Original Article

The relationship between cardiorespiratory fitness and blood pressure among airline pilots: a mediation analysis of body composition

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Objective: Blood pressure (BP), cardiorespiratory fitness (CRF), and body composition are independently associated with health outcomes, yet the relationship between these variables has not been explored among airline pilots. The aim of this study was to evaluate the relationship between CRF and BP, and further examine whether the relationship is mediated by body composition.

Methods: A cross-sectional study was conducted among 356 airline pilots in New Zealand. We measured height, body mass, BP, waist circumference, skinfolds, and CRF (via a WattBike cycle ergometer submaximal VO_{2max} test). Partial correlation coefficients were estimated to examine the relationships between all variables while controlling for age and sex. Haye's PROCESS macro and the Sobel test were utilized for the mediation analysis.

Results: All body composition variables (body mass index, waist circumference and body fat percentage) were positively correlated with all BP variables (systolic pressure, diastolic pressure and mean arterial pressure) ($P < 0.001$). CRF was negatively correlated with all body composition and BP variables ($P < 0.001$). The Sobel test and indirect effect were significant ($P < 0.001$), confirming that all body composition variables partially mediate the relationship between CRF and all blood pressure variables.

Conclusion: Lower CRF is associated with higher blood pressure, and body composition partially mediates the relationship between these health risk factors. These findings highlight the importance of physical fitness and healthy body composition in the management of blood pressure among this occupational group.

Keywords: blood pressure, body composition, cardiometabolic health, cardiorespiratory fitness, mediation analysis

Abbreviations: ANCOVA, analysis of covariance; BP, Blood pressure; BF%, body fat percentage; BMI, body mass index; CRF, cardiorespiratory fitness; CVD, cardiovascular disease; DBP, diastolic blood pressure; MAP, mean arterial pressure; SBP, systolic blood pressure; WC, waist circumference

INTRODUCTION

Hypertension, obesity, and low cardiorespiratory fitness (CRF) are among leading modifiable risk factors for cardiovascular disease (CVD) and all-cause mortality [1,2]. Airline pilots face various occupational demands that may negatively impact cardiovascular disease risk, including shift work and erratic work schedules, circadian disruption, psychological stress and fatigue, and prolonged periods of sitting [3]. Recent studies have revealed notable prevalence of cardiovascular health risk factors among airline pilots globally, comparable to general population estimates, including hypertension, overweight and obesity, and lifestyle behavioral risks such as insufficient physical activity [3,4]. However, investigation of the relationships between such factors among airline pilots has not been well addressed.

Previous research among the general population has reported a strong inverse relationship between CRF and blood pressure (BP), in which higher CRF is associated with lowered BP [5]. Further studies within the general population have suggested body composition variables may influence the relationship between CRF and BP [6]. BMI, body fat percentage (BF%), and waist circumference (WC) are the most widely investigated body composition parameters that have each independently demonstrated strong relationships with CVD risk [7,8], yet there are discrepancies among reports as to which of these parameters is optimal for predicting CVD [9] and hypertension risk [10]. Accordingly, research is warranted to evaluate the characteristics of these variables among airline pilots.

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Behavioral interventions that enhance CRF and body composition variables including BF%, BMI, and WC among airline pilots have demonstrated favorable changes in BP [11–13]. However, the specific relationships between CRF, body composition and BP have not been established among this occupational group. Progressive insights into the relationships between health risk factors will inform interventions and policy to mitigate cardiovascular health risk factors among airline pilots. Therefore, the aim of this study was to evaluate the relationship between CRF and BP and further examine whether the relationship is mediated by body composition.

METHODS

Design

A retrospective cross-sectional study was performed to evaluate whether the relationship between CRF and BP is mediated by body composition. This study examined objective cardiometabolic health variables: age, sex, weight, CRF (estimated VO_{2max}), BMI, WC, skin folds, and BP. This study was approved by the Human Research Ethics Committee of the University of Waikato in New Zealand (reference number 2019#35).

