3389/fnhum.2018.00353

Zhang, J., Li, W. C., & Andrews, G. (2022). Applying psychophysiological coherence training based on HRV-biofeedback to enhance pilots' resilience and wellbeing. *Transportation Research Procedia*, *66*, 49–56. https://doi.org/10.1016/j.trpro.2022.12.006