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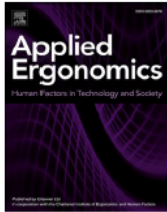
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## Effects of a modified shift work organization and traffic load on air traffic controllers' sleep and alertness during work and non-work activities

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### Highlights

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- Shiftwork reorganization had no overall effect on sleep or alertness

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- Air traffic load affects alertness both on-job and during daily non-work activities

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- Sleep satisfaction is lower for morning and night shifts

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- Subjective satisfaction measures refined self-reports of sleep duration

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### Acknowledgments

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### Declaration of interests

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The authors declare no competing interests.

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### Author contributions

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C.M. and N.C. designed the project, collected the data and performed statistical analyses and contributed equally to interpreting the results. C.M. wrote the manuscript and N.C. contributed to the final version.

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## Abstract

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2 A 'compressed' shift schedule (substitution of a rest day by a shift, shortening the duration of  
3 work breaks) was introduced for a better fit with aircraft traffic load. Thereafter, the company  
4 asked for a survey assessing the effects of the compressed shift system. Air traffic controllers  
5 (ATCOs) completed retrospectively a specific questionnaire assessing the effects of shift  
6 schedule (modified *vs.* initial) and of traffic load on fatigue, alertness (on-shift, upon  
7 awakening, during daily non-work activities), and sleep (duration, satisfaction). Work  
8 organization had marginal and unexpected effects, which might indicate ATCOs' disapproval  
9 of the intervention. Traffic load affected sleep satisfaction and alertness during work and non-  
10 work activities. Specific effects of shift included reduced sleep time prior to morning shifts  
11 compared to night shifts, whereas alertness and fatigue were rated at comparable levels for both  
12 shifts. Results suggest that shiftwork features which favor sleep loss across a work cycle have  
13 deleterious consequences on alertness and increase the need for recovery, which are further  
14 enhanced by traffic load.  
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27 **Key-words:** air traffic control, shift work organization, traffic load  
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## 1. Introduction

Air traffic controllers' (ATCOs) sleep and fatigue are determined by work-related factors, i.e. shiftwork, night-shift, workload, type of work performed, break frequency and duration, work environment conditions (ambient lighting, noise...), and by work-independent factors (for a review, Nealley and Gawron, 2015; Juda et al., 2013). While it is acknowledged that shift-work and workload, the most widely researched factors (Tucker and Folkard, 2012), produce work-related fatigue that may impact air traffic control (ATC) performance and safety, few field studies have examined the influence of these factors simultaneously (Edwards et al., 2012).

Traffic volume, traffic complexity, and working demanding positions several times during a shift cause fatigue (FAA, 2009). Fatigue is “a condition characterized by increased discomfort with lessened capacity of work, reduced efficiency of accomplishment, loss of power or capacity to respond to stimulation, and is usually accompanied by a feeling of weariness and tiredness” (Salazar, 2007, p. 1). Fatigue has been identified as a potential contributing factor in several operational errors (Della Rocco, 1999; FFA, 2009, 2013), and in 21 percent of aviation accidents (Wang and K e, 2013). According to ATCOs, mental workload, fatigue and alertness figure among the main human factors involved in ATC incidents, whereas an incident report indicated that these factors account for less than 24% of the incidents (Edwards et al., 2012). These results may indicate a reporting bias in incident reports, with normally present factors such as workload and fatigue being underreported. Mental workload *i.e.* traffic peaks and periods of continuous activity are considered to be the main sources of stress in ATC, enhanced by the necessity to operate under time pressure and by safety and security concerns (Costa, 2000), and are associated with health complaints (Cascino and M elan, 2019; Costa, 2000).

Around the clock ATC may exacerbate fatigue generated by high task demands as it requires individuals to work at times when they would normally be sleeping. More especially counter-clockwise shift rotations, scheduled overtime and on-the-job training could create potential fatigue conditions. Countries and companies regulate working time arrangements, in particular the number of working hours and the minimum rest periods between shifts, but also the number of controllers assigned to a shift, and recuperative breaks. In the absence of accurate metrics and systematic controlled studies, the extent to which the new policies impact ATCOs' fatigue is difficult to determine (FAA, 2013).

## 1.1. Workload during air traffic control

Task demands or task load is the demand imposed by the ATC task and is mostly assessed in terms of workload, *i.e.* the controller's subjective experience of that demand. Assessment of mental workload helps to understand the relationship between task demands and controller performance (Bommer and Fendley, 2018), which is crucial in the context of rapidly increasing air traffic density. In aviation-related research, mental workload is mostly assessed by subjective rating tools (Hart, 2006; Efthymiou et al., 2019; Mélan and Cascino, 2014), due to the availability and usability of these tools (Collet et al., 2009; Endsley and Rodgers, 1997; Galster, et al., 2001), though traffic density or traffic load (*i.e.* aircraft count by sector volume) has also been shown to be associated with psychophysiological measures of workload (Brookings, et al., 1996; Collet et al., 2009).

The present study focusses on ATCOs' sleep, fatigue and alertness in an *en route* ATC center (controlling commercial aircrafts flying in the airspace at high altitudes between airport approaches and departures). This working position is defined as a complex, safety-critical occupation involving a continuously changing workload (Efthymiou et al., 2019). In this working position, task load depends in particular on sector characteristics (sector volume), and traffic complexity in the sector *i.e.*, number of aircraft, flight altitude transitions, direction variations, trajectory uncertainty, proximity of aircraft, proximity measures between aircraft and weather conditions (Corver et al., 2016; Hilburn and Jörna, 2001; Loft, et al., 2007). Traffic load has been described as one of the strongest predictors of controller workload (Loft et al., 2007), more especially as it increases the likelihood that two or more aircraft will create traffic conflicts (Corver et al., 2016). In addition to high task demands, variable workload and night work have been identified as risk factors for fatigue and disturbed sleep (Åkerstedt et al., 2002; Bültmann et al., 2002; Flo et al., 2013; Takahashi et al., 2006). While the mental workload is perceived to be higher on day shifts (traffic peaks), a greater physical demand is perceived at night due to the need to remain alert and vigilant (Costa, 2000). Workload variations also occur within shifts (day and night shifts) (Mélan and Cascino, 2014), and the demands referring directly to the core ATC activities (psychological demands) are perceived as more demanding than those defining the context (physical demands, organizational demands, overcommitment and work-family interferences; Cascino and Mélan, 2019). Operator internal factors, including fatigue, skills, experience (Loura, 2014), and individual characteristics (Costa, 2000; Nealley and Gawron, 2015) are considered to mediate the relationship between task demands and the controller workload.

## 1.2. Fatigue and shift work components

Fatigue is generally acknowledged to be influenced by sleep length, number of hours awake, and work hours (Åkerstedt and Wright, 2009; Åkerstedt, 1998; Mélan et al., 2007). Short-term effects of shift work include reduced sleep, sleep quality and daytime alertness (Åkerstedt and Wright, 2009) for night and morning work (Åkerstedt, 1998; Costa, 2000; Flo et al., 2013; Luna et al., 1997; Sallinen and Kecklund, 2010) as a result of a circadian misalignment, and a sleep debt with early starts of morning work (Tucker et al., 1998; van de Ven et al., 2016). Accumulated sleep loss is also associated with impaired cognitive performance (Härmä, 2006), safety outcomes (Tucker and Folkard, 2012; Sluiter et al., 2003), long-term health effects and even increased mortality (Åkerstedt et al., 2018).