Participants

The study sample consisted of 356 airline pilots which were recruited from an international airline in New Zealand, who participated in voluntary face-to-face health assessments between 2019 and 2022 (see Table 1). The researchers invited all pilots working for the company via organization internal communication channels, to take part in the study. Based on recent populace estimates [4], our sample size represents approximately 26% of this occupational population. Prior to participating in the study, all participants gave written consent and were informed that they could leave the study at any point if they chose to. The criteria for being included in the study were having a valid commercial pilot license and working as a permanent employee. Participants were excluded if medical clearance was deemed necessary prior to performing a cardiorespiratory fitness assessment which was evaluated by the Physical Activity Readiness Questionnaire for Everyone (PAR-Q+) [14].

Outcome measures

Participants were instructed to avoid large meals, strenuous physical activity, and stimulants such as caffeine for 4 h before their physiological measurements were taken. Procedures for measuring BP and body composition have been previously described in detail [4,12]. In brief, body mass was measured using SECA 813 electronic flat scales and height with a SECA 206 stadiometer (SECA, Hamburg, Deutschland). Body mass and height values were utilized to determine BMI (kg/m^2). WC was measured with a thin-line metric tape measure (Lufkin; Apex Tool Group, Sparks, MD, USA) congruent with standardized technique [15]. Skinfold measurements were collected according to standardized procedures of the International Society for the Advancement of Kinanthropometry by a certified anthropometrist using Harpenden calipers (British Indicators, Hertfordshire, UK). Skin fold measures of biceps, triceps, sub scapular, and supra iliac in addition to WC were utilized to estimate BF% based on sex and ethnicity specific prediction equations reported elsewhere [16].

BP measurements were measured in accordance with standardized aviation medicine protocol [17]. The measurements were taken twice with an OMRON HEM-757 device (Omron Corporation, Kyoto, Japan) while the participant was sitting with their arm supported at the level of the atria. If the initial two readings were below 140/90, the lowest measurement was recorded. However, if the readings were above 140/90, two more readings were taken after a few minutes' interval. Mean arterial pressure (MAP) was calculated using the formula: DBP + 1/3(SBP-DBP).

To assess participants' aerobic fitness, estimated VO_{2max} was determined by having them perform a 3-min aerobic test (3mAT) on a Wattbike electro-magnetically and air-braked cycle ergometer, which has been previously validated among airline pilots [12,18]. Before the test, participants were given a thorough explanation of the protocol, safety procedures, they were provided with a Polar H10 heart rate strap (Polar Electro, Kempele, Finland) and the

TABLE 1. Characteristics of the study sample

Parameters	All subjects ($n = 356$)	Female ($n = 44$)	Male ($n = 312$)
Sex (f/m)	44/312	-	-
Age (years)	43.9 ± 10.8	37.1 ± 8.7	44.9 ± 10.7*
Short haul (*n*)	179	29	150
Long haul (*n*)	177	15	162
Height (cm)	177.9 ± 8.0	167.4 ± 6.5	179.3 ± 7.1
Body mass (kg)	90.2 ± 14.3	77.8 ± 10.8	92.0 ± 13.9
BMI (kg·m^2)	28.5 ± 3.9	27.9 ± 4.2	28.6 ± 3.8
Waist circumference (cm)	96.3 ± 11.3	86.5 ± 11.5	97.7 ± 10.6
Body fat (%)	24.1 ± 5.7	31.2 ± 6.6	23.1 ± 4.8**
CRF (ml·kg^{-1} min^{-1})	36.2 ± 7.0	33.8 ± 8.8	36.6 ± 6.6*
SBP (mmHg)	131.6 ± 9.6	128.8 ± 9.6	132.0 ± 9.5
DBP (mmHg)	84.2 ± 6.5	82.1 ± 8.6	84.5 ± 6.1*
MAP (mmHg)	100.0 ± 7.0	97.6 ± 8.5	100.3 ± 6.8

Note: Mean ± SD reported for all participants.
BMI, body mass index; CRF, cardiorespiratory fitness; DBP, diastolic blood pressure; MAP, mean arterial pressure; SBP, systolic blood pressure; SD, standard deviation.
*Indicates statistical significance $P < 0.05$.
**indicates $P < 0.001$.

seat and handle were fitted correctly. The full procedure has been described in detail elsewhere [18]. Participants completed a 10-min warm-up, which included self-paced cycling at 70–90 rpm, along with two 6-s sprints as suggested by the manufacturer. During the 3mAT, participants were encouraged verbally and allowed to adjust resistance and pedal cadence as necessary to maintain the highest power output possible for the full 3 min.

