



# COLA I

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Final Research Report

## REVISION HISTORY

VERSION	DATE	PREPARED BY	COMMENTS
0.1	28 February 2023	M Peukert	Document created, initial draft
0.2	31 March 2023	M Peukert	Structure, empirical background
0.3	24 April 2023	M Peukert	Data collection
1.0	21 August 2023	M Peukert	Final Report
2.0	13 December 2023	M Peukert	Updates

## Summary

This research project focused on evaluating fatigue among air traffic control (ATC) professionals in real-world field settings. A key goal was to monitor fatigue during live operations, addressing the underexplored connection between shift work and fatigue under varying task loads in ATC. This project aimed to fill the gap in longitudinal and repetitive field measurements. To assess the impact of specific shift patterns on fatigue, iterative 3-week longitudinal-baseline studies were conducted to gather subjective and objective fatigue using a simple, precise, and efficient method. The objective was thus to develop a reliable method for measuring field fatigue. Additionally, the project delved into the influence of timing and shift type on fatigue. It aimed to comprehend how rostering and shift schemes impact fatigue, particularly in diverse workload scenarios. The field studies also investigated the potential mismatch between subjective and objective fatigue. Research questions included the progression of fatigue during different shift types, the influence of preceding shifts on subsequent fatigue, and the progression of fatigue over time. Finally, a fatigue review was conducted as a result of thorough literature research.

## Sammanfattning

Detta forskningsprojekt fokuserade på att utvärdera trötthet bland personal inom flygtrafikledning (ATC) i verkliga fältmiljöer. Ett viktigt mål var att övervaka trötthet under skarpt läge och ta itu med det underutforskade sambandet mellan skiftarbete och trötthet under varierande arbetsbelastning inom ATC. Detta projekt syftade till att fylla luckan i longitudinella och repetitiva fältmätningar. För att bedöma effekten av specifika skiftmönster på trötthet genomfördes iterativa 3-veckors longitudinella baslinjestudier för att samla in subjektiv och objektiv trötthet med en enkel, exakt och effektiv metod. Målet var således att utveckla en tillförlitlig metod för att mäta trötthet på fältet. Dessutom undersökte projektet hur trötthet påverkas av tidpunkt och skifttyp. Syftet var att förstå hur schemaläggning och skiftsystem påverkar trötthet, särskilt i olika arbetsbelastningsscenarier. Fältstudierna undersökte också den potentiella obalansen mellan subjektiv och objektiv trötthet. Forskningsfrågorna omfattade hur tröttheten utvecklas under olika typer av skift, hur tidigare skift påverkar den efterföljande tröttheten och hur tröttheten utvecklas över tid. Slutligen genomfördes en trötthetsgranskning som ett resultat av grundlig litteraturforskning.

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## **1 INTRODUCTION**

Managing fatigue among professionals is crucial, as it can significantly affect their performance and safety. To effectively mitigate and manage fatigue, it is essential to monitor and quantify levels of fatigue and alertness. The Controller Alertness (COLA) I project aims to achieve this goal by measuring fatigue and alertness among operational staff in air traffic control (ATC) during live operations. The resulting data should provide valuable insights into the extent of fatigue and help in developing better shift planning and rostering strategies. Certainly, the results could contribute to a more efficient and safer aviation.

### **1.1 Motivation**

Over the past few decades, there has been an increasing awareness of the impact of fatigue on work performance. Empirical evidence has shown that fatigue not only affects well-being, emotional health, and physical health but also impairs cognitive processes and work performance (Matthews et al., 2012). This is particularly relevant in our society that operates around the clock, such as ATC, where operators are required to work shifts and night shifts regularly. These types of work schedules can significantly decrease alertness and performance, which can ultimately compromise safety.

To address these challenges, high-level regulations, such as the European Union's (EU) 373/2017 regulation (EASA, 2017), have been implemented to require adapted fatigue management strategies in ATC. The regulation emphasizes the importance of identifying and managing the effects of fatigue on the safety of operations, thus creating awareness of the negative effects of fatigue, and collecting data for further development.

### **1.2 Document Structure**

This is the final report of the COLA I project. The document contains a brief introduction to the topic of fatigue in aviation. Subsequently, the primary objective of developing a reliable and efficient data gathering method for field fatigue measurement is presented. Additionally, the report presents the results of the conducted field studies and refers to the produced public output. The report concludes with a brief discussion and an outlook towards the COLA II project.

## 2 EMPIRICAL BACKGROUND

Many researchers acknowledge that fatigue poses a safety risk in the aviation industry (Bongo & Seva, 2021). Results indicate that fatigue is associated with reduced performance and can be a major issue for flight safety (Hartzler, 2014). Numerous definitions of fatigue exist, often overlapping in significant aspects. However, the most widely accepted definition comes from the International Civil Aviation Organization (ICAO). ICAO (2011) defines fatigue as *a physiological state of reduced mental or physical performance capability resulting from sleep loss or extended wakefulness, circadian phase, or workload (mental and/or physical activity) that can impair a crew member's alertness and ability to safely operate an aircraft or perform safety-related duties.*

Alternatively, according to the Federal Aviation Administration, FAA (2013), fatigue is a complex condition characterized by decreased mental and physical performance and a lack of alertness, often accompanied by sleepiness. It is typically used to describe a state of exhaustion that goes beyond normal sleepiness, as defined by various dictionaries. Sleepiness is generally considered less severe than fatigue since it can be relieved by rest and sleep, while fatigue is a state of overwhelming. During fatigue, individuals typically experience a disrupted sleep pattern and difficulty concentrating (Olson, 2007). Fatigue also leads to increased reaction time, attentional disturbances, decreased cognitive speed, situational awareness, and motivation, according to the FAA (2013).

The upcoming sections provide a summary of current research on factors that contribute to fatigue (antecedents), its effects, and strategies to address it (countermeasures). Lastly, the fatigue risk management process is described, which can be considered a systematic approach for managing fatigue.

### 2.1 Antecedents of Fatigue

Fatigue among ATC operators can be influenced by various factors. Demanding work conditions, such as high workload or low workload with associated monotony, can impact task performance (Straussberger & Schaefer, 2007). A simple but precise fatigue model was developed by May and Baldwin (2009; depicted in Figure 1). The model takes external conditions into account, that lead to several types of fatigue. The model splits between task-related and sleep-related fatigue. Task related fatigue is either active due to high workload (overload) or passive due to low workload (underload) conditions. On the other hand, sleep related fatigue is influenced due to the circadian rhythm and time of day. In ATC, both factors play a role, since low and high traffic situations are usually present, as well as work around the clock.