Combinations of specific shift work features may further enhance the conflict of work schedules with the operators' biological clock, and deteriorate sleep, performance and health (van de Ven et al., 2016). This has been reported for instance for the combined influence of circadian and time-on-task factors (Folkard and Tucker, 2003), low levels of workload and lack of alertness on night shifts (Lee et al., 2012), consecutive night shifts (Folkard and Tucker, 2003; Garde et al., 2020), backward- compared to forward-rotating shift systems (Knauth and Hornberger, 2003; Sallinen and Kecklund, 2010), and slow versus fast shift rotations (Juda et al., 2013). Further, ATCOs under 8-h alternate shifts, rather than 6-h rotational shifts showed lower scores for quality of life, and less sleep time on working days, which characterizes inadequate shiftwork for this population (Sonati, et al., 2015). Conversely, organizational interventions redesigning shift-work schedules according to ergonomic criteria, *i.e.* a switch from slow to fast and from backward- to forward-rotating systems, and self-scheduling, improved health and work-life balance (Bambra et al., 2008). Delaying time of the morning shift start to 7:00 or 8:00, and allowing a 2-hr break during the nightshift (taking turns to sleep) also led to higher job satisfaction in ATCOs (Costa, 2000, 2010). Some findings are however contradictory, in particular concerning densified work schedules (fewer work-days but longer shifts). Thus, working four days during 10h vs. five days during 8h did not affect ATCOs' performance (Schroeder et al., 1998), nor when a forward-rotating 10h day/14h night system replaced a backward 8h rotating system, despite worsened sleepiness and mood across the extended work shifts (Paley et al., 1998). Likewise, total sleep duration did not differ between fast 12h rotations and weekly rotations of 8h, but night shift sleep decreased persistently while

1 self-rated sleep need increased (di Milia, 1998). Densified shift schedules are however quite  
2 popular due to social and domestic factors or advantages such as more free time available for  
3 personal needs (Costa, 2000).  
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### 8 **1.3 Study aims**

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10 Due to additional flights over the summer holidays in an *en* route control centre the  
11 aircraft traffic in the centre was more intense during the summer period, with daily traffic peaks  
12 observed around 07:00, 13:00, 17:00 and 21:00. For these reasons, the local ATC centre  
13 authorities tested an experimental reorganization of work schedules between 22 July 2015 and  
14 Sunday 27 September 2015 in application of a decree (DEVA1517367A, published in the  
15 Official Journal of the French Republic, July 2015). The reorganization was designed to achieve  
16 a better match with the dense day-time traffic during the summer period (traffic peaks). This  
17 was achieved by assigning more ATCOs to the control room on day time (*i.e.* dividing the  
18 airspace into smaller air traffic sectors), by substituting a rest day by a work day, by delaying  
19 the beginning and end of shifts for part of the teams (overlapping shifts), and by reducing the  
20 duration of the breaks scheduled within each shift. In parallel, shift duration was limited to a  
21 maximum of 8h, except for the night shift. The decree was further accompanied by the  
22 requirement to test the efficiency of the shift schedule reorganization. Thus, once the modified  
23 shift-schedule had been introduced, the present authors were entrusted with the mission of  
24 assessing the impact of the new shift-schedule in terms of fatigue. To control for the effects of  
25 traffic density and of shift, we recommended adding these factors to the study design. Further,  
26 we proposed to assess the effects of these factors on other dimensions closely related to fatigue,  
27 in particular alertness and sleep.  
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45 Hence, the aim of the present study was to investigate the effects of both shift-schedule  
46 arrangements and traffic load on ATCOs' sleep, fatigue and alertness. A significant effect of  
47 traffic load was expected, with increased sleep length and alertness and reduced fatigue for  
48 lower aircraft traffic (Åkerstedt et al., 2002; Corver et al., 2016; Nealley and Gawron, 2015;  
49 Lee et al., 2012). We hypothesized that the beneficial effect would be most marked for morning  
50 shifts, as reduced traffic may counterbalance the well-known deleterious effects associated with  
51 early morning shift beginning (Tucker et al., 1998). Further, ATCOs' fatigue was expected to  
52 decrease and their sleep quality and duration to increase with the modified work schedule as a  
53 consequence of an increased number of controllers on position. The beneficial effects were  
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1 expected to be reduced or even absent for the night shift as the length of this shift (10h)  
2 remained unchanged, in addition to shorter recuperative breaks, and a smaller number of  
3 ATCOs on position during the night shift (Luna et al., 1997; Mélan et al., 2007).  
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## 8 **2. Materials and Methods**

### 9 **2.1. Procedure**

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12 The study project was initiated at the end of the first summer period that ATCOs worked  
13 according to the modified schedule. This excluded the possibility of performing real-time  
14 measures, including physiological recordings or actigraphy measures. A retrospective study  
15 design was therefore proposed, using a questionnaire. The first two sections of the questionnaire  
16 assessed the effects of the initial and of the experimental work-schedule respectively. A third  
17 section assessed the impact of traffic density. The three sections of the questionnaire were  
18 identical, but each referred to a different working period: (period 1) initial work-schedule with  
19 dense traffic (July to September 2014); (period 2) initial work-schedule with reduced traffic  
20 (October to December 2014); (period 3) experimental work-schedule with high traffic density  
21 (July to September 2015). The questionnaire was available on-line over a 5-week period (13<sup>th</sup>  
22 January to 19<sup>th</sup> February 2016) and all ATCOs of the center were informed that they should  
23 complete the three sections in a single session and that they could not switch back to previous  
24 pages or sections. The data collected for each period were compared in order to explore the  
25 impact of the modified work schedule (comparisons between periods 1 and 3) and the effects  
26 of traffic density (comparisons between periods 1 and 2).  
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### 43 **2.2. Participants**

44 All ATCOs working in the *en route* center situated in the North-East of France were invited to  
45 participate in the study. A total of 57 ATCOs volunteered to complete the questionnaire,  
46 representing 21% of the ATCOs working in the center. Their mean age was 38.9 (range 28 to  
47 56) and they had been air traffic controllers for a mean of 11 years (range 1 to 36). 17 (29.8%)  
48 were female and 40 (70.2%) were male. The distributions according to gender and age were  
49 close to those of the entire ATCO population (respectively, 25.6% and 73.4% for gender and  
50 35.8 for mean age).  
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### 2.3. Work schedules

