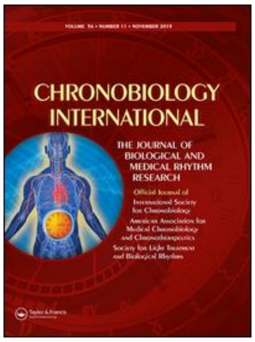

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The relationship between workload, performance and fatigue in a short-haul airline

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ABSTRACT
The aim of this study was to determine the relationship between pilot workload, performance, subjective fatigue, sleep duration, number of sectors and flight duration during short-haul operations. Ninety pilots completed a NASA Task Load Index, Psychomotor Vigilance Task and a Samn-Perelli fatigue scale on top-of-descent of each flight and wore an activity monitor throughout the study. Weak, but significant, correlations were revealed between workload and all factors. Subjective fatigue, number of sectors and lapses were significant predictors of workload. Pilots reported higher workload when fatigue increased, the number of sectors were higher, and objective performance was worse.

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PVT; short-haul; fatigue; pilot workload

Introduction

Short-haul airline pilots face high workload and fatigue due to flying multiple flights in a single day and reduced sleep due to early start times and long duty days (Flynn-Evans et al. 2018; Honn et al. 2016; Vejvoda et al. 2014). Most duty and rest regulations address the maximum amount of duty time on a given day, the cumulative time for a duty period and a minimum acceptable duration of rest periods between duty periods. The impact of these factors on alertness and performance has been evaluated in many studies. Workload has not been studied as extensively, although it is included in the definition of fatigue by the International Civil Aviation Organization (ICAO 2015). The association between sleep, performance and workload during short-haul flights remains unclear although sleep and workload each contribute to pilot performance and fatigue. Therefore, the objective of this study was to determine the relationship between pilot workload, performance, subjective fatigue, sleep duration, number of sectors and flight duration during short-haul operations.

Methods

Participants

Ninety-five pilots (eight females) from a short-haul commercial airline volunteered to participate in the study during standard operations. Five pilots were removed from analyses due to missing and outlier data (>2 standard deviations).

Protocol

The study protocol was reviewed and approved by the NASA Institutional Review Board (HRIRB, protocol HRI-319). Pilots working for a single airline were recruited through flyers and via company e-mails. The pilots who volunteered to participate in the study were invited for a training day when they gave a written, informed consent and completed a demographic questionnaire. They were provided with an iPod (5th generation, iOS 6.8.53, Apple, Cupertino, CA, USA) uploaded with the study questionnaires and were provided instructions on the timing and procedures of the tests. The pilots flew a roster that included four duty blocks separated by three or four days off. Each duty block consisted of five consecutive duty days; each duty day included two or four sectors. Pilots departed from and returned to their home base.

Pilots completed a sleep diary and wore an Actiwatch (Respironics Inc., Bend, OR, USA) throughout the study. On top-of-descent (just before the start of the approach for landing) of each flight, pilots completed a Samn-Perelli scale (Samn and Perelli 1982), a 5-minute Psychomotor Vigilance Task (PVT) and a NASA Task Load Index (NASA-TLX, Hart and Staveland 1988). The Samn-Perelli scale is a fatigue scale asking participants to rate their level of fatigue from 1 = “fully alert, wide

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awake" to 7 = "completely exhausted, unable to function effectively." The PVT is a validated test where participants are asked to respond as rapidly as possible to a stimulus appearing on the screen at different predetermined intervals (Arsintescu et al. 2017). The NASA-TLX is a measure of workload originally developed for use in the flight crew studies (Hart and Staveland 1988). NASA-TLX is comprised of six dimensions that measure mental demand, physical demand, temporal demand, performance, effort and frustration on a scale from 0 = "Low" to 100 = "High" except for performance for which the scale is from 0 = "Good" to 100 = "Poor." The unweighted TLX scores were used for the analyses, which is common and highly correlated to the weighted version of the index (Byers et al. 1989).

Statistical analyses

All data were analyzed using SPSS (version 26.0, IBM SPSS Statistics for Windows, Armonk, NY, USA). Response speed (mean 1/RT) and lapses (RT > 500 ms) were used as PVT outcomes. Spearman's rho non-parametric correlations ($\alpha = .05$) were used to compare PVT, Samn-Perelli, sleep duration, the number of sectors and flight duration with NASA-TLX. A multiple stepwise regression was conducted to test if PVT lapses, response speed, fatigue, sleep duration (obtained on the previous night), number of sectors, duty day and flight duration predicted the overall workload rated by pilots.

Results

The participants ranged in age between 21 and 54 with an average of 33 (±8) y. Data was collected on 3,243 short-haul flights. On average, flight duration was 2:14 (± 0:49) h long.

Overall, the mean raw TLX was significantly, but weakly, correlated with PVT lapses, response speed, Samn-Perelli fatigue, number of sectors, sleep duration and flight duration (Table 1).

