TASK ENGAGEMENT AND FLOW IN THE OPERATIONAL SAFETY OF SOUTH AFRICAN CIVIL AIR TRAFFIC CONTROLLERS

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DECLARATION

I hereby declare that this thesis is my own unaided work and has not been submitted to any other University.

Beverly Slater

4 January 2021

DEDICATION

For Emma Jayne and Abigail Sarah

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ABSTRACT

The field of research on human factors has grown rapidly, partly as a result of the importance of ensuring safety in aviation. Human factors, specifically human errors, contribute to significantly more aviation incidents than any other single factor, accounting for approximately 70% of all accidents and incidents (US National Research Council, 1998). Therefore, in order to continue to improve safety despite increasing air traffic, it is crucial to identify the factors that are the constituents of safety before their absence leads to an incident. This research focused on the human errors made by civil air traffic controller officers (ATCOs) during the high-risk period of shift handover. The aim of the current research was to obtain a deeper understanding of these factors in the South African context.

The profession of air traffic control involves a wide array of duties to ensure that aircraft take off, transit between airports, and land safely. Air Traffic Navigation Services (ATNS) have identified a pattern of increased safety incidents that occur within the first 30 minutes of a civil ATCO starting a shift, the first 30 minutes after a civil ATCO returns from a break, and the last 30 minutes of his or her shift. This is referred to as the 'shift handover period'. ATNS posited that the problem is a lack of mental alertness in ATCOs. The current research aimed to make a contribution to the knowledge and understanding of human factors that play a role in the underlying dynamics of mental alertness, mental task engagement, and flow in ATCOs during this high-risk shift-handover period, in order to assist in minimising safety incidents.

The present study investigated the systemic, psychological, and physiological human factors experienced by ATCOs in South Africa.

The research was conducted in three phases:

Phase 1: Review and analysis of safety incident reports;

Phase 2: Examining flow, mental task engagement, and mental workload; and

Phase 3: Administering interventions: music and mindfulness.

In Phase 1, a total of 123 safety incident reports for the period 2008 to 2012 were analysed. The analysis confirmed that the handover period is indeed a high-risk period.

In Phase 2, qualitative data were collected through interviews with 11 ATCOs. This data, combined with factors identified from the safety reports, yielded a number of systemic, psychological, and physiological factors that impact the operational safety of ATCOs from a Safety-I perspective (why things go wrong). The high-risk sectors are Approach and

Aerodrome. Periods of both high and low traffic volumes are high risk. A number of environmental upgrades are required, including equipment and the rest area, and noise levels need to be reduced. The rostering of ATCOs should be done to ensure sufficient staff, without extending their shifts, and ATCOs should be rostered sufficiently regularly to maintain proficiency. ATCOs require sufficient rest, which should be promoted, and management should ensure that ATCOs take their mandatory leave. From the interviews, it was clear that the relationship between management and ATCOs could be improved, especially through regular and open communication.

In Phase 3, two interventions were administered — one to enhance mindfulness and one using music therapy, together with a control condition, to determine whether these enhanced ATCOs' mental alertness (a Safety-II perspective: why things go right). Thereafter, quantitative data were collected through questionnaires to determine these ATCOs' mental workload, mental task engagement, and flow, to examine how these cognitive dimensions impact the occurrence of safety incidents. Mental workload, mental task engagement, and flow were identified as the most critical human factors from a Safety-II perspective, which relate to and theoretically overlap with mental alertness. Flow is not an easy concept to define and identify in this context, and could not be measured using standard measurement instruments. The results indicated that the music intervention had the more positive impact on mental alertness.

Overall, the findings of the research indicate that enhancing ATCOs' safety performance would require consideration of a number of factors that play a role throughout the entire shift, but with a particular focus on the high-risk shift-handover period.

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Abbreviations and Acronyms

ATCO	Air Traffic Control Officer
CAA	Civil Aviation Authority
FAA	Federal Aviation Administration
ICAO	International Civil Aviation Organisation
INSAG	International Nuclear Safety Advisory Group
NASA	National Aeronautics and Space Administration
NATCA	National Air Traffic Controllers Association
NTSB	National Transportation Safety Board
OTJI	On-the-Job Instructor
SACAA	South African Civil Aviation Authority
SESAR	Single European Sky ATM Research
TLX	Task Load Index (NASA)

Appendices

CHAPTER 1: INTRODUCTION

The focus of the current study is the field of aviation psychology within the South African context. Aviation psychology centres on human functioning within both civilian and military aviation. The current study concentrates on aviation in the civil sector, with particular emphasis on theoretical constructs drawn from the field of cognitive psychology.

The field of air traffic management is dynamic and complex, with the overall aim of ensuring safety and efficiency in aviation. As a function of air traffic management, air traffic control in aviation is concerned with the safe and efficient movement of aircraft through the air and on the ground, in communication with pilots and associated flight services personnel.