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2 ATCOs worked rapidly rotating shift systems of 12 days. Table 1 indicates the beginning and  
3 end of each shift (shift duration), and the duration of breaks for both the initial shift-schedule  
4 (white lines) and for the modified shift schedule (grey lines). This information is provided for  
5 the 12 two-member teams (the radar and the planner) working a shift. Each team was in charge  
6 of one air space sector.  
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11 During the initial work cycle, ATCOs alternated three shifts, three rest days (R), and again three  
12 shifts and three rest days. At the beginning of the cycle they worked successively a morning  
13 shift (M<sub>1</sub>, 06:00-13:00), a day shift (D, 08:00-18:30) and an evening-shift (E<sub>1</sub>, 15:00-23:00),  
14 and after the mid-cycle rest days, again a morning shift (M<sub>2</sub>, 07:00-13:00) and an evening-shift  
15 (E<sub>2</sub>, 15:15-23:45) followed by a night shift (N, 19:45-06:00). The work cycle can be  
16 summarized as follows, M<sub>1</sub>DE<sub>1</sub>RRRM<sub>2</sub>E<sub>2</sub>N<sub>2</sub>RRR.  
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23 In the modified work-cycle, the shifts were organized in the same order and the cycle-duration  
24 did not change (12 days). The main modification concerned the substitution of the third mid-  
25 cycle rest day by a work shift for half of the teams, thereby reducing the number of rest days.  
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28 This additional day shift (08:00 to 15:00 +/-1hr) is noted D\* in the work cycle  
29 (M<sub>1</sub>DE<sub>1</sub>RRD\*M<sub>2</sub>E<sub>2</sub>N<sub>2</sub>RRR). A second modification consisted in delaying the beginning and  
30 end of shifts for part of the 12 teams working a given shift. Both these modifications ensured  
31 that more ATCOs were in the control room at critical moments of the shift with respect to traffic  
32 peaks. This made it possible to control more air traffic sectors, and conversely to reduce the  
33 number of aircraft to be handled within each sector relative to the number typically handled  
34 when they worked according to the initial shift schedule.  
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42 Further, though the rest breaks were scheduled approximately after two hours of air traffic  
43 control in the initial and modified shift schedules, their duration decreased particularly during  
44 the shifts after mid-cycle, independently of reductions that resulted from a reduction in shift  
45 duration (in particular for the day shift D; see below). Thus, rest break duration on the morning  
46 and evening shifts following mid-cycle was reduced by 15 or 30 minutes in the modified shift  
47 schedule. More importantly, the duration of the breaks was shortened by 1 to 2h30 during the  
48 night shift in the modified compared to the initial work schedule.  
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55 To mitigate the densifying effects of the work schedules, the maximum shift duration (shift  
56 length) was limited to 8 and a half hours for shifts worked during the day. Consequently, the  
57 particularly long day shift, lasting initially between 10h30 and 11h30, was reduced by two to  
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three hours depending on the teams. The duration of the morning and evening shifts, which lasted initially between 9 and 11 hours for two teams, was set to a maximum of 8h30 for all the teams in the modified shift system. The length of the night shift was not modified: It lasted 10h for 10/12 teams in the initial schedule, and also for 8/12 teams in the modified schedule. On the night shift all the twelve teams worked until 06:00 in the initial schedule, but only eight teams in the modified shift schedule. The four remaining teams ended the shift shortly after midnight.

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Table 1. Work cycles, shift beginning and shift end, shift duration, and break duration for the initial shiftwork schedule (white lines) and the modified shiftwork schedule (grey lines).

Shift	Schedule system	ATCOs (=n)	Shift beginning and shift end	Shift duration	Modification of shift duration (min)	ATCOs (=n)	Break duration (min)	Modification of breaks length (min)
Morning shift M <sub>1</sub>	Initial	10	06:00-14:00	8h00	/////	8	45 + 60	/////
						2	30 + 60	
		2	06:00-16:30	10h30		2	15 + 60 + 60	
	Modified	4	06:00-14:00	8h00	unchanged	4	30 + 30 + 60	15 min more
		4	06:00-14:00	8h00	unchanged	4	30 + 60	15 min less
		2	06:00-14:00	8h00	unchanged	2	30 + 60	unchanged
2		06:00-14:00	8h00	150 min less	2	30 + 60	45 min less (shorter shift)	
Day shift D	Initial	2	07:30-18:30	11h00	/////			/////
		8	08:00-18:30	10h30		12	30 + 60 + 75	
		2	08:00-19:00	11H30				
	Modified	12	10:00-18:30	8h30	120 to 180 min less	12	60 + 75	30 min less (shorter shift)
Evening shift E <sub>1</sub>	Initial	2	09:15-19:45	10h30	////	2	90 + 45 + 60	/////
		2	15:00-23:00	8h00		2	60 + 45	
		8	15:00-23:00	8h00		8	60 + 60	
	Modified	2	13:00-21:30	8h30	120 min less	2	60 + 45 + 45	45 min less (shorter shift)
		2	15:00-22:00	7h00	60 min less	2	60 + 45	unchanged
		2	15:00-22:30	7h30	30 min less	2	60 + 60	unchanged
6	15:00-23:00	8h00	unchanged	6	60 + 60	unchanged		
Three rest days	Initial	/////						
Two rest day		/////						
Experimental shift D*	Modified	2	07:00-15:00	8h	additional shift			
		2	08:00-16:00	8h	additional shift	6	30 + 60	
		2	08:30-16:30	8h	additional shift			

Shift	Schedule system	ATCOs (=n)	Shift beginning and shift end	Shift duration	Modification of shift duration (min)	ATCOs (=n)	Break duration (min)	Modification of breaks length (min)
Morning shift M <sub>2</sub>	Initial	2	06:30-15:00	8h30	/////	2	30 + 60	/////
		8	07:00-15:00	8h00		8	45 + 60	
		2	07:00-18:00	11h00		2	45 + 60 + 90	
	Modified	2	06:30-15:00	8h30	unchanged	2	30 + 30 + 60	30 min less
		2	06:30-15:00	8h30	30 min more	2	30 + 60	15 min less
		6	07:00-15:00	8h00	unchanged	6	30 + 60	15 min less
		2	07:00-15:00	8h00	180 min less	2	30 + 60	105 min less (shorter shift)
Evening shift E <sub>2</sub>	Initial	2	11:30-20:45	9h15	/////	2	60 + 30 + 60	/////
		10	15:15-23:45	8h30		2	60 + 60	
						2	60 + 45	
						2	60 + 75	
						4	45 + 75	
	Modified	2	12:00-20:30	8h30	45 min less	2	120 + 30	unchanged
		2	15:15-23:00	7h45	45 min less	2	75 + 60	plus 15 min
		2	15:15-23:30	8h15	15 min less	4	60 + 60	minus 15 min
6		15:15-23:45	8h30	unchanged	4	60 + 45	minus 15 min	
Night shift N	Initial	2	19:00-06:00	11h00		2	135 + 180 (315)	
		10	19:45-06:00	10h15		2	105 + 180 (285)	
						4	105 + 100 + 150 (355)	
						2	105 + 150 + 90 (345)	
						2	60 + 150 + 90 (300)	
	Modified	4	16:30-00:30	8h	minus 180 min	4	45 + 30 + 60 (135)	only 8 ATCOs after 00:30
		8	19:45-06:00	10h15	unchanged	4	60 + 30 + 120 (210)	minus 145 min
						2	60 + 120 + 30 (210)	minus 135 min
					2	60 + 60 + 120 (240)	minus 60 min	
Three rest days	Initial							
Three rest day	Modified							

## 2.4. Materials

In order to investigate the effects of shift schedule and traffic load on several psychological and physiological dimensions according to the shift worked, we developed a specific self-administered questionnaire. Existing tools mostly assess operators' perceptions of shift work conditions in general rather than on specific shifts. Further, existing tools mostly focus on one psychological dimension, *i.e.* either on sleep, or on alertness. In the present questionnaire three shift-types were considered by grouping comparable schedules into "morning-shift" (M1, M2), "evening-shift" (D, E1, E2) and "night-shift" (N) respectively. The questionnaire included three identical sections relating respectively to the three 3-month periods described above. Each section comprised the same 24 items and was introduced by adequate rating instructions in reference to the work schedule and traffic period. Participants were asked to rate most of the items separately for each shift type and for rest days, and some items as an overall measure concerning the entire period. The present report focuses on ATCOs' self-ratings of sleep, alertness and fatigue (15 items) while the results concerning the nine remaining items are not detailed in the present report as they relate to other dimensions, *i.e.* quality of work life (team atmosphere, overall quality of work life), workload and stress (overall workload, perceived stress on shift beginning and end and across the shift) and quality of non-work life (atmosphere in personal and family lives, conciliation between work and non-work activities, overall quality of life). The three sections of the questionnaire were completed outside working time in about 15 to 20 minutes altogether.