Non-parametric correlations revealed weak, but significant, associations between lapses, response speed, Samn-Perelli, and each of the six workload dimensions (Table 1) showing a decrease in performance and an increase in fatigue when the subjective workload was rated higher.

Flight duration was weakly, but significantly, correlated with temporal demand, effort and frustration, such that temporal demand, effort and frustration were higher on shorter flights (Table 1). The number of sectors was weakly, but significantly, correlated with temporal demand, effort, performance and frustration, which were rated higher on the days with four sectors. Sleep duration was very weakly, but significantly, correlated with mental demand and frustration. The stepwise regression showed that the Samn-Perelli (ß =.22, SE = .38, $p < .001$), the number of sectors flown each day (ß = .08, SE = .44 $p < .01$) and the PVT lapses (ß = .08, SE = .04, $p < .01$) explained a small, but significant, amount of the variance in workload ($F(3, 1280) = 30.17$, $p < .001$, $R^2 = .07$).

Discussion

Our findings suggest that a higher self-reported workload is associated with slower reaction time and higher ratings of fatigue. There were very weak, but significant, correlations between mean pilot workload as measured by NASA-TLX and PVT performance, Samn-Perelli ratings, sleep duration, number of sectors and flight duration. In addition, each workload scale was significantly correlated with PVT performance and Samn-Perelli fatigue ratings. Pilots experienced more PVT lapses and their response speed was slower when workload was rated higher. Albeit still weak, the highest correlations of the study were between PVT performance and workload; workload was rated higher when fatigue was also rated as higher. Pilots reported being frustrated, experiencing time pressure and making more effort on shorter flights. The stepwise regression showed that Samn-Perelli fatigue, the number of sectors and PVT lapses were significant predictors of workload, although the effect was very small.

ur findings confirm and extend other studies that have shown that workload and fatigue are related to

Table 1. Correlations between NASA-TLX and PVT lapses, response speed, Samn-Perelli, flight duration, number of sectors and sleep duration.

Variables	M (SD)	Mental	Physical	Temporal	Effort	Performance	Frustration	Mean RTLX
M(SD)		41.72 (20.60)	26.73 (14.70)	37.89 (20.10)	15.87 (9.21)	42.49 (21.01)	30.31 (18.04)	32.59 (13.71)
PVT Lapses	6.07 (9.17)	.08**	.06**	.12**	.16**	.06**	.05*	.10**
Response speed	4.38 (0.92)	−.05*	−.05**	−.10**	−.20**	−.06**	−.07**	−.10**
Samn-Perelli	3.36 (1.26)	.12*	.11**	.06**	.10**	.15**	.21**	.16**
Flight duration	2:14 (0:49)	−.02	−.03	−.12**	−.05*	−.03	−.04*	−.06**
Sector number	2.22 (0.89)	.05	.05*	.12**	.10**	.06*	.07**	.08**
Sleep duration	7.65 (1.66)	.04*	.01	.03	−.00	.03	.04*	.04*

*p <.05, **p <.01; M = means, SD = Standard Deviation.

airline pilots. Previous studies also found a significant relationship between fatigue and multiple flight sectors (Flynn-Evans et al. 2018; Honn et al. 2016; Powell et al. 2007). Powell and colleagues found a linear relationship between fatigue as measured by Samn-Perelli and the number of sectors and time awake. Honn et al. (2016) found that subjective fatigue was greater and PVT performance was worse in a flight simulation with multiple sectors compared to a single long flight, with a modest effect on the fatigue of multiple takeoffs and landings. In the real world, Flynn-Evans et al. (2018) showed higher fatigue ratings and poorer performance among pilots flying multiple sectors with longer duty days compared to those flying fewer sectors, despite both groups having the same sleep opportunity. It is possible that sleep-deprived pilots perceive workload as higher because higher levels of workload and fatigue have been reported following shorter sleep duration (Bourgeois-Bougrine et al. 2003). The elevated fatigue observed in the present study may relate to multiple short sectors, and temporal and mental demand. Performance, mental and temporal demand were rated the highest of the six subscales, similar to previous studies investigating pilot workload (Burke et al. 2013).

Although significant, the correlations in the present study were very weak and the variance explained by the predictors in the regression model was very small. In addition, our study shows relationships between these factors but does not indicate causality. An additional limitation is that the TLX ratings referred to the flight up to the top-of-descent and it didn't capture landing, which is the most stressful phase of flight. Finally, the flight sectors that we studied were relatively short due to the short-haul nature of the study, which may explain why flight duration was not a significant predictor in the regression model. Studies including longer flights may yield different outcomes.

Further research is needed to determine how other factors such as weather, air traffic control communications and experience may contribute to high workload during flights. When combined with less sleep, long duty days, multiple takeoffs and landings, these factors have the potential to increase risk. Future studies should focus on disentangling the many factors that can cause one to report elevated workload and to determine which specific aspects of workload may cause pilots to experience reduced performance.

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