1.1 Background to the Problem

The profession of air traffic control officer (ATCO) involves typical operational demands, such as human–machine interaction, speed, continuous decision-making, and teamwork to ensure the safety of passengers (Goeters, 2004). This is done through the detection and resolution of conflicts of an aircraft with another aircraft or other obstacles and the safe, orderly, and expeditious flow of traffic in the air and at airports (Bergner & Hassa, 2012).

The International Civil Aviation Organisation (ICAO), in the Convention on International Civil Aviation (Annex 13, 2009), defines an accident as the worst occurrence in aviation, where a person is seriously or fatally injured, or the airplane sustains structural damage or failure. A serious incident is one in which an accident nearly occurred, and any other occurrences are referred to as 'safety incidents'.

The ATCO's role involves the control and supervision of aircraft departing and landing, as well as during flight, with ATCOs instructing pilots to fly at assigned altitudes and on defined routes. An ATCO's role is critical in the prevention of collisions between aircraft in the air, which requires keeping aircraft separated. ATCOs are also responsible for preventing collisions between aircraft and other vehicles and buildings in manoeuvring areas. They are, furthermore, responsible for preventing unnecessary aircraft noise. ATCOs inform appropriate organisations if an aircraft requires assistance, for example, in the form of search and rescue, followed by providing support for such organisations' efforts (Bergner & Hassa, 2012).

The literature on air traffic control is grappling with the issue of mental alertness during air traffic control operations, specifically with regard to the handover process. Mental alertness is one of the cognitive processes that will be investigated in the current study, whereby a contribution will be made to the academic literature on air traffic control functioning in the South African context.

1.2 Problem Statement

The initial request to investigate the problem was stated as such: "One of the main contributing factors to ATNS [Air Traffic Navigation Services] safety events during the past 24 months was an apparent lowered physiological and psychological alertness or arousal level amongst ATCOs that caused below par responses to unusual or critical scenarios of flight and conflict" (J. van der Westhuizen, personal communication, September 2012).

In the current research study, practical interventions will be developed and tested, with the anticipated outcome of enhancing ATCOs' functioning and, ultimately, operational safety.

In 2012, the University of the Witwatersrand was approached by South Africa's Air Traffic Navigation Services (ATNS) for assistance to research to improve understanding of and provide solutions to a problem they had identified — a pattern of increased safety incidents. It was suggested that most incidents occurred within the first 30 minutes of a civil ATCO being on duty (also referred to as 'on frequency'), returning from a shift break, and the last 30 minutes of a shift, when, duties are handed over from one ATCO to another, referred to as 'shift handover' (J. van der Westhuizen, personal communication, September 2012). These periods are therefore considered high-risk periods. The ATNS calculated an average of 26 safety incidents per year — an average of 2.1 incidents per month (A. van der Heiden, personal communication, October 2011). Therefore, the focus of the current research is on the shift handover process, with particular emphasis on shift handover.

Handover processes and procedures are strictly regulated by the Civil Aviation Authority (CAA). Handover takes place while air traffic control operations are ongoing; therefore, an ATCO is required to ensure that, before leaving an operating position, an appropriate handover takes place (CAA, 2009). In the South African context, particular issues affecting shift handover relate to logistical issues and factors affecting ATCOs' capacity to perform their duties. Logistical issues include transport, as many ATCOs rely on public transport. Bus- and taxi strikes that were not anticipated may cause ATCOs to be absent from work. The ATCOs who are at work are then not relieved and their shifts are extended, leading to fatigue, which impacts their operational safety.

Another consideration is strikes in the aviation industry that pose a risk to ATCOs' personal safety. ATCOs do not arrive to take over a shift out of fear for their personal safety. A South African ATCO's emotional state can be negatively impacted on by incidents of crime, such as a home invasion or mugging, leading to the ATCO arriving at work in a traumatised state before signing on.

Other factors impeding the ability to take over that are common to all ATCOs include being distracted by other ATCOs, illness, substance abuse (alcohol and/or drugs), fatigue, and personal and job stress.

1.3. Rationale for the Study

The research project was initially conceptualised by ATNS as a project to investigate mental alertness of ATCOs. Mental alertness, a construct that is related to cognitive ability, refers to ATCOs' level of mental engagement during the primary task of controlling air traffic. Following initial discussions with ATNS, it was decided to investigate the mental mechanisms of ATCOs during the shift handover period. The current researcher will attempt to identify the causes of inattention or lack of mental alertness and propose potential solutions for further investigation during this high-risk period (J. van der Westhuizen, personal communication, September 2012).

Constructs related to mental alertness, namely attention, judgement, memory, planning, perception, information processing, and decision-making, which may also impact ATCOs' functioning during the shift-handover period, will also be considered. These cognitive functions are considered executive functions, a set of processes related to managing oneself and one's resources in order to achieve a goal. Sereno, Babin, Hood, and Jeter (2009) consider attention (focusing on relevant information and ignoring distractors), working memory (maintaining information until execution), and motor planning (goal-directed planning of steps required to execute a task and programming or remembering these) to be key executive functions.