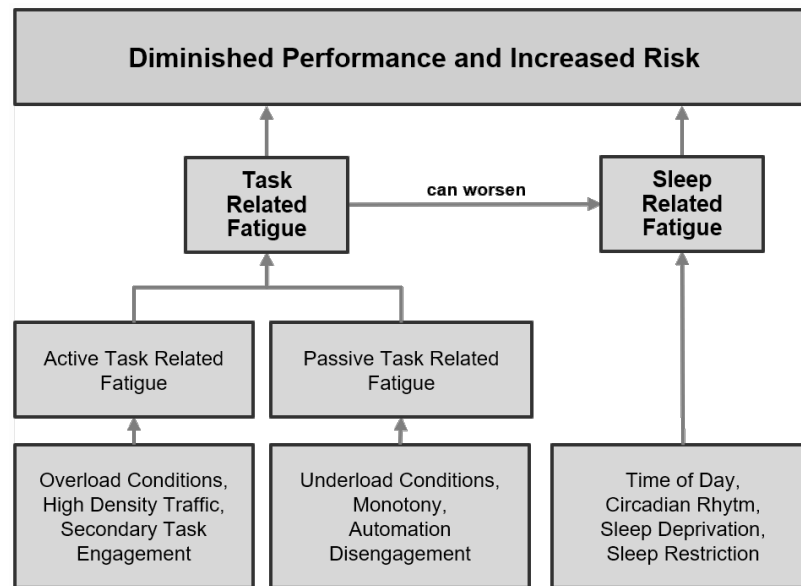


Figure 1. Fatigue process model adapted after May and Baldwin (2009).

Shift work is also known to affect alertness, and rostering factors such as shift type (e.g., day or night shift), shift length, and shift organization (e.g., time between successive shifts, rotation direction) can contribute to fatigue during operational work. Highest fatigue ratings are usually found towards the end of a shift (Chang et al., 2019; Chen et al., 2019; W.-C. Li et al., 2021; Peukert & Meyer, 2022). Along with this, time awake is linked to higher fatigue as well (Spencer et al., 2000). The following subsection provides an overview of current findings regarding the impact of shift work on fatigue, as this seems to be a major contributor.

Shift work is a major aspect of ATC work, and different types of shifts with varying lengths and fatigue potentials are common. Shift work per se seems to be linked to increased fatigue among Air Traffic Controllers, ATCOs (T. Li et al., 2019; W.-C. Li et al., 2021; Melton, 1985; Sonati et al., 2015). Early and night shifts have been found to disrupt sleep and lead to fatigue and reduced task performance (Nealley & Gawron, 2015). Night shifts, during the Window of Circadian Low (WOCL), i.e., 02:00 a.m. - 05:59 a.m., have been associated with higher objective and subjective fatigue ratings (Costa, 2009; Grandjean et al., 1971). Evidence suggests, that both, the early morning with early shifts (Cruz & Della Rocco, 1995; Della Rocco et al., 1996; Mélan & Cascino, 2022; Melton, 1985) and with early rise (Cruz & Della Rocco, 1995) as well as night shifts and night work (Bongo & Seva, 2021; Chang et al., 2019; Cruz & Della Rocco, 1995; Della Rocco et al., 1996; Gander, 2001; Grandjean et al., 1971; Mélan & Cascino, 2022; Peukert & Meyer, 2022; Russeng et al., 2021; Yoon et al., 2012) are associated with higher fatigue among ATCOs. Extended work duration and shifts longer than six hours also increase fatigue. Shift organization can be fixed or rotating, with rotating shifts being either regular or irregular. Regular rotation follows a fixed pattern, while irregular rotation is flexible and based on individual preferences, with the assumption that individuals will request shift types that prevent fatigue and enhance alertness. However, research has shown a poor match between self-evaluation and objective measures of fatigue, leading to potential fatigue-critical rostering factors, such as short time between successive shifts and counter clockwise rotation (Johnson et al., 1988; Yang et al., 2018). Quick returns, which are work shifts with less than 11 hours between successive shifts, have been found to promote fatigue and

reduce cognitive performance. Counter clockwise rotating shift schedules have been associated with increased fatigue, lower cognitive performance, and poorer health among ATCOs (Dall’Ora et al., 2016).

## 2.2 Effects of Fatigue

The impact of fatigue extends to both psychological and physiological processes. Studies demonstrate that fatigue reduces situational awareness, increases the risk of control errors, and impairs attention (Bongo & Seva, 2021). Additionally, information processing speed is slowed down (Papenfuss et al., 2010). Under fatigue, ATCOs exhibit slower work speed, reduced information processing, and diminished control initiative in performing their tasks (Zhang et al., 2018). Planning ability and performance are also negatively affected by fatigue, which is particularly concerning in the aviation industry where effective control strategies and planning skills that rely on cognitive resources are crucial (Karikawa et al., 2014). Interestingly, the FAA (2013) notes that subjective reports of fatigue may not always match objective observations of impaired performance, indicating that individuals may underestimate their level of fatigue.

## 2.3 Countermeasures of Fatigue

There are several measures identified to alleviate fatigue, including preventive and acute measures. None of these measures can entirely replace actual sleep, and combining various measures is likely to have a more significant effect (Rosekind et al., 1995). Operational measures aim to reduce acute fatigue during working hours and may include the use of psychoactive substances like caffeine, short recovery breaks (Neri et al., 2002), or environmental factors such as lighting (Cajochen, 2007). On the other hand, preventive measures are implemented before work and aim to promote sleep quality and quantity to prepare for long periods of sleep deprivation (Rosekind et al., 1995). Examples of preventive measures include maintaining proper sleep hygiene, taking naps, and ensuring a good shift organization. Timely organization of shifts is particularly important in rostering, where different shift types with varying organizational structures are used, necessitating the adaptation of countermeasures. Shift organization can be improved, for example, using rotating night shifts, which are a significant risk factor for fatigue.

## 2.4 Fatigue Risk Management Systems

The multifactorial nature of fatigue and its diverse effects highlight the need for a systematic approach to its management, which has resulted in the development of Fatigue Risk Management Systems (FRMS). The FRMS concept was developed to support airlines, pilots, regulators and operators (IATA et al., 2015, p. 202). ICAO introduced the FRMS in Annex 6 of the Standards and Recommended Practices, along with suggestions to reduce aircrew fatigue (ICAO, 2013). In 2016, a detailed guide for fatigue management for air navigation service providers was published, as well as a manual for the oversight of fatigue management approaches (ICAO, 2016). The FRMS is defined as a *data-driven means of monitoring and maintaining fatigue-related safety risks, based on scientific principles, operational experience and knowledge, with the aim of ensuring personnel perform at adequate levels of alertness*.

The FRMS can be implemented as standalone systems or integrated into existing Safety Management Systems (SMS), with the aim of improving work-life balance, alertness, and

increasing safety (Skybrary, n.d.). ICAO suggests several control mechanisms to mitigate the effects of fatigue, including recovery sleep prior to or after circadian lows for night shift work, as well as break opportunities during working times and between scheduled shifts (ICAO, 2016). However, personal circumstances can also contribute to fatigue hazards that are difficult to control.