- The assessment of sleep concerned both the duration of sleep (6 items) and the quality of sleep (2 items), rated separately for each shift and on rest days. The overall duration of sleep across the 24 h day was assessed by including nocturnal sleep (bedtime and waking hour) and diurnal sleep after night-shifts and naps (onset time and duration). Satisfaction with sleep duration ("*The duration of my sleep, the night before a morning/afternoon/night-shift/rest day was...*") and sleep quality ("*The quality of my sleep, the night before a morning/afternoon/night-shift/rest day was...*") were rated on a 6-point Likert scale (from 1 "not satisfied" to 6 "very satisfied").
- Alertness and fatigue (5 items) were assessed for each shift and on rest days using 6-point Likert-type scales (from 1 "not satisfied/strongly disagree" to 6 "very satisfied/strongly agree"). These items related to on-shift fatigue ("*During the morning/afternoon/night-shift I sometimes felt tired*") and alertness at the beginning of the shift ("*I felt very fit at the beginning of the morning/afternoon/night-shift*") and at

1 the end (“*I felt very fit at the end of the morning/afternoon/night-shift*”). Alertness  
2 outside working hours was also explored, i.e. alertness upon awakening (“*My energy*  
3 *level upon awakening on a morning/afternoon/night-shift/rest day was...*”) and during  
4 non-work activities (“*My energy level during non-work activities on a*  
5 *morning/afternoon/night-shift/rest day was...*”).  
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10 • Satisfaction with the work organization (2 items) was evaluated for the entire period by  
11 indicating satisfaction with the work schedule (“*I evaluate the work schedules for the*  
12 *period...*”) and with break duration (“*In my opinion, the daily work breaks were...*”) on  
13 6-point Likert-type scales (from 1 “not satisfied” to 6 “very satisfied”).  
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## 21 **2.5. Statistical analysis**

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23 The study data correspond to the responses collected with the on-line questionnaire. ATCOs’  
24 self-ratings on each of the 15 items (*i.e.* variables) were considered separately for each study  
25 period, and for each shift-type. Raw rating scores were considered for those items rated on 6-  
26 point scales and sleep duration (for night sleep, day-time sleep, naps, total sleep) was expressed  
27 in minutes.  
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31 All variables had a normal distribution (except for sleep duration) and were analyzed with 2-  
32 way repeated measure ANOVAs of study period and shift (morning/afternoon/night-shift/rest  
33 day), followed by planned pairwise comparisons. The effects of work organization were  
34 assessed by the comparison of the initial shift schedule (period 1) and of the modified schedule  
35 (period 3). The effects of traffic load were determined by comparing the high and reduced traffic  
36 periods (periods 1 and 2 respectively). Sleep duration data were analyzed with non-parametric  
37 statistics (Friedman’s test followed by Wilcoxon’s test). Pearson’s correlation test was used to  
38 test for significant associations between two variables. For all statistics, the level of statistical  
39 significance corresponded to  $p < .05$ .  
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## 49 **3. Results**

### 50 **3.1. Effects of traffic density on sleep duration and subjective variables**

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52 As expected, results indicated a marked effect of traffic density on most of the variables  
53 investigated.  
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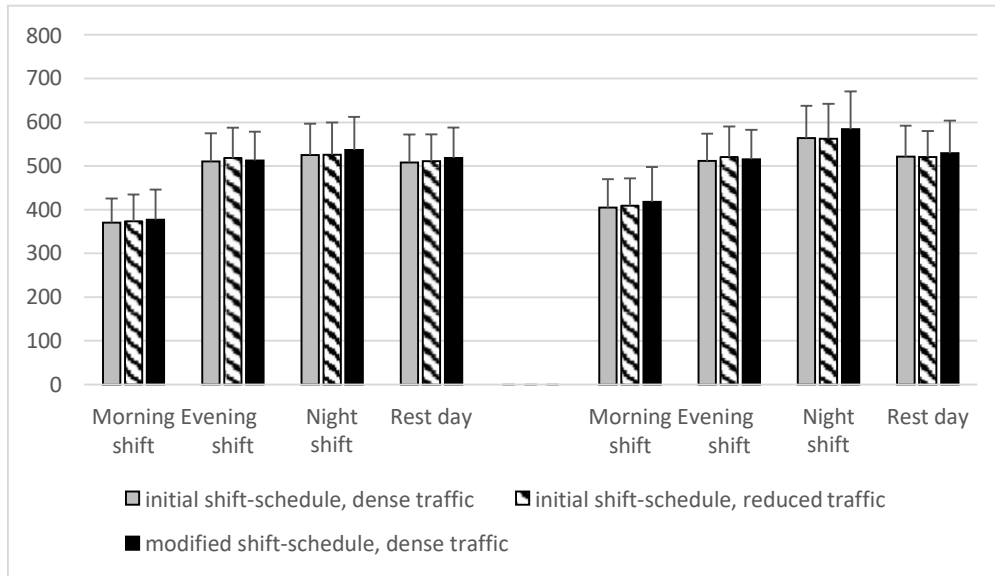


Figure 1. Night sleep duration (left panel) and total sleep duration (night rest and naps, right panel) expressed in minutes (M/S.D.) for the three research periods according to the shift worked and on rest days.

Sleep duration in ATCOs was first analyzed separately for night-time sleep (including the daytime sleep following the night shift) and naps (Tables 2 and 3), and thereafter the total sleep duration over the 24-h day was considered (Figure 1). The duration of the night rest and of the total sleep time were not significantly modified according to traffic density, whereas ATCOs' self-reported satisfaction with the duration of their sleep (Figure 2) varied consistently according to work period ( $F(2,159) = 6.05, p = .003$ ), with significant higher satisfaction when the traffic load was low ( $M = 4.39$ ) rather than high ( $M = 4.08; p < .001$ ).

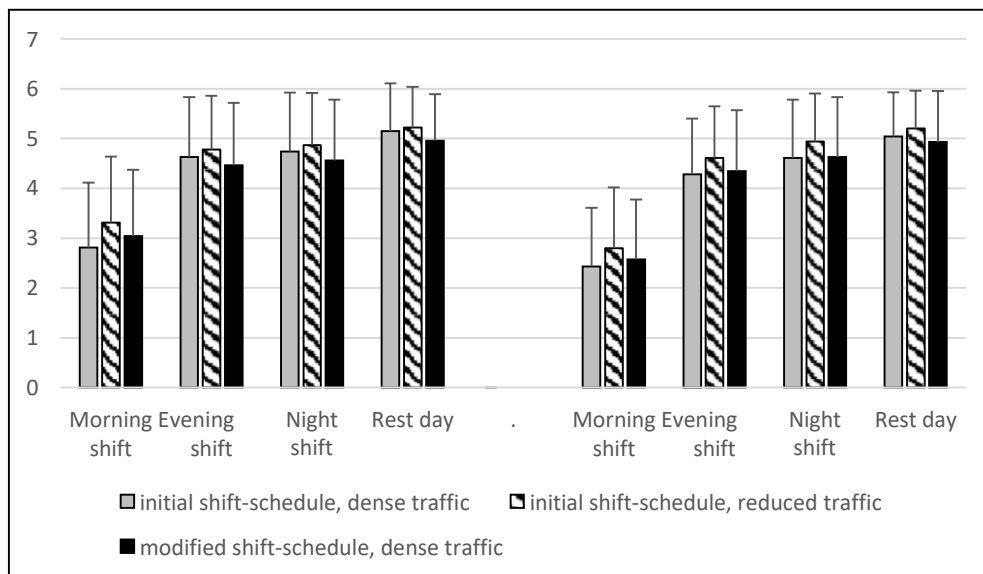


Figure 2. Self-rating scores (M/S.D.) of satisfaction with the quality (left panel) and the duration (right panel) of their night rest according to the shift worked and on rest days, for the three research periods.

