INTRODUCTION

Fatigue is a major cause of accidents in transport work, including aviation, according to the National Transportation Safety Board (NTSB, 1999). Because fatigue-related safety is linked to scheduling practice, authorities attempt to prevent fatigue through flight time limitations. The European Aviation Safety Agency (EASA) identifies night flying, early morning starts, long flight duty periods (>13 h during daytime) and a high level of sectors as scheduling characteristics contributing to aircrew fatigue (Commission, 2014). Several of these limitations are founded on experience and on results from circadian and sleep science (Rangan et al., 2020).

There is no consensus definition of fatigue, but in aviation research it has a connotation of sleepiness (Caldwell et al., 2009; Weiland et al., 2013), which refers to a drive towards sleep (Dement & Carskadon, 1982). Fatigue in aviation shows a pronounced link with sleep loss, time awake and time of day (Dawson & McCulloch, 2005; Gander et al., 2011; Hartzler, 2014). These are also the factors that
have been identified as fatigue determinants in laboratory studies (Dijk et al., 1992; Folkard & Åkerstedt, 1991).

With respect to aircrew scheduling variables, Powell et al. (2008) demonstrated the importance of time of day, duration of flight duty period and number of sectors (maximum of two) for fatigue in two-pilot crews in mixed short- and long-haul operations. We recently published a study of mixed long- and short-haul operations, finding that night flying (flights encroaching on the window of circadian low [WOCL], 0200–0559 hours) constituted the major cause of high fatigue (along with the associated sleep loss), whereas morning flights, duration of flight duty period (FDP) and number of sectors contributed only marginally (Sallinen et al., 2020). Night flights are, however, subject to several restrictions with respect to scheduling according to the European Flight Time Limitations (Commission, 2014). Thus, the number of sectors and the time of day combine to restrict the flight duty period, with maximum effects for night flights combined with many sectors. Block time is another variable of possible interest that has not been studied before in short-haul operations. It describes the time when the aircraft is moving, in the air or on the ground, and constitutes a subcategory of duty time.

In short-haul operations, with mainly day-oriented flights, duration of the flight duty period, number of sectors and time of day have been identified as sources of fatigue, as measured at the top of the descent of the last flight duty (Powell et al., 2007). Sleep was not measured in this study. The number of sectors varied between one and five. However, there is no information on the effects of more than five sectors and there are air carriers that greatly exceed five sectors, which is likely to increase fatigue, but empirical data are lacking. The effect of >6 sectors per flight duty period is also a research priority of the EASA with respect to flight time limitations (EASA, 2019a, 2019b). The Powell et al. (2007) study collected data only at one point per flight duty period (top of the descent of the last sector), and thus possible variation in fatigue across the sectors of the same flight duty period could not be studied.

In addition to restrictions pertaining to the 24-h window, the European Flight Time Limitations also restrict the total number of hours worked per work period ("week") to 60 h. However, empirical data on the effects of accumulated duty time on fatigue are lacking, except for one study that showed that fatigue at the end of the flight duty period did not change across 4 days with 39 h of work (Goffeng et al., 2019), whereas reaction time performance increased. Apparently, the cumulative effect of duty time and similar variables seems to be an understudied possible source of fatigue in aviation. Duty time, in this aspect, includes briefing time, turnaround, rest during split duties, ground duty, etc. One may also consider the effects of accumulation of block time, number of sectors and early or late duties, which might increase fatigue, as well as accumulation of amounts of sleep, which may affect fatigue depending on the speed of accumulation.

The overall objective of the present study was to investigate both the acute (24 h window) and cumulative (7-day work period) effects of scheduling characteristics on aircrew fatigue in short-haul flights, as well as the influence of sleep duration. With regard to acute effects, major questions were the role of sleep in relation to scheduling characteristics, if block time is an independent predictor of fatigue, if fatigue changes with time within the flight duty period (labeled "time from start"), and if the high number of sectors involved means a clearer association with fatigue.

With regard to cumulative effects across the 7-day work period, the main question was whether accumulated duty time, block time, number of sectors, non-day flights or sleep were associated with increased fatigue. We expected, for logical reasons, an increase in fatigue with accumulation of all variables, except sleep. With respect to the latter, it was not possible to formulate a hypothesis, because there was no reason to expect a particular pattern of accumulation. To be able to study the effects of many sectors, a carrier known for a high number of sectors was selected. The same carrier also had a derogation for a work period duration up to 70 h.