### 3 RESEARCH QUESTIONS AND PROJECT AIM

The idea behind this research project is to evaluate fatigue among ATC professionals present in a field setting. A major aim of this project was to monitor fatigue during actual live operations. As demonstrated, is the interplay of shift work and fatigue under varying task load conditions only limited investigated so far. Longitudinal and repetitive field measurements are lacking. This gap will be filled by the project.

To analyse selected shift patterns regarding their effect on fatigue, iterative 3-week longitudinal-baseline studies shall be carried out to gather fatigue ratings in a simple but precise and efficient method. Thus, the first aim of this project was to develop a simple but efficient and reliable method measuring fatigue in the field.

*Thus, a method to measure fatigue in the field is deliverable 1 (section 4).*

Further, the influence of timing and shift type on fatigue was in focus. An understanding of rostering and shift schemes as well as its effect on fatigue under varying workload situations is aimed for. A potential gap between subjective and objective fatigue was investigated. The following research questions will be answered:

- 1) Shift type as a predictor: How is fatigue developing during different shift types?
- 2) Fatigue hysteresis as a predictor: How does the previous shift influence fatigue in the following shift?
- 3) Rotating scheme as a predictor: How does fatigue develop over a time span? Is fatigue accumulating?

*The results of these research questions are deliverable 2 (section 5).*

Finally, a fatigue review was conducted. The decision to write a fatigue review resulted from the conducted literature research. Due to the vast amount of literature, we divided it into two separate publications. Even though the finalized fatigue review can be considered the third deliverable, it is not presented in this report as it has yet to be published. The review was split into separate parts due to the extensive findings. The aim of the fatigue review is to provide guidance to aviation researchers and practitioners on the latest status of fatigue research. The review will be part of the COLA II report.

The project output status is briefly outlined in section 5.2.

## 4 DEVELOPMENT OF A FATIGUE MEASUREMENT METHOD (DELIVERABLE 1)

Quantifying fatigue presents a challenging undertaking. Despite a range of available methods, a universally unbiased and direct measure remains elusive. Each method has inherent limitations. While some methods are highly precise, others are more indirect and measure fatigue-associated performance or require significant effort by the participants. Furthermore, a well-thought-out measurement design is necessary to obtain valid data. In essence, the key to fulfilling this deliverable is a good selection of appropriate methods paired with their ample application.

After workshops with operational experienced professionals and fatigue experts, a field study approach was determined. This approach comprises subjective fatigue measurement and an objective, performance-based fatigue assessment method. For measurement fatigue subjectively was the Stanford Sleepiness Scale, SSS (Hoddes et al., 1972), selected. The SSS is a one-item, seven-point scale, with anchored items per number. Participants indicated their level of sleepiness on a scale ranging from “Feeling active, vital, alert, or wide awake” to “No longer fighting sleep, sleep onset soon; having dream-like thoughts”. The scale is rated as highly reliable instrument, frequently used in field and lab studies. To measure objective fatigue, a performance-based approach was determined. The gold standard to measure fatigue objectively is the Psychomotor Vigilance Task, PVT (Dinges & Powell, 1985). The PVT involves a reaction time (RT) task where participants must press a button upon the appearance of a stimulus on the screen. The decision was made to employ the 3-minute version of the test, known as PVT-B, as it has demonstrated comparable reliability to the original 10-minute version (Benderoth et al., 2021). The stimuli, represented as red circles measuring about 2 cm in diameter, were displayed on a black screen. In a single 3-minute test run, the number of stimuli presented ranged between 35 and 53, depending on the randomly varying interstimulus intervals. Reaction time (RT) was defined as the duration between stimulus presentation and the participant's activation of the space button on the keyboard. RTs surpassing 500 ms were classified as lapses, while RTs below 200 ms were categorized as false starts. The adoption of a 500 ms threshold for lapses aligns with established scientific research consensus, while the range for false starts typically falls between 100 ms and 350 ms (Arsintescu et al., 2019; Basner & Dinges, 2011). Lapses were evaluated as an absolute count but were also analysed relative to the total number of stimuli presented in each individual test run. Furthermore, the study software included questions regarding sleep duration before the shift and between test runs.

Both the SSS and PVT were integrated into a study software specifically developed for this purpose in-house. A central design feature of the software was its self-guiding approach, ensuring that every participant was automatically directed through all pertinent tests at the appropriate moments. Screenshots of the software interface are provided below (Figure 2 and Figure 3). The workstations included two separate computer, running the COLA software (Figure 4).



Figure 2. Screenshots and flow of the COLA software.

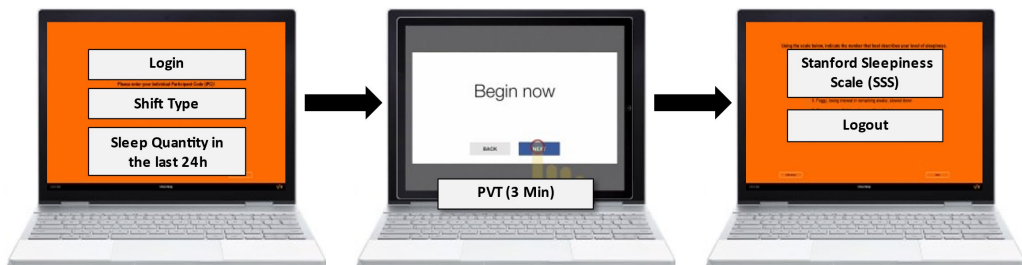


Figure 3. COLA method with structure.

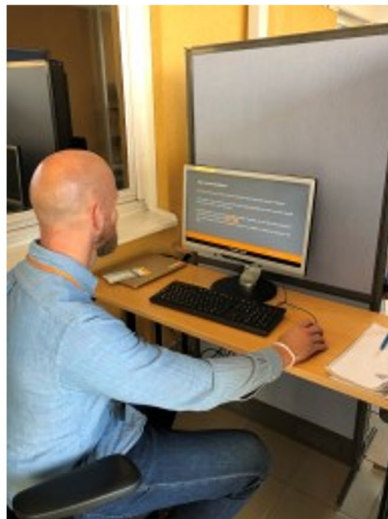


Figure 4. COLA computer and workstations.

Participants were directed to complete three computer-based sessions (at shift start of the shift, mid-shift, and at shift end) for all shifts over the three-week study duration. The extended study timeframe facilitated the collection of numerous shifts and diverse shift types per participant. Moreover, the three-measurement runs approach achieved a balanced compromise between efficiency and data quality. This method enabled the effective tracking of fatigue progression over time while avoiding excessive testing burdens on participants. An outlined overview of the method is provided below Figure 5.