Likewise, satisfaction with sleep quality (Figure 2) was significantly affected by work period ( $F(2,106) = 4.14, p < .019$ ), and an interaction of work period x shift ( $F(6,318) = 3.49, p = .002$ ). Satisfaction with sleep quality was lower when the traffic load was high ( $M = 4.33$ ) rather than reduced ( $M = 4.54$ ), but this difference fell short of significance ( $p < .065$ ). The interaction between research period and shift indicated on each research period lower satisfaction prior morning shifts compared to all other shifts and rest days, and prior night and evening shifts compared to rest days, while their satisfaction with sleep quality was comparable for evening and night shifts.

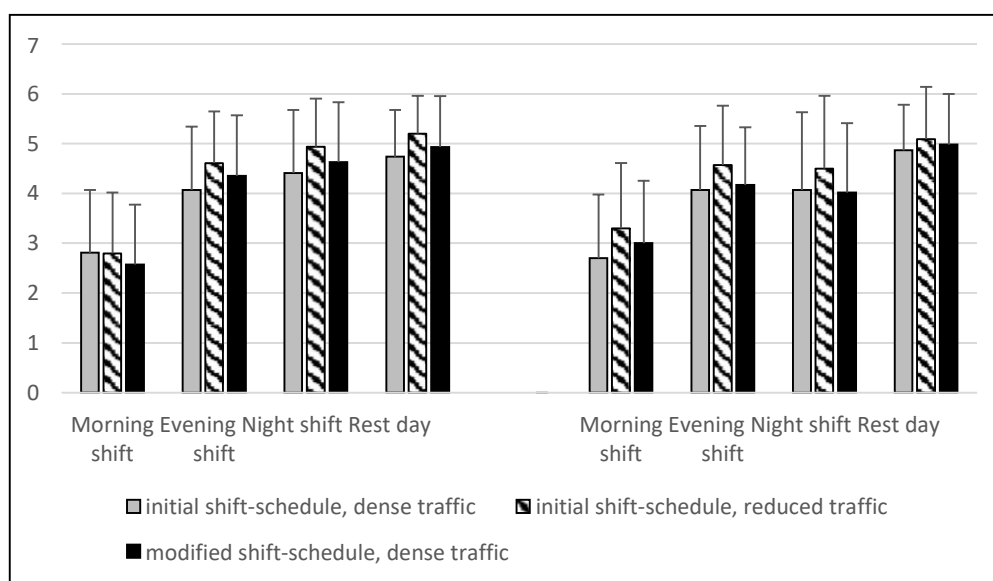


Figure 3. Alertness upon awakening (M/S.D., left panel) and during daily non-work activities (right panel) for the three research periods according to the shift worked and on rest days.

Analysis of ATCOs' alertness outside work (Figure 3) revealed a significant effect of research period ( $F(2,106) = 12.95, p < .001$ ) on alertness upon awakening and an interaction between research period and shift on this variable ( $F(6,318) = 2.53, p = .02$ ). Alertness was higher with reduced traffic load ( $M = 4.52$ ) compared to high traffic load (initial shift schedule,  $M = 4.0, p < .001$ ). The interaction with shift resulted in each research period from significant lower alertness for morning shifts compared to the other shifts and rest days, and on evening shifts and night shifts compared to rest days. ATCOs rated their alertness upon awaking however at comparable levels on evening and night shifts. Alertness during daily non-work activities also differed according to research period ( $F(2,106) = 7.17, p = .001$ ). As for alertness upon



awakening, alertness in non-work activities was significantly enhanced when the traffic load was low ( $M = 4.36$ ) rather than high ( $M=3.93$ ,  $p < .001$ ).

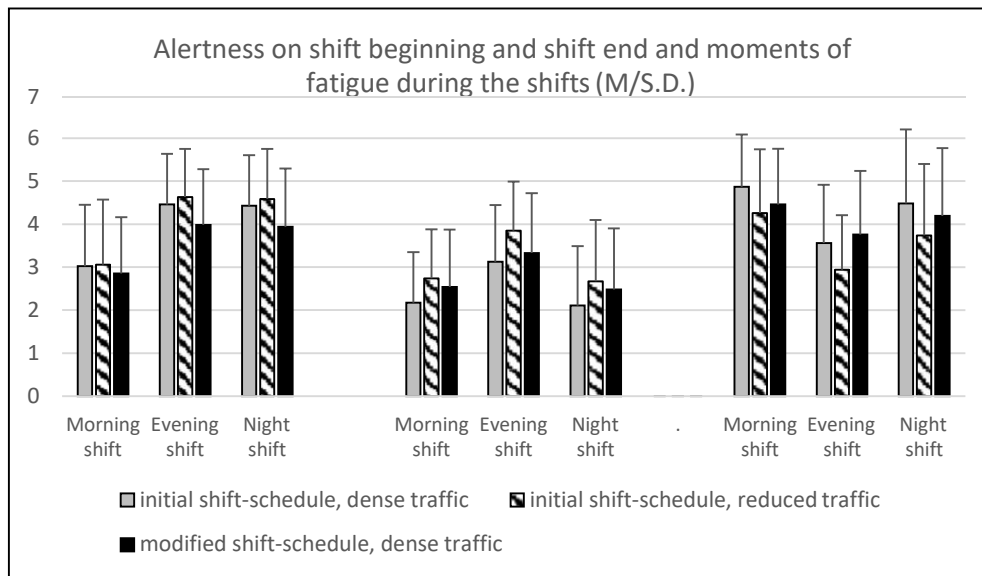


Figure 4. Alertness on shift beginning (M/S.D., left panel) and on shift end (middle panel) and fatigue during the shift (right panel) for the three research periods and the shift worked.

ATCOs' alertness ratings at work (Figure 4) differed significantly between research periods for shift beginning ( $F(2,106) = 6.41$ ,  $p < .002$ ) and for shift end ( $F(2,106) = 6.98$ ,  $p < .001$ ).

Pairwise comparisons revealed no significant differences for alertness on shift beginning according to traffic load (initial work schedule, low traffic load,  $M = 4.09$ ; high traffic load,  $M = 3.96$ ), whereas on shift end ATCOs rated alertness at a significant higher level when traffic load was lower rather than high (respectively,  $M = 3.08$  and  $2.47$ ;  $p < .001$ ). Analyses of ATCOs' on-shift fatigue self-ratings (Figure 4, right panel) also revealed a significant effect of research period ( $F(2,106) = 6.70$ ,  $p < .002$ ), with more moments of fatigue when the traffic load was high ( $M = 4.30$ ) than low ( $M = 3.65$ ;  $p < .001$ ).

In addition to sleep and alertness ratings, ATCOs also rated their overall satisfaction with the work schedule and with the breaks scheduled during the shifts. Analyses of the results indicated an effect of research period on both satisfaction measures ( $F(2,106) = 12.001$ ,  $p < .001$ ;  $F(2,106) = 18.37$ ,  $p < .001$  respectively). Satisfaction with the work schedule and break scheduling was increased when the traffic load was reduced ( $M = 4.50$  and  $M = 4.83$ , respectively) rather than high ( $M = 3.61$  and  $M = 3.85$ , respectively).