2 | METHODS

2.1 | Recruitment

Aircrew were informed by the employer about the purpose of the study and encouraged to participate. Participation was initiated by crew downloading the app CrewAlert TOD from either the Appstore (for iOS) or the Google Play store (for Android), on their personal (or company-provided) devices, and following the instructions for use. In the end, 145 aircrew (out of 460 pilots and 375 cabin crew, a total of 835) initially volunteered, and of those 115 chose to join the study and start their data collection. The final dataset contained data contributed by 106 crew members (a few could not be matched with roster data). The percentage of duty types for the whole aircrew group, and the group participating in the study, was 4 and 5%, respectively, for very early duties, 28/27% for early duties, 53/53% for day duties, and 15/15% for late duties. For sectors, the percentage with >6 was 19/25%, and for duty time >8 h the percentage was 35/28%. The participants received weekly emails that reminded them to collect data and also reported on the total amount of collected data up to the current time. The study was approved by the ethical committee of the region of Stockholm.

2.2 | Study design

The study was carried out during the peak operational period (October to mid-December). The crew was asked to record data in the app "CrewAlert" at least three times at the top of descent during the first, middle and last sectors for their duty days with active flying, and continue to do so for four (4) consecutive 7-day working periods (corresponding to a total data collection period of some 7–8 weeks because every other week represented time off). With the first rating, the crew were also asked to state their duration of sleep in the preceding 24 h.
Self-report of sleep duration has been validated in flight crew against actigraphy and polysomnography (Sigual et al., 2005).

2.3 | The app

The project used a method pioneered by Jeppesen Systems in a previous EASA study on long duration flights and “disruptive” flights (e.g., night flights). This method employs the CrewAlert app, which provides for reporting fatigue via a smartphone or iPad at particular points in time, such as close to top-of-descent (TOD) during flight. Responses are given by clicking on the appropriate value on the screen-presented Karolinska Sleepiness Scale (KSS), and for the rating during the first sector, also the hours of sleep in the past 24 h are given by moving a slider across a scale of hours. At the start of the project, age, gender and crew category were also entered.

2.4 | Variables

The ratings of fatigue were carried out using the KSS (Åkerstedt & Gillberg, 1990), which has been used extensively in similar studies (Åkerstedt et al., 2014). The scale ranges from 1 to 9, where 1 = very alert and 9 = very sleepy, fighting sleep, an effort to keep awake. It has been validated in real driving, and values at 8 or 9 show > 50% risk of crossing lines during the next 5 min (Hallvig et al., 2014; Sandberg et al., 2011). It is also associated with a 45% risk of being taken off the road for erratic driving during the subsequent 5 min (Åkerstedt et al., 2013), and of hitting a rumble strip in an advanced driving simulator (Anund et al., 2008). In the latter study, KSS = 8.1 was identified at the critical level in the 5 min before driving off the road. Common values for normal daytime alertness are 3–4, whereas values in the range 5–6 indicate increased sleepiness/fatigue, without any clearly increased risk of an accident, and 7 represents the point at which driving accidents and physiological changes start to increase (Akerstedt et al., 2014).

Roster data were provided by the company and covered all rostered on-duty activities with their actual timings across the full data collection period. These were then transformed to data describing number of duty hours, sectors, start time, end time, etc., used for the analyses. Timing was used to create the variable “duty type”, corresponding to daytime (7:00 AM to 22:59 PM), early (start 5:00–6:59 AM), late (ending 23:00 PM to 1:59 AM) and very early flights (starting 2:00–4:59 AM), as suggested in a previous report on fatigue to the EASA (EASA, 2019a, 2019b). All data were anonymised for analysis after the merge of the collected data and the flown roster data.

2.5 | Actigraph

For validation of ratings of sleep duration, 21 aircrew also wore actigraphs, which were used to provide objective information on sleep. These were used for 14 days.

2.6 | Statistical analysis

The data was analysed statistically using a mixed-effects regression model approach allowing for a random intercept for each subject. This permits data to be analysed within subjects across time, as well as between subjects (for crew category, for example), that is, a multilevel regression approach (Raudenbush et al., 2004). Thus, measures are repeated within each participant across: flight duty periods, sectors and time of day (duty type), and duty time. The main output for each individual is a regression coefficient for the change in KSS across different values of, for example, duty time, as well as a value for the intercept with the y-axis (KSS). The coefficients are then weighted together to give a mean regression coefficient for the group, with its standard error, and a mean intercept (labelled “constant” in the tables), with its standard error. The coefficient for each predictor (model 1 in the tables) is independent of the results of the other predictors. The adjusted values (model 2 in the tables) are adjusted for all other predictors.