The metacognitive tasks that are essential to aviation safety include situation awareness (understanding the current state and dynamics of a system and being able to anticipate future change and developments) (Endsley, 1995), mental task engagement (the effortful commitment to operational goals), which involves the combination of cognition, motivation, and emotion (Kahn, 1990), mental workload (the mental effort required to perform a task) (Brooker, 2003), and flow (the positive mental state of being completely absorbed, focused, and involved in one's activities, as well as deriving enjoyment from being engaged in that activity)

(Csikszentmihalyi, 1997). Factors identified from the incident reports as critical will also be focused on, to determine their impact on operational safety during the shift-handover period.

The research will assist ATNS to gain a deeper understanding of cognitive processes during the high-risk shift-handover process that contribute to safety incidents. The aim is to then identify interventions that may assist in reducing the likelihood of safety incidents occurring during the high-risk handover phase. It is hoped that the study will make a contribution to the understanding of the safe guidance of aircraft in South Africa by recommending strategies to minimise the occurrence of safety incidences during shift handover.

ATCOs, one of the core professions in aviation, will be the unit of analysis of the current research. Air traffic control is a critical role in the larger discipline of air traffic management and entails the provision of safe and efficient air traffic control. The study will also consider the challenge of the increasing demands and complexity of controlling air traffic.

According to Goeters, Maschke, and Eibfeldt (2004), the top task requirements of ATCOs are:

- mental (i.e. time sharing, selective attention, spatial visualisation, and working memory);
- sensory (hearing and speech recognition);
- interactive (co-operation, communication, decision making and situation awareness); and
- coping with emotional stress.

ATCOs' operational performance is monitored throughout their career. There is commonality of experience, as the common kinds of air traffic control problems are encountered and resolved many times (Brooker, 2003). The profession of ATCO remains a demanding field of work, despite increasing use of technology for information management and automated support functions. ATCOs are trained in standardised ways to make correct analytical judgements and to recognise and resolve problems, for example, authorising a climb for an aircraft through another aircraft's flight level in a particular way. A standard language that is a restricted subset of English is used for communication between ATCOs and pilots.

Air traffic control services are provided throughout most of the airspace, and are available to all aircraft, including private, military, and commercial. Aircraft flying in uncontrolled airspace do so without the assistance of air traffic control, and pilots alone are responsible for managing air traffic by communicating with other aircraft in the space. Whether ATCOs issue instructions to pilots that they are required to follow or merely provide flight data to assist pilots operating in the airspace is dependent on the type of flight and class of airspace. ATCOs provide flight information to pilots and issue instructions, which pilots are required to follow. The pilot in command has the final responsibility for the safety of the flight, and may therefore deviate from ATCOs' instructions in an emergency.

The ICAO has established a number of regulations from an operations perspective, to which ATCOs must adhere in order to maintain safety standards. Despite these regulations and measures being taken to ensure that ATCOs adhere to these regulations, safety incidents continue to occur during the course of ATCOs' work, due to the dynamic and complex nature of the work. Safety incidents are largely attributed to some form of human error, which, according to Woods et al. (2010), is typically done retrospectively.

Human error is often directly related to human factors and, hence, human performance. Human error implies that the cause of the incident was due to an insufficient interaction of one or more of several human operators within the technical system. Human error comprises all elements of the technical and organisational conditions that lead to insufficient interactions of the human operators with the system (Sträter & Van Damme, 2002).

A large amount of research has been done on factors that compromise operational safety of civil pilots in South Africa (e.g., Campbell, 2017; Davids, 2016; Hoole & Vermeulen, 2003). However, a gap has been identified in the literature and research with regard to South African ATCOs. The South African aviation community has recognised this gap, which has led to bi-annual symposia sponsored ATNS, the first of which was the South African Symposium on Human Factors and Aviation Safety, held in January 2014, followed by a further two symposia, in September 2015 and September 2017.

International studies have been carried out that relate to the current research study. For example, Della Rocco, Cruz, and Clemens (1999) found that 25% of all operational errors occurred in the first 15 minutes after position relief briefings in air route traffic control centres and terminal radar control facilities. However, no research has investigated South African civil ATCOs by examining cognitive concepts such as situation awareness, mental task engagement, mental workload, and flow.

1.4 Aims of the Study

Safety incidents are often attributed to human error, a component of human factors (Endsley, 1995). The current research will investigate the systemic, psychological, and physiological factors experienced by ATCOs with reference to safety incidents in South African airspace.

Human factors have grown increasingly important in air traffic control. Humans are ultimately responsible for ensuring safety in the aviation industry, and ATCOs have to knowledgeable, flexible, dedicated, and efficient, all while exercising good judgement. In industries such as aviation, and air traffic control in particular, the portion of incidents attributed to human factors is estimated to vary between 70% and 90% (Sträter & Van Damme, 2002). The conduct and etiquette of ATCOs, who are considered to be safety ambassadors, play an integral part of human performance, and are therefore significant considerations in safety improvement. The expectation is that undesired safety incidents could be avoided by gaining a more in-depth understanding of human performance and its constituent factors.