Statistical analysis

All analyses were performed in SPSS (Version 29; IBM Corp., Armonk, NY). The Shapiro–Wilk test and its histograms, *Q*–*Q* plots, and box plots were analyzed for data distribution normality. The Levene's test was used to test homogeneity of variance. Continuous descriptive data were compared via independent t-tests and the Chi square test was utilized for categorical variables. Partial correlation coefficients were estimated for examination of relationships between CRF, BP variables [systolic blood pressure (SBP), diastolic blood pressure (DBP), mean arterial pressure (MAP)], and body composition variables (BMI, WC, BF%), controlling for age, sex and use of antihypertensive medication.

ANCOVA models were utilized to quantify BP descriptive data across different CRF and body composition categories. BMI were categorized as underweight, normal weight, overweight, and obese by values <18.5, 18.5–24.9, 25–29.9, and >30 (kg/m^2), respectively. CRF, WC, and BF% were categorized as first, second, third, and fourth quartiles. ANCOVA model one controlled for age and sex, whereas further models also adjusted for CRF, BMI, BF%, or WC, depending on the fixed factor. Bonferroni correction pairwise post hoc hypotheses were utilized to account for multiple comparisons and examine significant relationships between categories.

For the mediation analysis, the PROCESS macro for SPSS [19] was utilized to examine the total, direct, and indirect effects (IE). The total effect represents the overall effect of one variable on another, encompassing all paths. The direct effect denotes the impact of CRF on BP without considering the influence of body composition, whereas the indirect effect reveals the change in this relationship that is mediated by body composition. The bootstrapping method advised by Preacher and Hayes [20] to test the mediation hypotheses was used at 10 000 bootstrap samples to calculate point estimates and confidence intervals for the IE. Further, the Sobel test [21] was conducted to determine if the relationship between variables was significant, which included estimating the IE, dividing by the standard error, and performing a *Z* test to determine if the IE is equal to zero.

RESULTS

Characteristics of the study population are depicted in Table 1. The population was entirely Caucasian ethnicity, which is comparable with a previously published cross-sectional study among this population [4]. Age, CRF, and DBP were higher in males ($P < 0.05$), whereas BF% was higher in females ($P < 0.001$). The partial correlation coefficients relationship between body composition, CRF and BP variables are presented in Table 2. All variables investigated were significantly correlated ($P < 0.001$). BMI, WC, and BF% were positively correlated with all BP variables ($P < 0.001$). CRF was negatively correlated with all body composition and BP variables ($P < 0.001$).

The mean difference in BP variables across body composition and CRF categories are displayed in Table 3 and the Supplementary File. Across all statistical models, lower values for BMI, WC, and BF% were associated with significantly lower SBP, DBP, and MAP ($P < 0.001$). Among CRF category models factoring age, sex, and each body composition variable (BMI, WC, or BF%), higher CRF was associated with lower SBP, DBP, and MAP ($P < 0.001$).

As shown in Figure 1, the results revealed a significant IE of all body composition variables as a mediator between CRF and BP variables, as the confidence intervals did not contain zero [19]. A significant direct effect of CRF on BP variables in the presence of the mediator was observed ($P < 0.001$). Furthermore, the total effect, representing the overall relationship between the predictor and outcome variables, including both the direct and IE was significant for all analyses ($P < 0.001$). Finally, the Sobel test was significant for each body composition variable in the relationship between CRF and BP. Overall, body composition variables partially mediated the relationship between CRF and BP variables.

DISCUSSION

To our knowledge, this is the first study to evaluate the relationship between CRF and BP in airline pilots. We believe it is also the first study to further examine whether

TABLE 2. Pearson correlation coefficients between body composition variables with cardiorespiratory fitness and blood pressure variables, controlling for age and sex

	WC	BF%	CRF	SBP	DBP	MAP
BMI	0.84*	0.85*	-0.51*	0.49*	0.49*	0.52*
WC		0.85*	-0.48*	0.43*	0.40*	0.44*
BF%			-0.56*	0.48*	0.48*	0.51*
CRF				-0.57*	-0.59*	-0.62*
SBP					0.75*	0.91*
DBP						0.95*
MAP						

BF%, body fat percentage; BMI, body mass index; CRF, cardiorespiratory fitness; DBP, diastolic blood pressure; MAP, mean arterial pressure; SBP, systolic blood pressure; WC, waist circumference.
*Indicates statistical significance $P < 0.001$.