The predictors in the analysis of the 24-h window were: duty time, number of sectors, hours of sleep, time since start and duty type, during the past 24 h. The same variables were also accumulated across the past work period (a 7-day week). The latter covers the time from the first day of the working period (a period of working days followed by at least 2 days off) up to the time of the last self-assessment of fatigue of the work period. Model 1 presents results for each variable separately, and model 2 presents results when all variables are entered together. Interactions were analysed in a pairwise fashion.

In addition, we analysed the influence of predictors of sleep in the same way as above, as well as analysing the change across the 7-day work period in the variables from the 24-h window to detect any systematic changes with time.

A separate analysis was carried out adjusted for age and crew type. As 10 participants did not provide their age and/or gender, those variables were removed in the main analysis in order to increase N. The two types of analyses did not differ in results and only the main analysis is presented here.

All recorded KSS data were used. For the analysis of the past 24 h, the dataset could be seen as one duty day, with all points of measurement from days and weeks pooled into 1 day for each participant. These points were then matched against the number of duty hours, number of sectors, duty time and time since start, accumulated at each point of rating. Amount of sleep during the past 24 h was collected only for the first rating of the day. For the past work period (7 days) the dataset consisted of the accumulation of, for example, duty time and days, number of sectors and number of duty types, across the work period. These values were then matched with the temporally corresponding fatigue ratings and the association analysed.

3 | RESULTS

A total of 106 individuals provided data. The number of individuals in the tables can be lower than this total number because of some
omissions. A total of 3,648 KSS ratings were collected. Table 1 presents basic information on the key variables. The proportion of cabin crew and women was low. The age span was wide. Day duties dominated the schedule, but also early duties were common. Actigraphy data on sleep duration correlated \((r = 0.61, p = .000)\) with sleep duration reported in the app.

### 3.1 Age, gender and crew category

In the first analysis we investigated differences in fatigue between gender, position (cabin crew/cockpit crew) and ages for the whole data collection period. None of the associations was significant. The coefficients ± standard error (SE) (and \(p\)-value) from the mixed model analysis were \(0.0138 \pm 0.0147 (p = .347)\) for age (in 1-year units).

| Variables                  | Mean ± SD or % |
|----------------------------|----------------|
| Age (years)                | 38.3 ± 8.6     |
| Women                      | 12.6%          |
| Men                        | 76.0%          |
| Missing on gender          | 11.4%          |
| Cabin crew                 | 7.2%           |
| Flight deck                | 84.2%          |
| Missing on crew            | 8.6%           |
| KSS                        | 4.2 ± 1.8      |
| Acc duty time WOP (h)      | 18.6 ± 13.9    |
| Acc sectors WOP (#)       | 11.0 ± 9.1     |
| Acc block time WOP (h)     | 8.3 ± 6.5      |
| Acc sleep WOP (h)          | 42.0 ± 1.4     |
| Acc early type WOP (#)     | 1.1 ± 1.1      |
| Acc very early type WOP (#)| 0.2 ± 0.5      |
| Acc late type WOP (%)      | 0.6 ± 0.9      |
| Time from start            | 4.1 ± 2.6      |
| Day in wop                 | 2.8 ± 2.6      |
| Sleep 24 h (h)             | 6.8 ± 1.4      |
| Fatigue 24 h (KSS)         | 4.2 ± 1.8      |
| Fatigue >724 h             | 5.0%           |
| Duty time 24 h (h)         | 7.1 ± 3.2      |
| Sectors 24 h (#)           | 4.3 ± 2.6      |
| Block time 24 h (h)        | 3.2 ± 1.8      |
| Duty type 24 h             |                |
| Late                       | 17.8%          |
| Early                      | 33.2%          |
| Very early                 | 7.2%           |
| Day                        | 41.8%          |

Note: WOP = work period. Values for past 24 h represent all collected duty days. Values for WOP represent all recorded WOPs (3–4). # = amount. Acc = accumulated.