The next section discusses the research objectives of the current study.

1.4.1 Research objectives

The current study's research objectives (ROs) are:

RO1: Determine whether the suspected pattern of incidents indeed conforms to the ATNS's hypothesis that the first or last 30 minutes of a shift and first 30 minutes after a break are high-risk periods.

This objective will be achieved by analysing incident reports for all South African airports for the years 2008 to 2012.

RO2: Investigate the theoretical basis for the occurrence of safety incidents during the handover period beyond simply attributing any error to cognitive limitations.

This objective will be achieved through an extensive literature review and interviews with ATCOs.

Once theoretical explanations have been identified, two interventions will be assessed to test these theoretical assumptions. In meeting the research objectives, the following research questions were formulated.

1.4.2 Research questions

RQ1: What human factors issues can be identified from the safety incident reports as significantly impacting the operational safety of South African civil ATCOs?

ATNS' identification of a pattern of safety events provided the rationale for current research, to identify the most critical human factors that have already been reported to lead to the potential for human error. It is expected that the incident reports will consist primarily of factors related to Safety-I.

RQ2: To which psychological and physiological factors do South African civil ATCOs attribute to their safe functioning at work?

This question will be answered from data gathered through one-on-one interviews with ATCOs. The factors will include those that contribute to things going wrong (Safety-I) and things going right (Safety-II). Previous research into human errors has mostly focused on what went wrong. With an understanding of the importance of a Safety-II approach, the current research will focus on things going right — systemically, psychologically, and physiologically, in addition to things going wrong, in the day-to-day operations of an ATCO.

RQ3: What is the impact of mental task engagement, the state of flow, and mental workload on the occupational safety of South African civil ATCOs during the shift hand-over process?

In the present study, how mental task engagement links to the state of flow will be considered. This question will be answered with insights gained from an extensive literature review of the importance of an ATCO entering into a state of flow ('being in the zone') in order to ensure operational safety. It is proposed that safety events are likely to be minimised when ATCOs achieve situation awareness such that they are mentally engaged, thereby reducing the potential for human error.

RQ4: Does a music intervention or mindfulness intervention improve flow and mental task engagement, that is, work performance, in South African civil ATCOs?

Studies highlighted in the literature review support the opinion that music and mindfulness have the potential to increase arousal, alertness, and attention which the current research set out to explore with regard to enhancing the safe functioning of ATCOs.

Currently, there is a lack of baseline knowledge on a local and international level with respect to the current research focus. On a theoretical level, the aim of the research is to gain a deeper understanding of the theoretical overlap(s) between mental task engagement, mental workload, and flow, as well as the interplay between these concepts. In the present study, two interventions will be administered to determine whether these improve ATCOs' mental alertness and mental task engagement within the first and last 30 minutes on shift, as well as for the first 30 minutes after returning from a break (i.e. the handover period). Achieving this would assist with the promotion of operational safety.

In addition to examining what induces a state of flow in ATCOs, the study will contribute to the understanding of factors that inhibit the state of flow. An important theoretical contribution would be to demonstrate the link between mental task engagement and the state of flow. ATNS posits that safety incidents are attributable to ATCOs lacking mental alertness.

The present researcher investigated whether an ATCO's mental alertness is heightened during an optimal state of flow, leading to an enhanced mental engagement with the operational demands of ATC and the desired situation awareness. Situation awareness is comprised of mental task engagement, mental workload, and flow, while mental task engagement is only one aspect of flow. Psychophysiological factors will be considered with respect to the impact on the ATCO's ability to function optimally

1.5 Significance of the Study

This thesis is intended to make a contribution on two levels. First, it will contribute to the body of knowledge in the field of aviation psychology in South Africa, which is currently lacking. Second, the study will make a contribution to existing knowledge regarding mental alertness. Extensive research has been undertaken internationally in this domain, for example, by the European Organisation for the Safety of Air Navigation, commonly known as Eurocontrol. Eurocontrol is an international organisation working to achieve safe air traffic management across Europe. Single European Sky Air Traffic Management Research (SESAR) is another example of an organisation aiming to improve air traffic management by modernising and harmonising systems through the definition, development, validation, and deployment of innovative technological and operational solutions.

From a theoretical perspective, this study aims to make a contribution to the knowledge and understanding of factors that contribute to enhancing situation awareness, mental task engagement, and flow in ATCOs, in order to promote optimal mental alertness and thereby minimise safety events, especially during the high-risk shift handover period.

1.6 Layout of Study

Chapter 1 explained the background and context of the study, as well as the aims and objectives.

Chapter 2 provides a discussion of issues related to the role of an aviation psychologist within the profession of air traffic control. Human factors and human error are considered with regard to their contribution to operational safety and safety incidents in air traffic control. The concepts defined and discussed are: situation awareness, mental task engagement, mental workload, and flow, followed by the consideration of mindfulness and music as possible interventions that could enhance situation awareness, mental task engagement, mental workload, and flow, in order to ensure optimal mental alertness in ATCOs.