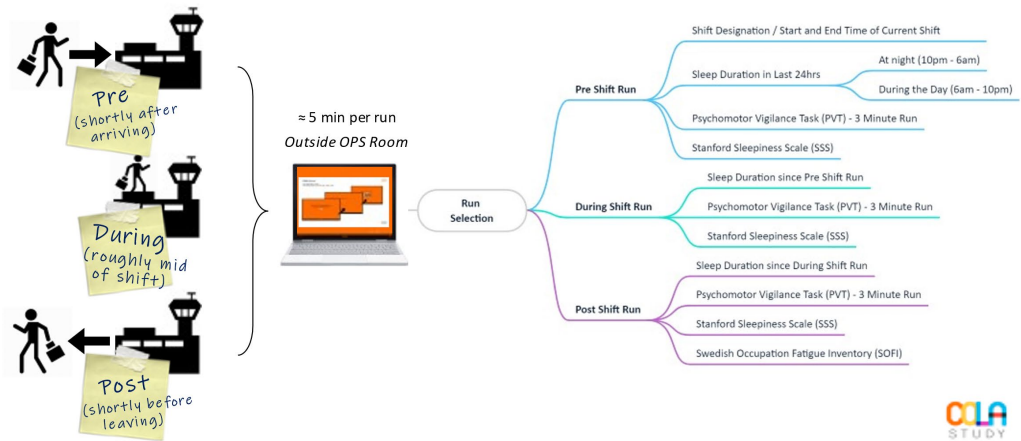


Figure 5. COLA method, systematic overview.

Prior the main data collection were participants asked to fill in an online presurvey. The presurvey consisted of a demographic questions (gender, age, work experience, work role), the chronotype (measured by means of a chronotype questionnaire MEQ, Griefahn et al., 2001) and the sleep quality (measured by means of the PSQI, (Buysse et al., 1989). The pre survey was adapted and renewed for every separate study run. An overview of the questions is given in Figure 6.

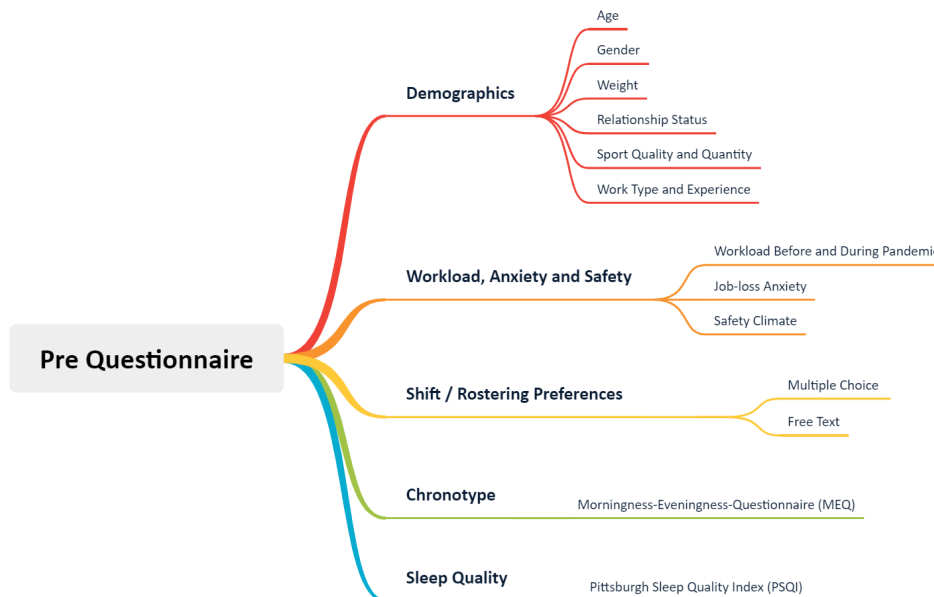


Figure 6. Sections and questions of the presurvey.

The overall time plan of the study approach and per data gathering is separated in different phases. An overview is given in Figure 7.

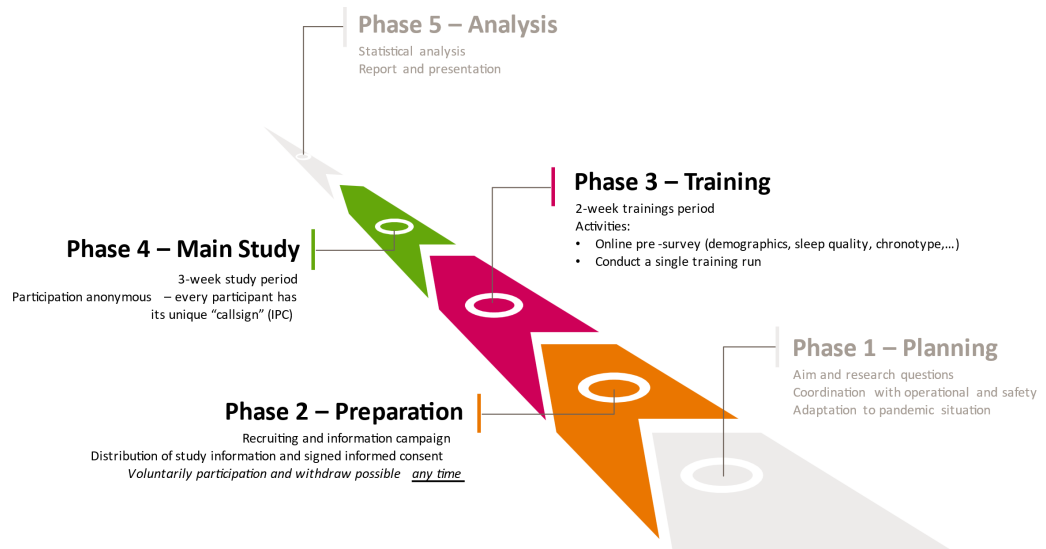


Figure 7. Time plan of a separate COLA study.

## 5 DATA COLLECTIONS AND STUDY RESULTS (DELIVERABLE 2)

During the COLA I project, which took place between September 2020 and December 2022, four field studies were conducted. This chapter not only presents the major results of the studies but also outlines the specific characteristics of each data collection. Additionally, it describes the given and planned research output of the project.

### 5.1 Study Campaigns

In the frame of COLA I were four field measurements conducted. This section gives an overview about the specifics of every study, including the major results. A synopsis over the data collections conducted so far are given in Table 1.

*Table 1.* Summary of all data collections conducted within the scope of the COLA I and COLA II.