\(-0.0287 \pm 0.3576 (p = .600)\) for gender (male = 1, female = 0), and \(-0.0036 \pm 0.3779 (p = .992)\) for position (0 = cabin crew, 1 = cockpit crew). Total \(N = 95\) because some individuals would not provide their age or gender.

### 3.2 Fatigue and scheduling during the past 24 h: acute effects

For analyses within the 24-h window in Model 1, all predictors became significant (Table 2). Duty time (Figure 1), block time, sectors, hours since start (Figure 1), and very early, early and late duties, were associated with increased fatigue, whereas sleep was associated with reduced fatigue (Figure 1). The coefficient for duty time means that every hour of duty increased fatigue by 0.18 KSS units. This corresponds to an increase in fatigue of 1.8 KSS units at 10 h of duty time. To obtain the KSS value at that point, 1.8 should be added to the constant of 3.6, yielding KSS = 5.4 units. For sleep, fatigue decreased by 0.26 units per hour of sleep, and for 8 h of sleep the decrease in fatigue corresponds to 1.96 units. Note that no sleep at all would bring the fatigue value to 6.8 units. For duty type, there was an increase in fatigue from day to late, early and very early flight duty periods, with 0.58–0.79 units compared to day duty.

In model 2 (all variables entered together), only duty time, sleep and duty type retained their significant coefficients. Sensitivity analysis showed that entering sectors reduced the contribution of duty time considerably, from a \(Z\)-value of 19.5 to 7.5 with \(p = .000\) (and a \(Z\)-value of 3.3 for sectors and \(p = .001\)). Entering block time further reduces the \(Z\) values, but all three remained significant. Further sensitivity analysis showed that the entry of duty type into the analysis rendered block time, sectors and hours from start non-significant.

Pairwise interactions were computed between the significant variables in model 2. The interaction between early duties and sleep became significant (regression coefficient \(C = -0.203 \pm 0.047, p = .000\)). This indicates a steeper decrease of fatigue with increasing sleep in early duties, compared to day duties (Figure 2). Also, the interaction between early duty and duty time was significant with early duty \((C = -0.047 \pm 0.021, p = .023)\). This indicates a less steep increase in fatigue with duty time in early duties, compared to day duties.

In order to estimate interdependencies between duty time, block time, number of sectors and hours from start we computed correlations and found the lowest value was \(r = 0.76 (p = .000)\).

Because sleep during the past 24 h was an important predictor of fatigue, we also analysed the association between scheduling characteristics and sleep amounts. For very early duty the resulting coefficient became \(C = -1.530 \pm 0.082\) compared to day duty (i.e., 1.5 h less sleep in connection with very early duty). For early duty the coefficient became \(C = -1.226 \pm 0.046\) compared to day duty (i.e., 1.2 h less sleep). For late duty, the coefficient became \(C = 0.391 \pm 0.058\) compared to day duty (i.e., 0.4 h more sleep). All showed \(p\)-values = .000. None of duty time, block time, number of sectors or hours from start showed significant coefficients.
3.3 | Fatigue and cumulative influences across the 7-day work period

Table 3, model 1, shows that the analysis of the predictors singly yielded significantly increased fatigue with accumulation of very early and early duties, and of days into work period, and reduced fatigue with accumulation of sleep and of day duties. When all predictors were entered together (model 2), accumulation of sleep and day duties remained significantly associated with decreased fatigue, and early duties remained significantly associated with increased fatigue, whereas duty time, block time and number of sectors, now became significant predictors of fatigue. A stepwise sensitivity analysis showed that accumulation of duty time, block time and sectors became significant when accumulated sleep was entered into the analysis (Figure 3).

In order to determine whether work period variables would influence the association between accumulated duty time and fatigue, pairwise interaction analyses were carried out when the other variable (aside from accumulated duty time) of a pair