TABLE 3. Mean differences in blood pressure variables by fat mass and cardiorespiratory fitness categories

	Model 1				Model 2			
BMI categories								
	Underweight	Normal	Overweight	Obese	Underweight	Normal	Overweight	Obese
SBP	116.1 ± 6.1^{4}	$123.3 \pm 1.2^{3,4}$	$130.9 \pm 0.6^{2,4}$	$136.2 \pm 0.8^{**}$	121.6 ± 5.4	$127.1 \pm 1.2^{3,4}$	$131.4 \pm 0.6^{2,4}$	$133.9 \pm 0.7^{**}$
DBP	76.6 ± 4.0^{4}	$78.3 \pm 0.8^{3,4}$	$83.4 \pm 0.4^{2,4}$	$87.8 \pm 0.5^{**}$	80.2 ± 3.5	$80.8 \pm 0.8^{3,4}$	$83.7 \pm 0.4^{2,4}$	$86.3 \pm 0.5^{**}$
MAP	89.7 ± 4.3^{4}	$93.3 \pm 0.9^{3,4}$	$99.3 \pm 0.4^{2,4}$	$103.9 \pm 0.5^{**}$	94.0 ± 3.7	$96.2 \pm 0.8^{3,4}$	$99.6 \pm 0.4^{2,4}$	$102.2 \pm 0.5^{**}$
CRF categories								
	1st Quartile	2nd Quartile	3rd Quartile	4th Quartile	1st Quartile	2nd Quartile	3rd Quartile	4th Quartile
SBP	$137.7 \pm 0.9^{2-4}$	$133.6 \pm 0.9^{1,3-4}$	$130.3 \pm 0.9^{1-2,4}$	$124.5 \pm 0.9^{**}$	$135.6 \pm 0.9^{3-4}$	133.5 ± 0.8^{4}	$130.6 \pm 0.8^{1,4}$	$126.5 \pm 0.9^{**}$
DBP	$88.6 \pm 0.6^{2-4}$	$85.1 \pm 0.6^{1,4}$	$83.4 \pm 0.6^{1,4}$	$79.4 \pm 0.6^{**}$	$87.2 \pm 0.6^{2-4}$	$85.1 \pm 0.6^{1,4}$	$83.6 \pm 0.6^{1,4}$	$80.7 \pm 0.6^{**}$
MAP	$105.0 \pm 0.6^{2-4}$	$101.3 \pm 0.6^{1,4}$	$99.0 \pm 0.6^{1,4}$	$94.4 \pm 0.6^{**}$	$103.4 \pm 0.6^{3-4}$	101.2 ± 0.6^{4}	$99.2 \pm 0.6^{1,4}$	$96.0 \pm 0.6^{**}$

Note: The data are presented by marginal estimated mean ± s.e. The measurement unit for all blood pressure values is mmHg. Model 1 = controlling for age and sex. Model 2 = controlling for age, sex, and CRF (for body mass categories) or BMI (for CRF categories).
BMI, body mass index; CRF, cardiorespiratory fitness; DBP, diastolic blood pressure; MAP, mean arterial pressure; SBP, systolic blood pressure.
*Indicates ANCOVA statistically significance group difference at level $P < 0.05$.
**Indicates $P < 0.001$. Superscript number identifies significant relationship within categories from the post *hoc* analysis, 1 represents the leftmost category, 2 denotes the second category from the left and so forth.

this relationship is mediated by body composition. Our findings demonstrate a negative relationship between CRF and BP, with higher CRF levels associated with lower BP levels. Body composition variables, including BMI, WC, and BF%, were also significantly related to BP. When controlling for these variables in partial correlation analysis, the relationship between CRF and BP remained significant, suggesting that body composition does not fully mediate the relationship between CRF and BP in this population.

These findings provide further insight into the cardiovascular health risk factors present among airline pilots. As BP is incorporated in CVD risk evaluation models utilized in aviation medicine [17], our findings add new insights relevant to the field, uncovering CRF and body composition as relevant metrics for modifying BP. It is the responsibility of aviation medical regulators to apply safety management principles to the aviation medical assessment process and to implement appropriate health promotion for license holding pilots to mitigate future health risks to flight operation safety [17]. Recent reports of notable health risk factor prevalence for insufficient physical activity, excess body mass, and elevated blood pressure among airline pilots globally [3] highlight the need for enhanced health risk factor mitigation strategies among this occupational group.