STUDY	TIME	WORKPLACE	SPECIFICS	SECTION
<b>COLA I-1</b>	Oct 2020	Area Control Center	Initial study, included ATCOs, FDOs, WSs and Technicians	5.1.1
<b>COLA I-2</b>	May 2021	Area Control Center	Only night shifts, included only ATCOs and FDOs	5.1.2
<b>COLA I-3</b>	Oct 2021	Area Control Center	Same design as COLA I-1, included only ATCOs and FDOs	5.1.3
<b>COLA I-4</b>	Nov 2021	Tower	First data gathering in tower environment, included only ATCOs	5.1.4
<b>COLA II-1</b>	Oct 2022	Area Control Center	Same design as COLA I-1, included only ATCOs and FDOs	<i>not included in this report.</i>
<b>COLA II-2</b>	Oct 2023	Area Control Center	Same design as COLA I-1, included only ATCOs and FDOs	<i>not included in this report.</i>

### 5.1.1 COLA I-1

The first COLA study (conducted in October 2020) aimed to provide an overview of fatigue during operations. Data collection included ATCOs, watch supervisors, technicians, and flight data operators. The results of the study were published in a paper, presented at a conference in 2022 (section 5.2.1). The abstract is presented below.

The aim of this field study was to investigate the effects of rostering factors on subjective and objective fatigue in an irregular and preference-based shift system in Air Traffic Control. Subjective and objective fatigue as well as sleep duration were measured over a three-week period in N = 21 operational active individuals. The Stanford Sleepiness Scale and a three-minute Psychomotor Vigilance Task were administered three times during each shift in the study period. Differences in objective and subjective fatigue were found within and between shifts. Fatigue increased over time for three of four shift types. Fatigue was highest on night shifts and lowest on late shifts. A shorter time interval between shifts and a counterclockwise rotation pattern increased initial fatigue on the subsequent shift. Overall, a discrepancy was found between objective and subjective fatigue, indicating lower accuracy in self-evaluation of fatigue.

The full publication is available for download here:

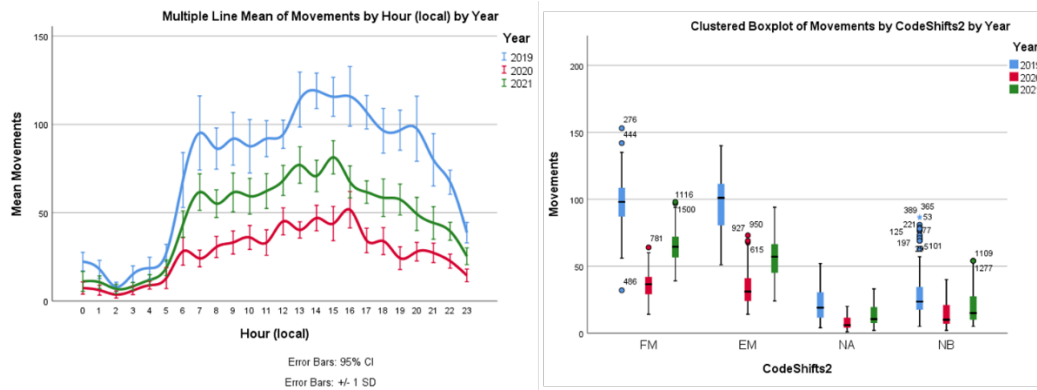


Figure 8. Traffic load over three years of the covered area, retrieved from Eurocontrol. The blue colour indicates traffic load prior the pandemic. Red (2020) and green (2021) indicate the traffic load during the pandemic and indicate the huge impact on traffic figures due to corona.

The results of COLA I-3 will be part of the final report of COLA II project.

5.1.4

COLA I-4

Since COLA I-1, I-2, and I-3 involved data collection in the ACC environment, we took the chance to investigate fatigue in shift work conditions in a tower environment. Therefore, we used the COLA method in a major tower. Results are presented below.

A total of  $n = 12$  subjects took part in the study. The sample's mean age was  $M = 46.4$  years, consisting of 11 ATCOs and 1 watch supervisor (WS). The mean work experience was calculated to be  $M = 22$  years (11 females and 3 males). 223 Test Runs were performed among them, including 85 Pre-, 68 During-, and 70 Post-Shift Runs. Figure 9 and Figure 10 provide an overview of the measured shifts.

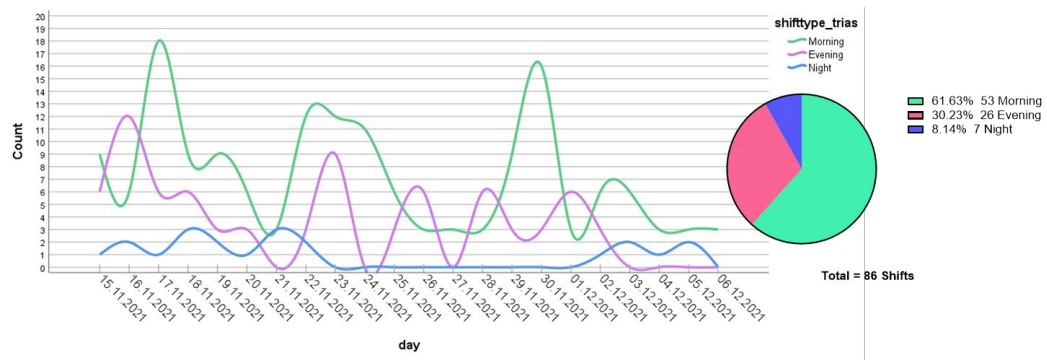


Figure 9. Measured shift types within COLA I-4.

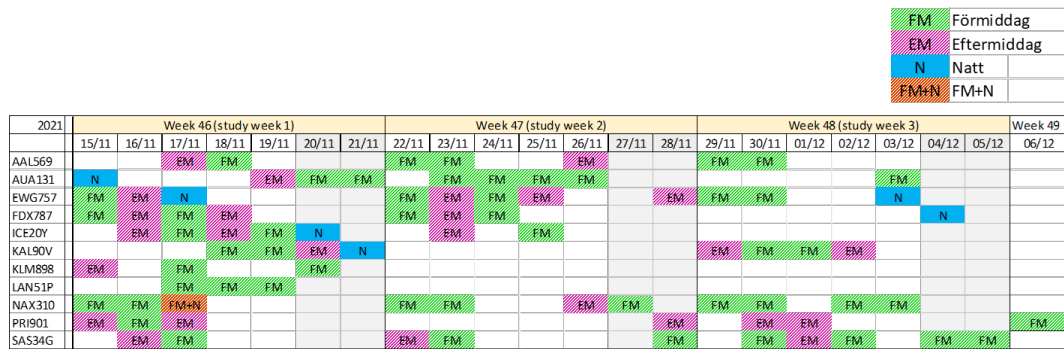


Figure 10. Measured shifts (the first column indicates the “callsign”, which corresponds to a single subject).

5.1.4.1.1

Results

Sleep length before shift was investigated. The results are shown below (Figure 11).