### 3.2. Effects of shift-schedule on sleep duration and subjective variables

No effect of shift schedule was observed on sleep duration and satisfaction, nor on alertness. The duration of the night rest and of the total sleep time (Figure 1) were not significantly modified according to shift-schedule. Likewise, no effect of shift schedule occurred on satisfaction with sleep duration (initial schedule,  $M = 4.09$ ; experimental schedule,  $M = 4.12$ ) and on satisfaction with sleep quality (initial schedule,  $M = 4.33$ ; experimental schedule,  $M = 4.26$ ; Figure 2).

As indicated on Figure 3, no significant change occurred for alertness upon awakening (initial schedule,  $M = 4.01$ ; experimental schedule,  $M = 4.05$ ) and during daily non-work activities (initial schedule,  $M = 3.93$ ; experimental schedule,  $M = 4.04$ ). ATCOs' alertness ratings at work (Figure 4) for the beginning (initial schedule,  $M = 3.97$ ; experimental schedule,  $M = 3.59$ ) and end of shift (initial schedule,  $M = 2.47$ ; experimental schedule,  $M = 2.78$ ), and for on-shift fatigue self-ratings (Figure 4, right panel; initial schedule,  $M = 4.30$ ; experimental schedule,  $M = 4.14$ ) also revealed no significant change with work organization.

Further, neither their overall satisfaction with the work schedule (initial schedule,  $M = 3.61$ ; experimental schedule,  $M = 3.76$ ) nor their overall satisfaction with the breaks scheduled during the shifts (initial schedule,  $M = 3.85$ ; experimental schedule,  $M = 4.30$ ) differed according to work organization.

### 3.3. Effects of shift on sleep duration

Table 2 summarizes the percentage of ATCOs taking a nap when they worked either shift-type and on rest days. The table shows that about half of the ATCOs had a nap when they worked a morning shift or a night shift (45% to 50%), but only 10% or less when they worked an evening shift.

Table 2. Percentage of ATCOs having naps for the three research periods according to the shift worked and on rest days.

% of ATCOs having a nap				
	Morning shift	Evening shift	Night shift	Rest day
Initial shift schedule, dense traffic	45.61	10.53	56.14	28.07
Initial shift schedule, reduced traffic	45.61	7.02	50.88	21.05
Modified shift schedule, dense traffic	50.88	7.02	56.14	26.32

Table 3 indicates a longer mean duration of naps when ATCOs worked a morning or a night shift (one hour at least), compared to days they worked an evening shift (around 20 minutes). On rest days, about 25% of the ATCOs took a nap, of an intermediary duration. As the number of ATCOs napping varied considerably according to the shift worked, these data could not be analyzed with statistical tools. The table indicates, however, that no marked apparent differences occurred for the napping behavior according to shift schedule or traffic load.

Table 3. ATCOs' mean nap duration (mn) for the three research periods according to the shift worked and on rest days.

Mean duration (min) of naps				
	Morning shift	Evening shift	Night shift	Rest day
Initial shift schedule, dense traffic	71.48	20.00	50.47	46.56
Initial shift schedule, reduced traffic	76.35	24.00	66.33	42.08
Modified shift schedule, dense traffic	67.34	26.67	80.97	41.00

As indicated by the left panel on Figure 1, ATCOs indicated a night rest of about six hours prior to a morning shift and about eight and a half hours prior to an evening and a night shift, and on rest days. The difference between shifts was significant for the three research periods, *i.e.*, when traffic load was high (initial work schedule,  $X^2(3, 56) = 124, p < .001$ ; modified work schedule,  $X^2(3, 52) = 106.99, p < .001$ ), and when traffic load was reduced,  $X^2(3, 54) = 99.69, p < .001$ ). Post-hoc tests revealed a significantly reduced night rest prior to morning shifts compared to the other shifts and to rest days in each of the three research periods (in all cases,  $p < .001$ ). Further, the night rest was longer before a night shift compared to a rest day during the two periods with high traffic independently of the shift schedule (initial shift schedule,  $p = .003$ ; modified shift schedule,  $p = .004$ ) and compared to the evening shift worked according to the modified shift schedule ( $p = .004$ ).

Analyses of the total sleep duration (night rest plus naps; Figure 1, right panel) confirmed the significant differences between shifts during high traffic periods worked with the initial shift schedule ( $X^2(3,56) = 116.13, p < .001$ ) and with the modified shift schedule ( $X^2(3, 52) = 103.02, p < .001$ ), and during the reduced traffic period ( $X^2(3, 54) = 90.46, p < .001$ ). As for the night rest, the total sleep duration in all research periods was significantly reduced prior to morning shifts compared to the evening and night shifts (in all cases,  $p < .001$ ). While the total sleep duration was enhanced prior to night shifts compared to evening shifts and rest days, in this case systematically in all research periods (in all cases,  $p < .001$ ), a difference between evening shifts and rest days occurred only when ATCOs worked the modified shift system ( $p = .032$ ).

### 3.4. Effects of shift on sleep satisfaction, alertness and fatigue

ATCOs' self-reported satisfaction with the duration and the quality of their sleep is illustrated on Figure 2. Statistical analyses revealed a main effects of shift ( $F(3,159) = 133.41; p < .001$ ) that resulted from a markedly lower satisfaction with sleep length prior to morning shifts ( $M = 2.60$ ) than prior to evening shifts ( $M = 4.41$ ), night shifts ( $M = 4.73$ ), and on rest days ( $M = 5.06$ ) (in each case,  $p < .001$ ). ATCOs were also less satisfied with the duration of the sleep that preceded a night shift ( $p = .008$ ) than the one preceding an evening shift, and when they worked an evening ( $p < .001$ ) or a night shift ( $p = .001$ ) compared to rest days. Satisfaction with sleep quality also differed according to shift ( $F(3,159) = 91.20, p < .001$ ), indicating lower satisfaction with the quality of sleep on morning shifts ( $M = 3.05$ ) compared to evening shifts ( $M = 4.62$ ), night shifts ( $M = 4.72$ ), and rest days ( $M = 5.11$ ), and on evening and night shifts compared to rest days (in all cases,  $p < .001$ ), as was observed for satisfaction with the duration of sleep. However, unlike for the latter, ATCOs rated the sleep quality at the same level for evening and night shifts.

ATCOs' self-ratings of alertness upon awakening, illustrated by the left panel of Figure 3, differed according to the shift worked ( $F(3,159) = 89.35, p < .001$ ), with lower alertness for morning shifts (2.93) than for evening shifts (4.36), night shifts (4.53), and rest days (4.95), and on evening shifts and night shifts compared to rest days (for all comparisons,  $p < .001$ ). Alertness upon awaking did however not differ between evening and night shifts. The effects of shift on alertness during daily non-work activities (Figure 3, right panel) ( $F(3,159) = 64.77, p < .001$ ) resulted again from significantly lower alertness when ATCOs worked morning shifts ( $M = 3.0$ ) than any other shift (respectively, evening shift 4.27 and night shift 4.19) or on rest days ( $M = 4.98$ ), and on evening and night shifts compared to rest days (in all cases,  $p < .001$ ), except again for similar alertness levels on evening and night shifts.