| Past 24-h period | Model 1 Singly, Coeff. ± SE | \(Z^p\) | Model 2 Together, Coeff. ± SE | \(Z^p\) |
|------------------|-----------------------------|--------|-------------------------------|--------|
| Duty time (h)    | 0.182 ± 0.009               | 19.5^d | 0.114 ± 0.032                | 3.6^d  |
| Constant model 1 | 3.583 ± 0.133               |        |                               |        |
| Block time (h)   | 0.299 ± 0.015               | 19.1^d | 0.019 ± 0.047                | 0.14   |
| Constant model 1 | 3.713 ± 0.131               |        |                               |        |
| Sectors (#)      | 0.228 ± 0.012               | 18.2^d | 0.019 ± 0.047                | 0.41   |
| Constant model 1 | 3.791 ± 0.135               |        |                               |        |
| Hours from start (h) | 0.142 ± 0.008          | 17.4^d | 0.028 ± 0.021                | 1.3    |
| Constant         | 3.667 ± 0.139               |        |                               |        |
| Duty type        |                             |        |                               |        |
| Late             | 0.581 ± 0.066               | 8.9^d  | 0.554 ± 0.067                | 8.3^d  |
| Early            | 0.636 ± 0.055               | 11.5^d | 0.238 ± 0.061                | 4.0^d  |
| Very early       | 0.787 ± 0.096               | 8.2^d  | 0.488 ± 0.102                | 4.8^d  |
| Constant model 1 | 3.882 ± 0.137               |        |                               |        |
| Sleep (h)        | −0.264 ± 0.018              | 14.9^d | −0.260 ± 0.021               | 12.6^d |
| Constant model 1 | 6.143 ± 0.177               |        |                               |        |
| Constant model 2 | 5.220 ± 0.286               |        |                               |        |

Note: \(N = 106\) for all analyses.

Coeff. = regression coefficient. SE = standard error of the regression coefficient.

\(Z =\) statistic. Constant = intercept with \(Y\)-axis. a = \(p < .05\), b = \(p < .01\), c = \(p < .001\), d = \(p = .000\).
from model 2 showed a significant association. The interaction was significant for the accumulated number of early flights (−0.007 ± 0.002, Z = 5.2, p = .000), interpreted as early flights showing a less steep increase in fatigue, compared to day duty, with increasing accumulated work period duty time. Also, the main effect of both variables showed a significant increase in fatigue with accumulated work period duty time (compared to day duty) (p = .000 for both). The interaction was significant also for duty time and late duties (C = 0.047 ± 0.021, p = .000), interpreted as late duties having a steeper increase in fatigue with duty time than
day duties. Other duty types did not show significant interactions, nor did work period accumulated sleep, work period accumulated block time or work period accumulated sectors.

3.4 | Changes in other variables than fatigue across the 7-day work period

In order to determine if the indices of amount of work or sleep were stable across the work period, we analysed the association between work period accumulated duty time with a number of variables from the 24 h window. Table 4 shows that duty time, sectors, block time, day duties and sleep increased, and very early and late duties decreased across the work period.

4 | DISCUSSION

For the 24-h window (acute) all variables entered singly were significantly associated with fatigue. Duty time, block time, sectors, time from start and non-day duty types were all associated with increased fatigue, whereas amount of sleep was associated with decreased fatigue. When all variables were entered at the same time, sleep, non-daytime duties and duty time retained their significant regression. Block time, hours since start and number of sectors lost their explanatory power due to the influence of duty type and sleep. For the 7-day work period, the results indicate that the accumulation of early and very early duties was associated with increased fatigue, whereas accumulation of sleep was associated with decreasing fatigue. When accumulated sleep was entered into the regression, accumulated duty time, number of sectors and block time became associated with increasing fatigue, and early duties lost their significant association.

### Table 4

| Variable                  | Singly Coeff. ± SE | Z^\text{p} |
|---------------------------|--------------------|------------|
| Day duty (yes/no) Constant| 0.023 ± 0.005      | 4.53^d     |
| Early duty (yes/no)       |                    |            |
| Constant                  | 0.003 ± 0.005      | 0.58       |
| Very early duty (yes/no)  |                    |            |
| Constant                  | −0.006 ± 0.003     | 2.44^a     |
| Late duty (yes/no)        |                    |            |
| Constant                  | −0.013 ± 0.004     | 3.34^c     |
| Sleep (h)                 |                    |            |
| Constant                  | 0.012 ± 0.002      | 6.74^d     |
| Sectors (#)               |                    |            |
| Constant                  | 0.020 ± 0.002      | 9.39^d     |
| Block time (h)            |                    |            |
| Constant                  | 0.057 ± 0.002      | 29.30^d    |
| Duty time (h)             |                    |            |
| Constant                  | 0.105 ± 0.003      | 33.13      |

Note: Coeffic. = regression coefficient. SE = standard error of the regression coefficient. a = p < .05, b = p < .01, c = p < .001, d = p = .000. p = level of significance.