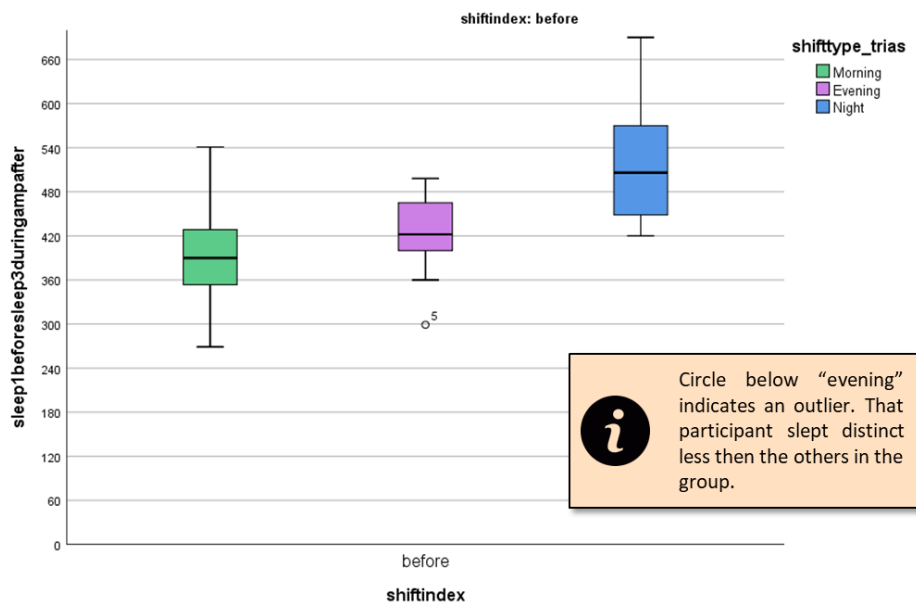


Figure 11. Sleep duration prior shift.

Sleep duration prior shift was investigated based on the rotation pattern. We investigated clockwise vs. counter-clockwise vs. same. The one-way ANOVA was (scarce) not significant  $F(2,41) = 3.190, p = .052$ . However, a post-hoc test (Games-Howell) showed a significant difference between clockwise and same (.021). The data indicates that individuals sleep longest prior a shift following a clockwise rotation scheme. When rotating anti-clockwise or same this led to reduced sleep duration. The results are shown in Figure 12.

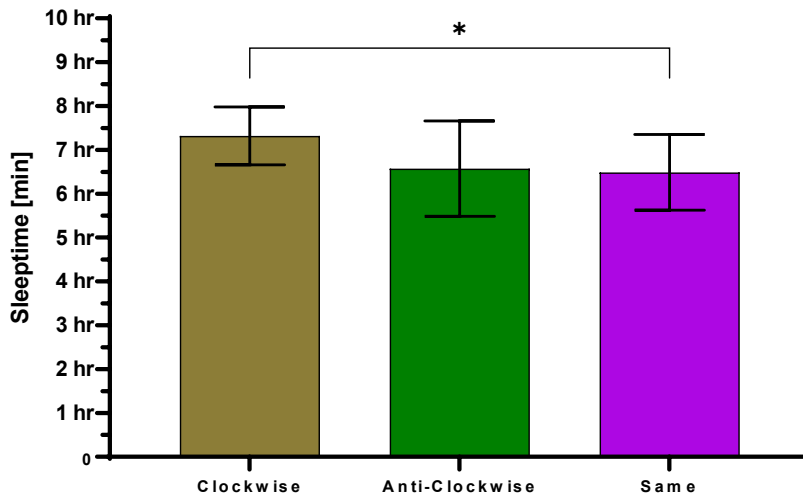


Figure 12. Sleep duration based on rotation direction.

A comparison of the subjective fatigue (SSS) is given in the following figures (Figure 13 and Figure 14).

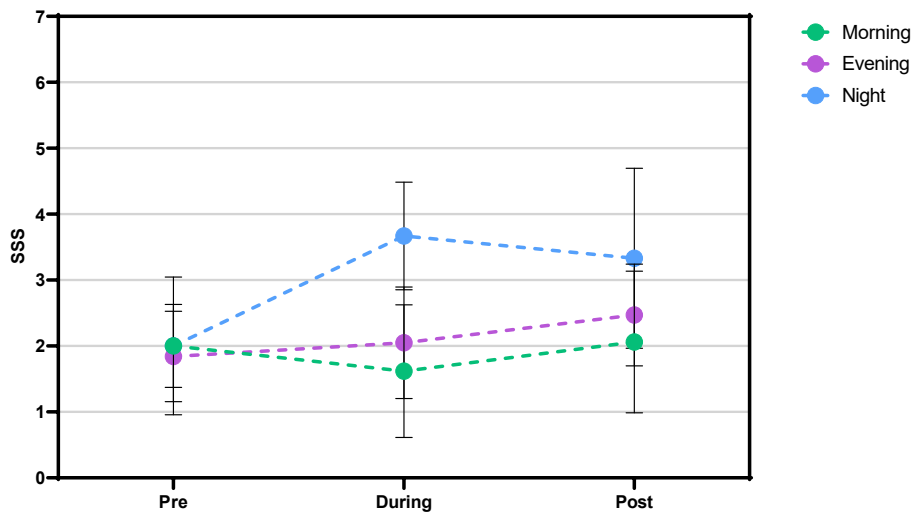


Figure 13. SSS data depending on shift type and time point.

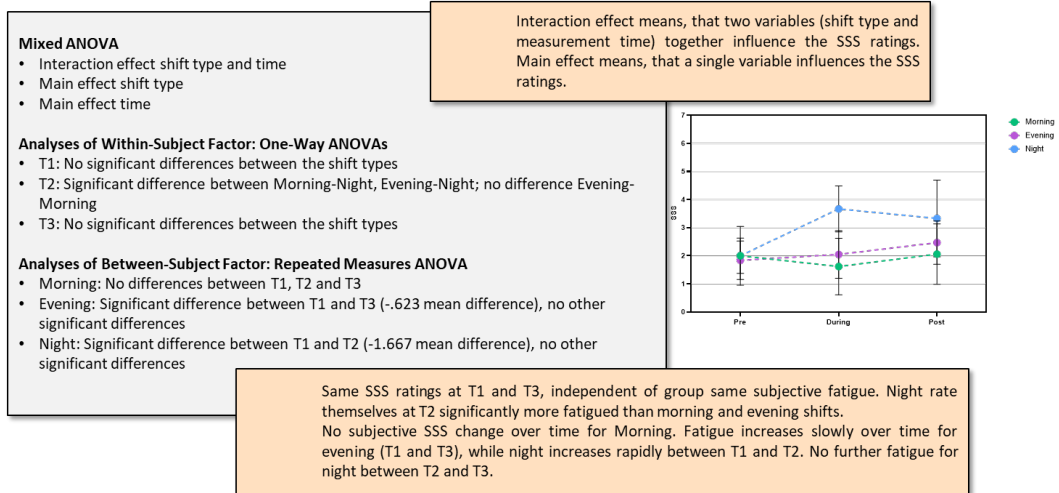


Figure 14. Statistical analyses of SSS.