ATCOs' ratings of alertness for shift beginning (Figure 4, left panel) differed significantly between shifts ( $F(2,106) = 52.30, p < .001$ ), indicating significant lower alertness ( $p < .001$ ) on morning shifts ( $M = 2.97$ ) compared to evening ( $M = 4.36$ ), and night shifts ( $M = 4.32$ ), and comparable alertness levels on evening and night shifts. Alertness on shift end also varied between shifts ( $F(2,106) = 24.12, p < .001$ ; Figure 4, middle panel), and this time alertness was significantly decreased both on morning ( $M = 2.48$ ) and night shifts ( $M = 2.42$ ) compared to evening shifts ( $M = 3.44$ ; in both cases,  $p < .001$ ). The effect of shift on ATCOs' self-ratings of on-shift fatigue ( $F(2,106) = 24.02, p < .001$ ; Figure 4, right panel) resulted from increased

fatigue on morning (M = 4.53) and night shifts (M = 4.13) compared to evening shifts (M = 3.42; in both cases,  $p < .001$ ), while no difference occurred between morning and night shifts.

### 3.5. Correlation analyses

Correlation analyses were performed between the different variables in order to test for relationships in particular between sleep duration and sleep satisfaction. Results indicate that sleep duration (night sleep and total sleep) was not correlated with sleep satisfaction (duration and quality) or any alertness measure (results not shown). However, sleep satisfaction measures (Table 4) were positively correlated with the different alertness measures (upon awakening, during extra-professional activities, on shift-beginning, on shift end), independently of shift and research period, except for alertness at the end of the night shift (satisfaction with sleep duration). Conversely, the subjective sleep indicators were negatively correlated with fatigue during the shift when ATCOs worked either shift with the initial shift organization or night shifts of the modified shift system.

Table 4. Results of correlation analyses between subjective sleep indicators (satisfaction with sleep duration and sleep quality) and various indicators of alertness and of on-job fatigue on morning shifts (M), evening shifts € and night shifts (N). Statistical significance: \*  $p < .05$ ; \*\*  $p < .01$ ; \*\*\*  $p < .001$ .

Initial shift schedule, dense traffic						
		Alertness shift start	Alertness shift end	Fatigue on shift	Alertness awakening	Alertness activities
Satisfaction with sleep duration	M	0.465**	0.427**	-0.481**	.588**	.642**
	E	0.627**	0.487**	-0.323*	.787**	.621**
	N	0.446**	0.185	-0.430**	.624**	.471**
	R	//	//	//	.655**	.642**
Satisfaction with sleep quality	M	0.431**	0.339*	-0.334*	.656**	.513**
	E	0.631**	0.442**	-0.238	.555**	.621**
	N	0.456**	0.118	-0.372**	.566**	.495**
	R	//	//	//	.576**	.632**
Initial shift schedule, reduced traffic						
		Alertness shift start	Alertness shift end	Fatigue on shift	Alertness awakening	Alertness activities
Satisfaction with sleep duration	M	.609***	.548***	-0.471***	.803***	.680***
	E	.664***	.523***	-0.461***	.834***	.759***
	N	.607***	.301*	-0.447***	.808***	.701***
	R	//	//	//	.788***	.526***
Satisfaction with sleep quality	M	.526**	.401**	-.377***	.733***	.632***
	E	.661**	.532***	-.521***	.719***	.811***
	N	.583**	.244	-.409**	.727***	.670***
	R	//	//	//	.784***	.489***
Modified shift schedule, dense traffic						
		Alertness shift start	Alertness shift end	Fatigue on shift	Alertness awakening	Alertness activities

Satisfaction with sleep duration	M	411**	.647***	-.164	.686***	.672***
	E	.440**	.529***	-.142	.830***	.783***
	N	.384**	.165	-.104	.655***	.634***
	R	//	//	//	.744***	.714***
Satisfaction with sleep quality	M	0.533**	0.524**	0.265	.662***	.613***
	E	0.409**	0.408**	0.210	.683***	.748***
	N	0.495**	0.185	0.276*	.657***	.682***
	R	//	//	//	.773***	.702***

### 3.6. Summary of the results

As expected, results revealed beneficial effects when the aircraft traffic load was lower, as indicated by significant reduced moments of fatigue and higher alertness at work and outside worktime, in addition to enhanced sleep satisfaction. In contrast, working the modified work organization did not produce similar positive effects on neither of the subjective measures. Further, neither work organization, nor traffic load yielded a significant effect on the more objective variable of sleep duration. However, the factor of shift induced a consistent main effect rather than an interaction on all the objective and subjective variables investigated. Further, while ATCOs reported a shorter sleep duration prior the morning shift compared to the other shifts, they indicated decreased sleep satisfaction and alertness and increased on-job fatigue prior both morning and night shifts compared to evening shifts. Interactions between research period and shift, observed for satisfaction with sleep quality and for alertness upon awakening, confirmed the effects of shift.

## 4. Discussion

### 4.1. Assessment of the results with regards to the research questions

In the present study ATCOs were asked to make shift-specific judgments for sleep length and satisfaction, and for alertness and fatigue rather than average judgments or "best case scenarios". They rated separately their on-job alertness and their alertness while doing non-work activities, given that both work related and non-work related factors have been shown to affect fatigue (Nealley and Gawron, 2015) and work load (Cascino and Mélan, 2019; Edwards et al., 2012). Further, workload on each shift was assessed by rating alertness once for shift beginning and once for shift end and by rating on-shift fatigue. This methodology revealed significant differences in particular for sleep duration, sleep satisfaction, and alertness according to shifts (and rest days) and according to traffic load and work organization. A

1 marked impact was observed for traffic load and for the shift worked whereas quite marginal  
2 and partly unexpected effects were observed for shift schedule.

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4 The modified work organization did not produce the expected beneficial effects, as  
5 results did not indicate an improvement in ATCOs' perceptions consecutively to the  
6 intervention. Rather, ATCOs indicated sleeping more prior to night shifts than prior to evening  
7 shifts while working the experimental work organization compared to the initial work  
8 organization. On the one hand, this was unexpected as the duration *per se* of the night shift was  
9 similar in both work organizations. On the other hand, the number of teams working the night  
10 shift was reduced in the modified shiftwork schedule and work breaks were much shorter. From  
11 this point of view, the work conditions had worsened and may explain an increased need for  
12 sleep prior to the night shift. Alternatively, this and other results concerning the modified work  
13 organization (longer sleep on rest days, low sleep satisfaction for night shifts) might reflect  
14 ATCOs' disagreement with the schedule change. The work schedule modifications proposed  
15 by the flight center authority aimed to achieve a better fit with traffic load. Informal discussions  
16 with several ATCOs highlighted that their main expectation was different, *i.e.* to arrange the  
17 work conditions during the very difficult night shift, in order to lessen the risk of extreme  
18 fatigue. Hence, this expectation was not considered in the work reorganization process and  
19 work conditions actually worsened. Taken together these considerations suggest, in agreement  
20 with several intervention studies, that participants' expectations and attitudes towards a shift  
21 schedule change may affect the expected results (van de Ven et al., 2016).  
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38 Traffic load induced marked effects on ATCOs' perceptions, in agreement with the  
39 literature (Corver et al., 2016; Loft et al., 2007; Takahashi et al., 2006; Wang and Ké, 2013).  
40 ATCOs reported increased on-shift fatigue and decreased alertness on shift end for the period  
41 with high traffic load. The significant increase in fatigue before and after work in ATCOs has  
42 been shown to be related to an increase in mental load (Triyanti et al., 2020). The results support  
43 the idea that controller internal factors including alertness and fatigue mediate the relationship  
44 between task demands and the workload experienced by ATCOs (Edwards et al., 2012; Loura,  
45 2014). End of shift fatigue has thus been accurately predicted in nurses by including work  
46 demand variables from organizational data sources and from individual measures (Brzozowski  
47 et al., 2021). Furthermore, alertness upon awakening and during daily non-work activities was  
48 also enhanced in the period with reduced traffic load. These results indicate, though indirectly,  
49 that work interfered with ATCOs' general state while they were engaged in non-work activities.  
50 Such interferences have been reported in relation with health complaints (Cascino and Mélan,  
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2019) and stress the interest of considering in future shiftwork studies measures that provide information about participants' fitness outside working hours. Moreover, the reported sleep duration did not change according to traffic load, in contrast to the results reported in other studies (Åkerstedt et al., 2002; Corver et al., 2016; Nealley and Gawron, 2015; Lee et al., 2012). However, ATCOs' satisfaction with the duration of sleep was increased during the period with decreased traffic. Further, the more ATCOs were satisfied with the duration and quality of their sleep, the more they declared being alert during the day and also on shift. Taken together, these findings indicate that satisfaction measures may usefully refine sleep duration measures. Lower satisfaction with sleep duration has also been suggested to reflect an anticipatory effect of high workload (Mélan and Cascino, 2014). This explanation may also account for decreased satisfaction with sleep prior to morning shifts associated with high traffic.