Chapter 3 describes the study's methodology, including research design, sampling, and analysis.

Chapter 4 presents the qualitative findings and quantitative results of the study.

Chapter 5 provides a detailed discussion of the findings, coupled with recommendations for practice, followed by an overview of the study's limitations and directions for future research.

1.7 Chapter Summary

The culture in ATNS is changing, evident in an increase in the number of studies on safety and ATCOs now being more likely to report safety incidents. In addition, ATCOs are now less fearful of suspension when reporting a safety incident. In order to achieve the theoretical and practical objectives of the research as outlined above, the focus of the current research is human factors related to safety incidents and to why handovers go well. The next chapter provides an overview of extant literature in this domain.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

A theoretical background pertinent to the research is the focus of this chapter. The literature review starts with an introduction to the concept of a safety culture, followed by and overview of safety and safety incidents in air traffic control. This is followed by an explanation of the profession of air traffic control, together with the roles and responsibilities of an ATCO. Aviation psychology and the role of an aviation psychologist with special reference to safety is then discussed, followed by the different types of safety events. Human factors and human error are considered from a traditional and non-traditional perspective, whereby the concepts of situation awareness, mental task engagement, and mental workload fall within the traditional realm, and flow within the non-traditional realm. Music and mindfulness tasks and their potential application to safety in air traffic control are then explored as possible solutions for improving mental alertness in ATCOs during the high-risk shift-handover period. Shift handover is an important procedure to elucidate, most importantly due to the shift handover being identified by ATNS as the period with the highest safety risk in air traffic control operations.

2.2 Safe Handover

In the CAA Standards and Procedures Manual (2009) it states that appropriate handover requires that the successor be provided with comprehensive information on the current traffic situation and matters of significance that have influenced the development of the situation, or which may have a bearing on any situation arising during the course of the next shift. ATCOs are expected to remain on duty until such time as a traffic situation has been resolved before handing over to the next ATCO. The ATCO to whom control is being handed over should ensure that he/she has assimilated all of the information regarded as relevant to a safe handover. Responsibility should be accepted by this ATCO once he/she is entirely satisfied that he/she has complete awareness of the traffic situation being taken over. The ATCO who has handed over is expected to remain for several minutes following handover, in case essential input or information regarding developing situations is needed.

The next section addresses approaches to safety.

2.3 Defining Safety and Safety Culture

According to Hollnagel, Wears, and Braithewaite (2015), safety is thought of as an absence of accidents and incidents, and even as an acceptable level of risk. Hollnagel et al. (2015) define safety as the system quality that is necessary and sufficient to ensure that the number of unacceptable events is acceptably low, that is, events that can be harmful to operators, the public, and the environment. The challenge in safety performance is for things to go right in spite of uncertainties and ambiguities (Hollnagel et al., 2015). The starting point for safety concerns, historically speaking, is the occurrence of accidents and recognised risk. Adverse outcomes have mostly been explained by identifying presumed causes, which led to the response of eliminating or containing.

Safety culture is a psycho-organisational factor that plays an important role in minimising and preventing safety incidents and accidents. An organisation's safety culture comprises several components, for example, the provision of adequate training, a just culture, a reporting culture, management involvement, and the empowerment of the ATCOs (Arvidsson, 2006). The attainment of a positive and strong safety culture within organisations is critical in minimising the occurrence of safety incidents. The International and Nuclear Safety Advisory Group (INSAG, 1991) defines a safety culture as the characteristics and attitudes in organisations and individuals that prioritise safety, giving it due attention.

A safety culture has as aim to recognise unwanted issues before these develop into safety issues (Frick-Ernst, Kötteritzsch, & Chenkova, 2009). Therefore, a safety culture is achieved through safety-risk management, defined as the state in which the possibility of harm to individuals or damage to property is reduced (ICAO, 2009). All parts of the system should be addressed by a sound safety management system (ICAO, 2006). However, even the best safety management system does not always ensure the prevention of safety incidents and accidents (Frick-Ernst et al., 2009).

There are two broad approaches to safety: Safety-I and Safety-II. These are discussed in the sections to follow.

2.4 Safety-I

Safety-I is the traditional approach to safety, and focuses on explaining the *when*, *what*, *where*, and *why* of a safety incident.

The purpose of investigation in Safety-I is to identify causes and contributory factors that lead to adverse outcomes. Risk is assessed with the aim of determining the likelihood of adverse outcomes. From a safety management perspective, a response is required as soon as something has happened. This can be done by attempting to eliminate causes or removing barriers to safety, to prevent a recurrence (Hollnagel et al., 2015). In applying Safety-I, it is essential to establish the cause, together with the individual's response, in assessing whether it is safe to proceed. Braithwaite, Wears, and Hollnagel (2015) consider Safety-I a 'find-and-fix' model that identifies what went wrong — after the event. Safety-I has as aim that as few things as possible go wrong, therefore, the absence of unwanted outcomes such as incidents or accidents, thereby maintaining an acceptable level of risk. This approach is based on the assumption that things go wrong as a result of identifiable failures or malfunctions of specific components: technology, procedures, the human operators, or the organisation in which they are embedded. Humans, acting either alone or collectively, are viewed as a liability, as they are the most variable component in the system (Hollnagel et al., 2015).