The results of the objective, performance-based fatigue are given in the following figures (Figure 15 and Figure 16).

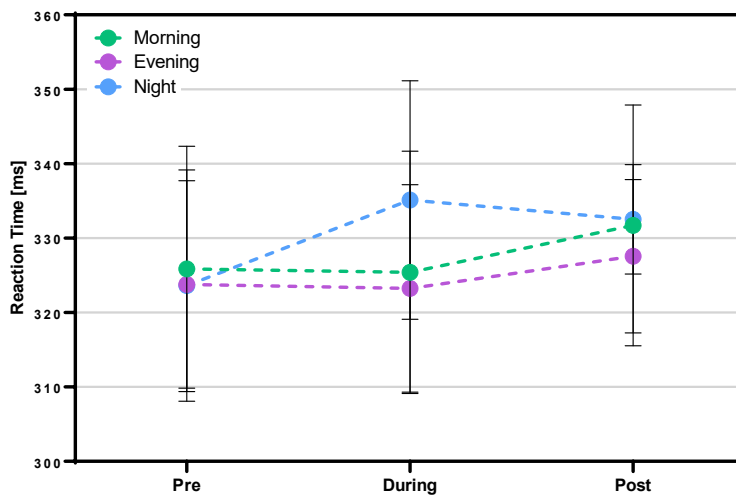


Figure 15. PVT data per shift type and time point.

**Mixed ANOVA**

- No interaction effect shift type and time
- No main effect shift type
- No main effect time

**Analyses of Within-Subject Factor: One-Way ANOVAs**

- T1: No significant differences between the shift types
- T2: No significant differences between the shift types
- T3: No significant differences between the shift types

**Analyses of Between-Subject Factor: Repeated Measures ANOVA**

- Morning: No differences between T1, T2 and T3
- Evening: No differences between T1, T2 and T3
- Night: No differences between T1, T2 and T3

**i** Differences exist only on a descriptive basis. No statistical differences between measurement timing and shift types. Means, that fatigue did not vary over time and between shifts. This is likely an artifact due to the small sample size.

Figure 16. Analyses of PVT data.

A further analysis of clockwise vs. anti-clockwise effects to PVT and SSS is given in the Figure 17 below.

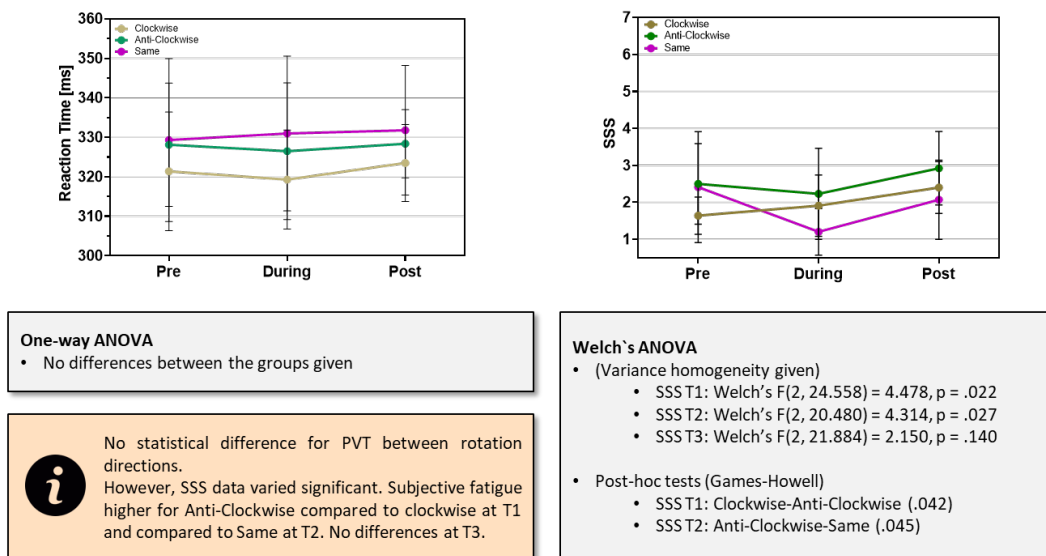


Figure 17. Effects of rotation direction.

#### 5.1.4.1.2

#### Conclusion

The majority of measured shifts were morning and evening shifts, with night shifts constituting only a small proportion (8%) of all shifts. Sleep duration prior to night shifts was found to be longer than before morning shifts, with morning shifts exhibiting the shortest sleep duration. Among night shifts, sleep period was between T1 and T2 (the corresponding night shift that features a sleep period between T2 and T3 was not observed due to lack of participants). The average sleep duration between T1 and T2 was approximately 2 hours (raw data not presented above).

Subjective fatigue, as measured by the SSS, showed a significant association with both shift type and measurement time. While no differences in subjective fatigue were

observed between shifts at T1, significantly higher subjective fatigue was reported at T2 during night shifts compared to day shifts. Subjective fatigue increased over time across most comparisons. Evening shifts exhibited a significant increase in subjective fatigue from T1 to T3. Interestingly, the night shift displayed an increase between T1 and T2 despite participants having slept, but no further increase was observed between T2 and T3. Morning shifts did not show a statistically significant increase in subjective fatigue over time.

Objective fatigue, as assessed by the PVT, did not mirror the patterns observed in subjective fatigue (SSS). Anti-clockwise shift rotation (from evening to morning) was associated with higher fatigue ratings compared to clockwise rotation at T1. However, this effect was not reflected in the objective fatigue measurements using the PVT.

The study also revealed that sleep quality was generally reduced across the sample (raw data not presented above). Most participants exhibited an intermediate or slight morning chronotype. Interestingly, evening and morning shifts were preferred over night shifts. Shift and roster selection were primarily driven by private reasons, such as personal habits, preferences, and family commitments. Nevertheless, participants highlighted the importance of a smooth adaptation between subsequent shifts. The qualitative data suggested that night work should be valued more highly than regular day hours to facilitate a longer recovery period, potentially counterbalancing the strain associated with night work. When analysing gender effects on fatigue, no differences were found between genders. This is in line with previous evidence (Caldwell & Leduc, 1998).

## 5.2 Public Research Output

This section outlines the given and scheduled written outcomes of the project.