4.1 | Fatigue and scheduling during the past 24 h: acute effects

For the 24-h analysis, the main new findings when all variables were analysed together were that sleep loss was the strongest predictor of fatigue and that non-day duty types strongly reduced the regression coefficients for duty time, block time, sectors and hours from start, rendering all but the first of these variables non-significant. Sleep was also strongly curtailed for early and very early duty types, as well as increased for late duty types (i.e., pre-flight sleep), but not affected by temporal variables (such as duty time) and sectors. The effect of duty time on fatigue agrees with the findings of Powell et al. (2007) and Powell et al. (2008), as does the effect of duty type on fatigue. Similar effects of early and late flights have also been demonstrated by Roach et al. (2012) and Vejvoda et al. (2014) respectively.

In addition, the significant interaction between sleep and early duty type indicates that the fatigue-reducing effect of sleep before early duties is steeper than that in day duties. This is probably because early duties contain higher fatigue levels due to greater closeness to the circadian nadir of fatigue (Dijk et al., 1992) and also when sleep is very short. The interaction between duty type and duty time indicates that early duties show a less steep increase in fatigue with duty time than day duties, presumably because fatigue is relatively high already at the start of duty time. Again, this is likely to be due to a stronger influence of closeness to the fatigue inducing circadian nadir (Dijk et al., 1992), but here the sleep loss of early rising is likely to have contributed, as also demonstrated by Roach et al. (2012). The interaction between duty time and late duties was also significant, suggesting that the increase in fatigue with duty time is steeper for late duties than for day duties (Figure 3).
here, as suggested by Vejvoda et al. (2014). However, the present study did not collect data on time of rising, which would have been necessary for an analysis of the contribution of time awake. The interactions between duty time and early and late duties were also found in Powell et al. (2007) and Powell et al. (2008), although analysed in a different way, and sleep was not factored into those studies. The strong role of sleep in fatigue levels in short-haul daytime operations is a new finding, even if the role of sleep in aircrew scheduling is well established in general. However, such a role is usually more explicit in overnight operations (Petrilli et al., 2006; Sallinen et al., 2020).

The results on sectors contrast with the findings of Powell et al. (2007), who found that the number of sectors remained a significant predictor of fatigue after adjustment for several schedule characteristics, but sleep was not included in that study, which may have been crucial. Goffeng et al. (2019) did not find a link between number of sectors and rated fatigue, although psychomotor vigilance test (PVT) reaction time showed a significant link. Honn et al. (2016) showed in an experimental simulator study that the number of sectors (5 vs. 1) had a modest, but significantly, increased effect on KSS and Samn-Perelli ratings, as well as PVT lapses. However, a laboratory study leaves out many of the influences of real life and it is not clear to what extent one can generalize the findings. The lack of influence of sectors on fatigue in the multivariable analyses of the present study seems to have been due to duty time dominating the association with fatigue and sectors and duty time being highly correlated. Other carriers may not have such a close correlation, leaving more space for both predictors.

### 4.2 Accumulation of fatigue during the 7-day work period

Despite the absence of previous work on cumulative effects on fatigue, the lack of association (Table 4, model 1) between fatigue and accumulation of duty time, number of sectors and block time was somewhat unexpected. Some support is found in the study by Goffeng et al. (2019), which did not find any change in Samn-Perelli fatigue scores or reaction time after 4 days of around 40 h of duty time. On the other hand, the same study found an impairment in reaction time performance with a higher number of sectors during the four-duty day period (range 10–20 sectors). Outside the aviation area, construction and oil rig workers working 14 or 7 days with 12-h shifts (with corresponding days off) also failed to show any effect of fatigue across the work days (Bjorvatn et al., 1998, 2006; Persson et al., 2003).

The clearest predictor of fatigue was accumulation of early and very early duties. These duties were also linked to fatigue in the analyses of the 24-h window and to sleep loss. As discussed above, it is a common observation that early starts of flights are associated with increased fatigue (Roach et al., 2012), and much of the effect is likely to be due to the interference with sleep (Roach et al., 2012). The latter notion is supported by the observation in the present study that the association with fatigue of accumulated early duties disappeared when accumulated sleep was entered into the regression.