There are limitations to the Safety-I view. It does not consider the reason behind why things, including human performance, go right. A further consideration is that things may not go right despite people having done as they were supposed to, rather than adjusting what they do to match the conditions. As systems continue to develop and introduce more complexity, being able to effect adjustments becomes increasingly important in maintaining acceptable performance.

Weick et al. (1999) support the view that there has been a preoccupation with failure rather than success (the Safety-I approach) in high-reliability organisations such as air traffic control. According to Weick et al. (1999, p. 32), air traffic control systems "are rich with the potential for error", and anticipation and avoidance of errors are viewed as essential. According to Perrow (1984), some of the necessary, but not sufficient, conditions for higher reliability theory emphasise a strategic prioritisation of safety, continuous training (simulation), as well as a strong culture of vigilance and responsiveness in order to avoid accidents. Earlier studies on high-reliability organisations focused only on safety; more recently, there has been a shift to a focus on safety and efficiency (La Porte & Rochlin, 1994).

Braithwaite et al. (2015) consider the linearity of Safety-I another limitation, and put forward the concept of proactive safety management with the goal of understanding why things go right, rather than why things went wrong, which constitutes the foundation of Safety-II.

2.5 Safety II

According to Hollnagel et al. (2015), things go right more often than things go wrong. The goal of a Safety-II approach is to ensure as many things as possible go right, rather than ensuring as few things as possible go wrong (Hollnagel et al., 2015). It is a truism that the world we live in has become more complex and interdependent, and the pattern continues to accelerate. During the second half of the 20th century, the focus in safety shifted from technological problems to human factors as problems, and ultimately to problems with organisations and a lack of a safety culture (Hollnagel et al., 2015).

Human beings are viewed as the most predominant liability, as they are the most variable component. The safety management principal has to respond when something happens or is characterised as an unacceptable risk (Hollnagel et al., 2015). The challenge therefore in safety improvement is to understand the required adjustments. This refers to the understanding of how performance goes right despite any uncertainties, ambiguities, and goal conflicts that pervade complex work situations (Hollnagel et al., 2015).

Traditional safety management has paid scant attention to this view. Safety management is encouraged to move from ensuring that as few things as possible go wrong to ensuring as many things as possible go right (Hollnagel et al., 2015). A Safety-II approach assumes that everyday performance variability provides the adaptations that are needed to respond to varying conditions, which is the reason why things go right. Humans are seen as a resource that is required in order to obtain system flexibility and resilience. In Safety-II, the purpose of investigations is to gain an understanding of why things go right; this also forms a basis for explaining why things occasionally go wrong. In this way, risk assessment is aimed at understanding the conditions under which performance variability can become difficult or impossible to monitor and control. The safety management principle of Safety-II is to facilitate everyday work, anticipate developments and events, and maintain the adaptive capacity to respond effectively to unforeseen events (Finkel, 2011).

Shorrock (2018) highlights the importance of focusing on the complete picture from a Safety-II perspective, i.e. focusing on work that may be considered routine, ordinary, and even unremarkable. Shorrock (2018) considers this to be the work that potentially ends up being reported on in investigations of safety incidences.

It is essential to assimilate the Safety-II view and hence adopt new practices to assess what goes right, to focus on frequent events and to maintain sensitivity to the possibility of failure, wisely balancing thoroughness and efficiency, and to view an investment in safety as an investment in productivity. Shorrock (2018) emphasises how both Safety-I and Safety-II focus on accidents (real and potential), while Safety-I is a reaction to events by considering the human approach, while Safety-II focuses on desired goals.

The tables below summarise the essential differences between Safety-I and Safety-II according to Hollnagel et al. (2015).

Table 2.1

Differences between Safety-I and Safety-II Approaches

	Safety-I	Safety-II
Definition of safety	That as few things as possible go wrong	That as many things as possible go right
Safety management principle	Reactive; responding when something happens or is categorised as an unacceptable risk	Proactive, continuously trying to anticipate developments and events
View of the human factor in safety management	Humans are predominantly seen as a liability or hazard. They are a problem to be fixed.	Humans are seen as a resource necessary for system flexibility and resilience. They provide flexible solutions to many potential problems.
Accident investigation	Accidents are caused by failures and malfunctions. The purpose of an investigation is to identify causes.	Things basically happen in the same way, regardless of the outcome. The purpose of an investigation is to understand how things usually go right as a basis for explaining how things occasionally go wrong.
Risk assessment	Accidents are caused by failures and malfunctions. The purpose of an investigation is to identify causes and contributory factors.	To understand the conditions where performance variability can become difficult or impossible to monitor and control

Table 2.2

Differences between Safety-I and Safety-II Approaches

Safety I	Safety II
Learn from our errors	Learn from our successes
Safety defined by absence	Safety defined by presence
Reactive approach	Proactive approach
Understand what goes wrong	Understand what goes right
Accident causation	Repeat what goes right
Avoid errors	Enforce successful behaviours
Reduce losses	Create new process on successful behaviour

The current research considered both the Safety-I and Safety-II approach in examining ways to enhance safety during the high-risk shift-handover period.