### 5.2.1 Project Output 1

<b>Title</b>	<u>The Influence of Rostering Factors on Fatigue in an Irregular Shift System in Air Traffic Control</u>		
<b>Authors</b>	Maximilian Peukert, Lothar Meyer		
<b>Published in</b>	International Conference on Research in Air Transportation (ICRAT 2022)		
<b>Year</b>	2022		
<b>Status</b>	<input type="checkbox"/> in preparation	<input type="checkbox"/> in review	<input checked="" type="checkbox"/> published

### 5.2.2 Project Output 2

<b>Title</b>	<u>Investigating Fatigue in Operational Nightshifts: A Study of Work-Sleep Organization in Air Traffic Control</u>		
<b>Authors</b>	Maximilian Peukert, Annika Sobotta, Lothar Meyer		
<b>Published in</b>	The International Journal of Aerospace Psychology		
<b>Year</b>	2023		
<b>Status</b>	<input type="checkbox"/> in preparation	<input checked="" type="checkbox"/> in review	<input type="checkbox"/> published

### 5.2.3 Project Output 3

<b>Title</b>	<u>Reviewing Fatigue in Aviation: Definition, Concepts and Antecedents</u>
<b>Authors</b>	Maximilian Peukert, Michaela Schwarz, Harald Kolrep
<b>Published in</b>	Aviation Psychology and Human Factors (Journal)
<b>Year</b>	2023
<b>Status</b>	<input type="checkbox"/> in preparation <input checked="" type="checkbox"/> in review <input type="checkbox"/> published

### 5.2.4 Project Output 4

The findings were disseminated through multiple presentations. Internally, the results were shared with both participants and professionals employed within the studied entity. Externally, the outcomes were presented to groups such as the EASA human factors group, the EASA fatigue study group, and other air navigation service providers. The study results were, moreover, presented at LFV Automation Day (2023) in Kista.

**Note**

All research publications and results are or will be accessible through the portal [www.researchgate.net](http://www.researchgate.net).

## 6 INTEGRATION AND OUTLOOK

This research project aimed to evaluate fatigue among ATC professionals in real-world conditions. The central objective was to observe fatigue during live operations, investigating the limited understanding of the dynamic relationship between shift work and fatigue, particularly under diverse task demands. The project aimed to fill the void in longitudinal and repetitive field measurements that pertain to this setting. To analyse the influence of specific shift patterns on fatigue, the project carried out iterative 3-week longitudinal studies to obtain fatigue ratings utilizing a streamlined and precise approach. The primary deliverable was to devise a competent and dependable approach to evaluate field fatigue to accomplish that. The study focused on investigating how the timing and type of shift impact fatigue. Goal was to understand how rostering and shift schemes affect fatigue, especially under different workload scenarios. The research also explored the possible differences between subjective and objective fatigue.

### 6.1 Lessons Learned

The field study approach enabled the investigation of fatigue within a real-world setting, enhancing ecological validity. However, due to the study being conducted alongside operational tasks, participation was influenced by additional factors like workload, job tasks and domestic responsibilities, potentially introducing bias. Moreover, crucial factors such as caffeine consumption and physical activity were not monitored, despite their potential to significantly impact fatigue. This compromise was made to avoid overburdening participants with excessive questions and maintaining a low barrier to participation.

In forthcoming studies, incorporating secondary factors could enhance the accuracy of fatigue assessment. Given the voluntary nature of participation, a bias among the subjects who participated was inherent. It is possible that individuals who were already acutely aware of fatigue issues were more likely to participate, or conversely, participants without fatigue concerns joined the study. Eliminating this bias requires random participant selection, which is challenging for field studies. Nonetheless, future research might consider assessing general fatigue awareness to comprehend potential subject bias more comprehensively.

Not all participants showed equal motivation to engage in the study. We observed that some individuals contributed by participating in just a single shift, while others displayed high motivation and adhered closely to the instructions. The underlying cause of this variance remains unclear. This discrepancy, however, introduces bias into the data, necessitating a more sophisticated statistical approach, such as Linear Mixed Models (LMM), for analysis. In subsequent data analyses, the implementation of LMM is recommended. Alternatively, participants could be informed about the required number of shifts to be measured precisely. This step could enhance the alignment of subjects' actions with the instructions provided and increase compliance with the study protocol.

Separate analyses of the effect of gender did not reveal any differences between genders in relation to fatigue, which is in line with existing evidence.

The safety department played a vital role in providing focused support to the field study. This ensured feasibility and safety throughout the study, making it a recommended practice for all field studies. Close communication facilitated strong management support, a key achievement, and a principle that should be applied universally in such studies.

Additionally, support was given from all relevant entities, backed by the study's external financing from Trafikverket. This financial backing contributed to a neutral and unbiased perspective on the data maintained by the researchers. The latter aspect is of paramount significance for ensuring high data quality, unbiased of any political interests.

## 6.2

### Conclusion

The COLA software method, which involved three measurement runs per shift in a three-week-long field research period, was considered successful. We observed a high participation rate initially, but it decreased over time. The reason for this decline is unknown, but it could be due to operational factors. Overall, the software can be used for other research projects that investigate fatigue, such as HCL:AURORA and OWL. The findings on fatigue have been positively received in the aviation community. It was made clear that studies at such a fine-grained level are rarely conducted. Aside from the downsides, the results give a good understanding of how different types of shifts influence fatigue. Furthermore, it was fascinating to observe how fatigue progresses differently over time depending on shift type, sleep phases, and time of the day. The effect of rostering factors - such as rotation scheme and time between consecutive shifts - on fatigue was also investigated. Thus, it is possible to gain a much clearer understanding of an ideal roster for ATC. In conjunction with existing shift recommendations, the results provide better guidance on what can be improved for an ideal roster. Based on extensive literature research, the project concluded that a fatigue review was necessary, resulting in two publications due to its extensive scope. Even though the finalised fatigue review, which aims to update aviation researchers and practitioners on the current fatigue research landscape, is not included in this report, it is the project's third deliverable. The subsequent COLA II project should now concentrate more deeply on the effect of traffic-related workload on fatigue. Therefore, the same study approach should be adopted. Additionally, it is possible to test alternative measurement methods. One could discuss non-intrusive methods. Besides, one should focus on comparing with other workplaces that have a different airspace structure. Furthermore, since FDO and ATCOs had the same shift structure, the focus was only on them in COLA I-2, I-3, and I-4. Although FDOs are not commonly researched, this presents an innovative approach to study. Nevertheless, technicians are also hardly ever examined, making COLA II a suitable platform to investigate technicians and their unique schedules.

In conclusion, this project has provided insightful findings on how fatigue varies between and within shifts. Objective fatigue does not always mirror subjective ratings, which may indicate insufficient self-awareness among ATC professionals. Finally, it should be noted that although fatigue changes over time, the study cannot estimate the effect of fatigue on performance. The purpose of this study was to demonstrate the changes over time and between different types of shifts. Fatigue is likely to have a performance-degrading effect, but it must be measured by other means.

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## APPENDIX

*Further information is available upon request.*