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Tangible results were also obtained when ATCOs were asked to rate alertness and sleep according to the shift worked. More especially, the night rest was reduced by more than two hours for morning shifts compared to other shifts and rest days, confirming in this occupational situation the well-established curtailment of sleep by early start of morning shifts (Costa, 2000; Tucker et al., 1998; Van de Ven et al., 2016). Naps increased the total sleep time per 24-h day by approximately one hour for the morning and night shifts, enabling partial recovery from the sleep debt on a day-to-day basis. Total sleep time remained significantly shorter for morning shifts while it was enhanced for night shifts compared to rest days. Garde and co-workers (2020) reported shorter sleep for night shifts compared to recovery days. However, recovery days included both day shifts and rest days, which may have resulted in a lower mean sleep duration than the one that might be expected when only rest days are considered. Further, in their study night shifts lasted 8h whereas they lasted 10h in the present study, suggesting that the longer sleep duration reported here for the night shift may be attributed to the combined effects of time-of-day effects (circadian nadir) and of time-on-task factors (Folkard and Tucker, 2003; Lee et al., 2012; Sonati et al., 2015). Clearly, night shifts are associated with a high need for recovery which needs to be satisfied in order to maintain efficient cognitive functioning over time (Sluiter et al., 2003; Härmä, 2006; Sallinen and Kecklund, 2010) and health (Costa, 2010; Wang and Ké, 2013).

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Further, naps on rest days also probably provided an opportunity to recover on a weekly basis by compensating short night sleep on workdays (Åkerstedt et al., 2018). Indeed, 25% of the ATCOs had a nap on rest days and about 50% when they worked morning or night shifts. This result agrees with a survey reporting that 57% of ATCOs had a nap when they worked



1 night shifts (Costa, 2000). However, in Costa's study ATCOs reported sleeping roughly one  
2 hour more prior to morning shifts and one hour less following night shifts than the ATCOs  
3 reported on equivalent shifts in the present study. Unlike the work organization in the present  
4 study, shifts were scheduled according to ergonomic criteria, including late morning shift start,  
5 napping opportunities during night shifts, and shorter night shifts. Though methodological  
6 differences may contribute to the discrepant results, the data highlight the finding that shiftwork  
7 scheduling according to ergonomic criteria improves quality of life in shift-workers (Khaleque,  
8 1999; Knauth, 1996). More especially, redesigning better sleeping arrangements may improve  
9 sleep quality and thus daytime alertness and performance (Iridiastadi, 2021). Rest breaks are  
10 also associated with reductions in on-job sleepiness (Onninen et al., 2020). According to When-  
11 Chin and co-workers (2020), sufficient rest breaks and roster schedule optimization represent  
12 first-line countermeasure strategies, while monitoring ATCOs' task loads (*i.e.* traffic volume)  
13 is a secondary strategy.

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Subjective measures refined the interpretation of self-reported sleep duration. They indicated a systematically lower satisfaction with sleep quality and duration prior to morning shifts, associated with lower alertness during non-work activities. Whereas on-job alertness and fatigue were comparably low on both morning and night shifts, sleep duration was shorter for morning shifts than for night shifts. Accordingly, the effects of night shifts on work activities appear to be as disruptive as those of early morning shifts despite the longer sleep length associated with night shifts. This finding contrasts with studies reporting concurrent decreases in objective and subjective sleep indicators (Åkerstedt and Wright, 2009; Åkerstedt, 1998; Juda et al., 2013; van de Ven et al. 2016), raising the possibility that the subjective satisfaction ratings used in the present study were inadequate to assess shift-work effects on sleep. In this respect, Berastegua and colleagues showed that sleep-deprived individuals or people functioning under adverse circadian phase tend to underestimate fatigue-related impairments (Berastegui et al., 2020). They found no significant association between subjective sleepiness and time since awakening. On the other hand, subjective sleep variables, but not objective sleep duration, were positively correlated with on-job alertness, alertness upon awakening and while performing extra-professional activities and negatively correlated with moments of fatigue on duty. Taken together, these findings raise the possibility that objective and subjective sleep measures may assess different aspects of sleep.

## 4.2. Study limitations

1 In the present study, there are several methodological issues that need to be mentioned.  
2 Due to the closing date of the data collection fixed by the ATC authorities, it was unfortunately  
3 impossible to include in the study design a reduced traffic period worked according to the new  
4 work schedule. This would have made it possible to explore the effects of traffic load when  
5 ATCOs worked the modified shift schedule. In addition, the concurrent change of several  
6 aspects of the work organization did not enable a detailed analysis of the respective contribution  
7 of each shift work feature to the above reported effects. Interpretation of the effects of specific  
8 aspects of a shift schedule was also complicated by the fact that studies in the literature mostly  
9 assess issues of major modifications to the shift system, such as densification of shifts or  
10 forward- vs. backward rotations. Comparisons are made even more difficult by the erratic work  
11 schedules in the field of air traffic control, with variable start and stop times for day, evening,  
12 and night times. Such irregular controller work schedules are known to induce fatigue (FFA,  
13 2013). Further, retrospective self-ratings may not adequately report participants' momentary  
14 state, even more so when non-validated tools are used. Self-rated fatigue and alertness do not  
15 assess all the aspects of workload, *i.e.* the processes involved by task demands (planning,  
16 decision making, monitoring), internal factors (skills, training, experience, fatigue, various  
17 stressors), and individual characteristics (Costa, 2000; Loura, 2014; Nealley and Gawron, 2015;  
18 Wilson et al., 2021).

### 33 **4.3. Concluding remarks**

34 The present findings support the idea that reorganization of shift schedules should  
35 consider the well-known effects of circadian disruption induced in particular by early morning  
36 shifts and by night work. They demonstrate that a work reorganization that favors sleep loss  
37 across a shift cycle, for instance by replacing a rest day by a work shift or by reducing the  
38 duration of work breaks and thus of napping during the nightshift, has deleterious consequences  
39 on alertness and increases the need for recovery. Other work-related factors, and in particular  
40 the workload induced by the density of the air traffic to be controlled, also enhance fatigue and  
41 reduce alertness, increasing the need for recovery across a work-cycle. Subjective measures  
42 proved to be very useful in assessing ATCOs' perceptions of alertness beyond the more  
43 objective measure of sleep duration. The findings indicate that managers should define shift  
44 systems based on ergonomic criteria in order to minimize sleep loss and allow appropriate

recovery (on rest days), and ultimately ensure safety and security, in particular in safety-related job situations.

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Effects of a modified shift work organization and traffic load on air traffic controllers' sleep and alertness during work and non-work activities

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**Declaration of interests**

The authors declare no competing interests.