The following sections explain the types of safety incidents that may occur.

2.6 Typical Safety Events in Air Traffic Control

The current research placed emphasis on safety, whereby incidents and accidents should be at an acceptable level of risk, but preferably absent. Eurocontrol (2003) highlights how the scope or extent of a safety occurrence can be difficult to identify, due to difficulty in ascertaining when an occurrence actually began. In order to work towards attaining the goal of safety, a number of safety incidents have been identified in aviation. There are four main safety events that could occur through erroneous air traffic control, namely loss of separation, runway incursions, missed approaches, and surface safety events. The following sections explicate what is considered infringement of standards in these scenarios.

2.6.1 Loss of separation

Any infringement of either vertical or horizontal separation minima taking place in controlled airspace is referred to as a loss of separation (ICAO, 2013). According to the South African Civil Aviation Authority (SACAA) Standards and Procedures Manual, Section 6, Separation Methods and Minima, Part 1, point 1.2, Vertical Separation Minima, vertical separation exists when the vertical distance between aircraft is never less than the prescribed minima. The separation minima are:

1 000 ft up to flight level (FL) 290 between all aircraft;

1 000 ft between to FL290 and FL410 between [reduced separation in the vicinity of an airfield] RVSA approved aircraft only;

2 000 ft between FL290 and FL410 between non-RVSM approved aircraft and any other aircraft;

2 000 ft between all aircraft above FL410.

With regard to horizontal separation states, SACAA Standards and Procedures Manual, Section 6, states that the minimum separation shall be five nautical miles. Separation standards are permitted to be increased only when it is requested by a pilot, an ATCO considers it to be necessary, an aircraft is being subjected to unlawful interference, an aircraft experiences navigational difficulties, or in other relevant emergencies and as specified in the station standing instruction manual. The standard separation minima can be reduced if adequate separation can be provided by the aerodrome ATCO when each aircraft is continuously visible to this ATCO, there is continuous visibility of each aircraft to flight crews of any other aircraft concerned, the pilot reports that that aircraft's own separation can be maintained, and, in the case where one aircraft is following another and the flight crew of the succeeding aircraft reports that the other aircraft is in sight and separation can be maintained (CAA, 2013).

Loss of separation occurs "if, for any reason, an ATCO is faced with a situation in which two or more aircraft, or an aircraft and obstruction, or an aircraft and terrain are separated by less the prescribed minima. The ATCO then has to (SACAA, 2013):

a) *use every means at his/her disposal to obtain the required minimum separation with the least possible delay, and*
b) *pass essential traffic information as soon as possible.*

Loss of separation in this case may be due to ATCO error or differences in the pilot's estimated and actual times over reporting points (SACAA, 2013).

2.6.2 Runway incursions

A runway incursion is defined as any incident or occurrence at an aerodrome or on a runway (Wilson, 2013). A runway incursion occurs when there is an incorrect presence of an aircraft, vehicles, or person in the area that is specifically assigned for the landing and take-off of aircraft (ICAO, 2007). It is crucial that the manoeuvring area is free of obstructions, vehicles, and any and all other obstructions that would prevent the required movement of aircraft. This is the responsibility of the aerodrome ATCO, who has the task of maintaining a constant visual watch over the area (ICAO, 2007; SACAA, 2013).

The SACAA Standards and Procedure Manual (2013) states that aerodrome control is responsible for issuing information and instructions in order to prevent collisions between aircraft flying in, taking off, and landing, as well as aircraft in the vicinity of the aerodrome traffic zone. The runway is to be kept sterile, whereby, if there are any vehicles operating on a runway (including runway inspections or maintenance), no aircraft are permitted to line up on the runway while these operations are in progress. This procedure does not apply to normal vehicular crossings, rather to vehicles that will be on the runway for extended periods of time (CAA, 2013).

2.6.3 Missed approaches

There are two types of approaches in controlled airspace, namely instrument approach and visual approach. A missed approach occurs when an approach is evaluated as not being safe, due to a risk that landing the aircraft will not be successful, and a 'go-around' flight is required (CAA, 2013). A missed approach procedure has to be followed to allow the aircraft to land without incident. There are many reasons for discontinuing an approach, including that the required visual references have not been established, or were acquired but subsequently lost; the approach is or has become destabilised; the aircraft is not positioned so as to allow a controlled touchdown within the designated runway touchdown zone, with a consequent risk of aircraft damage; the runway is obstructed; landing clearance has not been received or is issued and later cancelled; or a go-around is flown for training purposes, with approval by air traffic control (Eurocontrol, 2003).