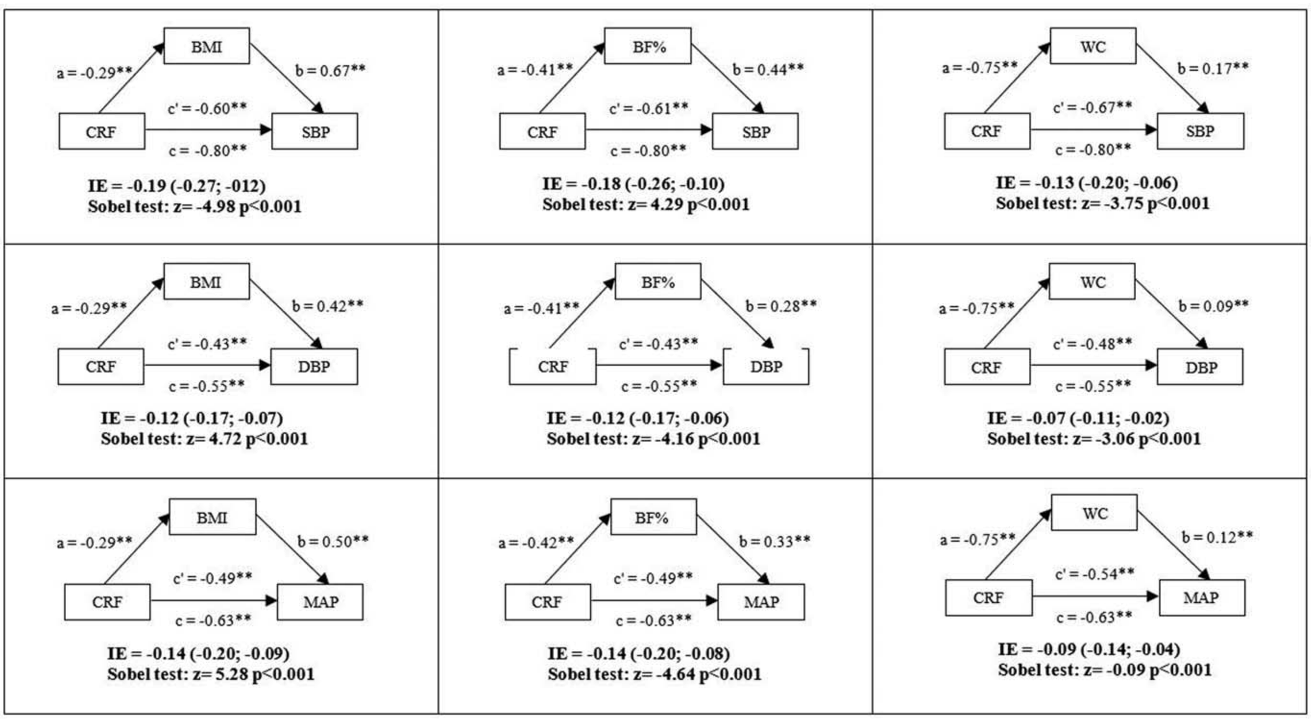

FIGURE 1 Body composition mediated models of the relationship between cardiorespiratory fitness and blood pressure variables, controlling for age and sex. BF%, body fat percentage; BMI, body mass index; CRF, cardiorespiratory fitness; DBP, diastolic blood pressure; IE, indirect effect; MAP, mean arterial pressure; SBP, systolic blood pressure; WC, waist circumference. * Indicates within group statistical significance $P < 0.05$, and ** indicates $P < 0.001$. *a*, *b*, *c'* and *c* represent unstandardized regression coefficient. *a* = independent variable to mediator path, *b* = mediator to dependent variable path, *c'* = direct effect, *c* = total effect.

The evident role of CRF and body composition in influencing BP underscores the importance of evaluating these outcomes in aviation medical practice and warrants implementation of evidence-based approaches to promote physical fitness and healthy body mass among airline pilots to mitigate cardiometabolic health risk.