The observation that accumulated sleep brought out a significant effect for accumulated duty time, seems to suggest that more sleep is counteracting the fatigue-increasing effects of accumulation of duty time. Furthermore, sleep duration increased with accumulation of duty hours, possibly preventing an increase in fatigue with accumulation of duty hours. We don’t know the reason for this increase, but very early and late duties decreased with accumulation of duty hours, possibly as a conscious strategy of scheduling. It is also possible that aircrew adapt their sleep strategy to yield more sleep during the work period. However, we did not collect data on bedtimes, which may have been used to support this notion. In addition, sleeping at hotels close to the airport probably allows a wider window for sleep, as does the absence of social obligations. One implication of the findings is that accumulated duty time may well increase fatigue if combined with rosters that include many very early and early flight duty periods.

In interpreting the results on accumulation of duty time across the work period, we suggest that high fatigue levels, present at the end of a duty day (see discussion of 24-h window), are reset by adequate sleep during the night. This needs empirical confirmation, however. Also, average accumulated duty time across the work period seems rather modest, even though the variability is considerable. One must also consider the positive effects of the 7-day rest period that preceded each 7-day work period.

Despite the arguments above for a lack of effect on fatigue of duty time (analysed singly) or number of sectors across a work period, one must consider that at some point of a theoretical continuum of duty time, there will occur an interference with sleep and rest opportunities, which will affect fatigue. The level at which this might occur is not known, however, and attempts to find such a point must include the added effect of time for commuting, eating, hygiene and socializing.

### 4.3 Limitations

Among the limitations of the present study is that the dependent variable was based on self-report. Yet, there are no well-established objective measures of fatigue usable in real-life work situations. EEG content and blink duration correlate with, for example, lateral variability in a high-fidelity driving simulator, but the amount of variance accounted for is modest (Anund, Kecklund, Peters, et al., 2008). The Psychomotor Vigilance Test is a well-established fatigue measure under controlled conditions (Lim & Dinges, 2008), but it has never been validated against real work performance during a work shift, and would take too long to carry out in a study with many (short) sectors. However, there is an urgent need for valid objective measures of work performance. Another limitation is that some participants did not provide information on age and gender, probably due to concerns of anonymity. Another limitation is that we did not collect data on bedtimes and times of rising, which would have made it...
possible to evaluate effects of time awake. Notwithstanding this, the purpose of the study was to evaluate effects of scheduling characteristics. A weakness is also that the study did not attract sufficient numbers of cabin crew to make a proper evaluation of that group. Finally, the results are only generalizable to daytime operations, albeit with a wide span of early and late flights.

4.4 | Summary

The main determinant of acute fatigue during short-haul flights was amount of sleep obtained, but scheduling factors such as early, very early or late duties and duty time were also important. The first two seemed to exert their effects via reduced sleep. The worst combination in terms of fatigue seemed to be reduced sleep and early duty type. Number of sectors, block time and time since start appeared to lack importance. With respect to the 7-day work period, fatigue increased with accumulation of more very early flights and decreased with accumulation of more sleep. It was also observed that the number of very early flights per day decreased across the work period, which may have allowed for more sleep being obtained, thus countering possible fatigue due to cumulation of duty time. This implies that long work weeks, with up to 60–65 h, may not cause high fatigue levels, as long as sleep is adequate.

4.5 | Implications

From a practical point of view the present results suggest that the amount of sleep, timing of flights and duty hours constitute important targets for intervention/regulation in the 24-h window. Number of sectors and block time seem to be without importance, based on the present findings. With respect to cumulative effects, it seems most important to keep the number of very early flights low to ensure adequate sleep. Apparently, many duty days can be worked in succession, without increased fatigue, as long as sleep is protected. However, although outside the scope of this paper, social aspects of a long working week must also be considered when scheduling such work.

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CONFLICT OF INTEREST

TÅ, HH, LW and MS report no conflicts of interest. TK and DK represent Jeppesen Systems AB, which has a business relationship with the airline involved. The app “Crew Alert” is owned by Jeppesen Systems AB.

AUTHOR CONTRIBUTIONS

TÅ, TK and DK designed the study. TK and DK handled the data collection. HH, LW and TÅ analysed the data and MS advised on the analysis and the manuscript. TÅ drafted the paper and all co-authors commented on and approved of the manuscript.

DATA AVAILABILITY STATEMENT

Data may be obtained upon request to torbjorn.akerstedt@ki.se

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