Although comparable literature pertaining to airline pilots is scant, some of our findings regarding the relationships between CRF, body composition and BP are consistent with past research in other populations. These include a large cohort study ($n = 1\ 547\ 478$) among adult males revealed CRF and BMI were each strongly and independently associated with BP, and those with a combination of high BMI and low CRF were associated with the highest risk of hypertension [22]. A recent study among middle aged adults ($n = 24\ 349$) utilizing whole-body dual-energy X-ray revealed both central adiposity and lean mass were independently associated with blood pressure [6]. Moreover, another study reported body composition variables BMI, WC and BF% also mediated the relationship between CRF and BP in cohort of young adults [23]. A meta-analysis of experimental randomized control trials revealed improvements in moderate-intensity leisure-time physical activity was associated with significant reduction in both SBP and DBP [24]. Further, a meta-analysis of weight-reduction randomized control trials reported a 4-kilogram weight reduction was associated with 6 mmHg reduction in SBP [25]. Collectively, these studies demonstrate congruent trends with our present findings.

Previous research has proposed measures of adiposity such as BF% may be a better predictor of CVD risk factor profile than standard body mass indices such as BMI [26]. Indeed, BMI fails to account for the proportion of skeletal muscle mass that contributes to an individual's body mass. As low skeletal muscle mass [27] and high adiposity [28] have been associated with adverse outcomes to cardiovascular health, such as vascular dysfunction, metabolic impairments, dyslipidemia, hypertension, and inflammation, the relevance of investigating BF% may be postulated. Interestingly, in our study, BMI demonstrated a marginally stronger correlation with MAP, compared with estimated BF % ($r = 0.52$ and 0.51, respectively). Therefore, this preliminary evidence suggests BMI has similar utility as BF% in predicting BP among airline pilots, of which measurement is typically more resource intensive. However, future research utilizing measures of higher validity such as DEXA to precisely quantify body composition are needed to enhance the accuracy and generalizability of conclusions.

Our findings which revealed higher BP among higher body composition categories is consistent with past research [29]. This trend continued in our analysis when CRF was integrated into the ANCOVA as a covariate (model 2). Therefore, it appears that CRF does not fully mitigate the adverse effects of excess body mass on BP. Indeed, past research has reported higher visceral adipose tissue is associated with elevated blood pressure, independent of CRF [29]. However, our analysis also revealed lower BP in higher CRF categories regardless of body composition variables being included as covariates. Collectively, these findings demonstrate the notable independent effects of CRF and body composition on BP, yet further research is needed to better understand the specific mechanisms and modifiable factors that contribute to the relationship between CRF, body composition, and BP among airline pilots.

There are various limitations that need to be considered in the interpretation of our findings. First, as participants were those who chose to engage in voluntary health evaluations, these individuals may have higher motivation to improve their health than those from the population that did not choose to participate. More robust recruitment methodology such as population random sampling may yield a superior representation of the population and enhance generalizability of findings. Second, airline pilots routinely have their blood pressure taken during aviation medical examinations, of which outcomes influence their flight certification. Consequently, some individuals experience white coat syndrome [30] when blood pressure is measured in a physician's venue. Future research utilizing at home ambulatory blood pressure measurement may enhance accuracy [30] of population blood pressure quantification. Third, due to resource availability and feasibility reasons, a submaximal CRF test was used to quantify estimated VO_{2max} and skinfold measures were implemented for BF% estimation. Future research utilizing gold standard measures such as a graded maximal CRF test and dual-energy X-ray for body composition would add value to the scientific body. Fourth, various dietary behaviors are associated with body composition and cardiometabolic disease risk status. Thus, future research should quantify dietary behaviors including energy balance, sodium and omega-3 fatty acid intake, and the Western dietary pattern to evaluate their independent role in the relationship between physical fitness, body composition and blood pressure. Finally, our sample comprised a largely homogenous sample of New Zealand Caucasian airline pilots. Therefore, a more diverse demographic representation is needed to enhance the generalizability of findings.

In conclusion, our study found that higher cardiorespiratory fitness was associated with lower blood pressure, and that body composition variables such as body mass index, waist circumference, and body fat percentage also had an impact on the relationship between CRF and BP. These findings highlight the importance of addressing health risk factors among airline pilots through targeted interventions and policies to mitigate the risk of cardiovascular disease and other health problems.

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Conflicts of interest

The authors declare they have no competing interests.

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