2.6.4 Surface safety events

A surface safety incident or wrong-surface event occurs when an aircraft lands or departs or tries to land or depart on the wrong runway or on a taxiway. It can also occur when a pilot lands or tries to land an aircraft at the wrong airport (Aviation, 2018). Reducing the risk of wrong-surface events is one of top priorities of the Federal Aviation Authority (FAA) in the United States of America (USA) (FAA, 2018). A number of groups have been convened to continue to monitor and track the issue, for example, the Commercial Aviation Safety Team, the General Aviation Joint Steering Committee, and the Runway Safety Council. These efforts augment a wide range of steps already taken to improve runway safety.

One of the most important runway safety technologies, which is in place at 35 major airports, is the Airport Surface Detection Equipment Model X (ASDE-X). ASDE-X enables ATCOs to detect potential runway conflicts by providing detailed coverage of movement on runways and taxiways. Other steps taken by the FAA include: highlighting the issue of wrong-surface events in recurrent training for controllers; resolving runway geometry issues to aid pilots' perception of landing surfaces; and outreach to pilots, flight instructors, and flight schools to increase awareness of wrong-surface events (FAA, 2018).

The next section provides insight into what air traffic control is by considering the role and/or function of an ATCO, the rules and regulations that are applicable to ATCOs, location and challenges that ATCOs face.

2.7 ATCOs' Roles

Air traffic control takes place behind the scenes, and is a service that is provided by ATCOs, with the goal of the safe, efficient, and orderly flow of traffic in the airways and at airports (Bergner & Hassa, 2012). In other words, air traffic control controls air traffic, not only in the airport vicinity, but also between destinations. In air traffic control, the departure and landing of aircraft are supervised through instructions communicated to pilots during flight to fly at assigned altitudes and on defined routes (Bergner & Hassa, 2012). The objectives of air traffic control is to prevent collisions between aircraft in the air and in the manoeuvring area; between aircraft and obstructions in the manoeuvring area; provide advice and information for the safe and efficient conduct of flight; and notify appropriate organisations regarding aircraft in need of search and rescue and assist such organisations as required (CAA, 2009).

The current research focused air traffic control within controlled airspace, where ATCOs have the responsibility of ensuring that aircraft are minimally separated per rules and regulations with regard to separation criteria. ATCOs assist the pilots to reach their destination safely. They work in small, relatively stable teams. Although the computerisation of aviation has had a positive influence on job requirements, the field of air traffic control remains a demanding field of work for qualified personnel (Goeters, 2004). It is important that ATCOs familiarise themselves with weather statistics at the current airport and future destination, to ensure the safest route of air travel. ATCOs prepare specific flight information prior to the flight taking off, and issue instructions to pilots and ground workers at the airport. Control is handed over to the aircraft's destination traffic control tower with whom ATCOs maintain contact. In this way, ATCOs can let the destination tower know which airline is coming into their vicinity, as well as the approximate time of arrival (Exforsys, 2006).

ATCOs are required to abide by strict federal regulations and specific policies and procedures. Air traffic services in South Africa are provided in accordance with the Civil Aviation Regulations and Technical Standards. These are in line with the standards and recommended practices of the International Civil Aviation Organisation. The Civil Aviation Technical Standards (Air Traffic Services), contains standards and procedures for civilian ATCOs providing air traffic services. The South African Civil Aviation Authority (SACAA) has overall safety and security oversight functions, exercised in terms of the Civil Aviation Act, 2009, and the Civil Aviation Security Regulations, 2011. The act provides for the establishment of the independent Aviation Investigation Board (Christodoulou & Harrison, 2019).

Air traffic control is provided at different locations. The current research focused on enhancing safety within the high-risk shift handover period at all of these locations. These locations are discussed below.

2.7.1 Aerodrome control

ATCOs work in the airport tower, which is high above the ground and next to the runway. As soon as the aircraft is ready for take-off, the aircraft is under the control of tower ATCOs. The tower ATCO issues clearance for take-off once the runway is clear of other aircraft. The tower ATCO is in continuous contact with the pilots and the approach ATCOs. Tower ATCOs resume control from the approach ATCO when the aircraft has landed on the runway (Bergner & Hassa, 2012).

2.7.2 Approach control (with or without the assistance of radar)

Approach ATCOs take over from the tower ATCO as soon as the aircraft has departed. The aircraft is guided onto one of many airways, and the prescribed minimum separation is maintained between aircraft (Bergner & Hassa, 2012).

2.7.3 Area control (with or without the assistance of radar)

Area ATCOs assume control of the aircraft from the approach ATCOs, and pass control to approach control to prepare the aircraft for landing. The approach ATCO arranges the aircraft along the runway before the taxiway ATCO takes over (Bergner & Hassa, 2012).

2.7.4 Radar control

A radar ATCO monitors the radar display and issues instructions and clearances to pilots via radiotelephony, with the goal of vectoring aircraft s to allow for separation as well as assist with the navigation of an aircraft. The progress of flights is monitored by radar ATCOs. A radar display consists of a two-dimensional display of aircraft moving in three-dimensional space. Each aircraft is represented by a symbol showing their current position, and is labelled with regard to speed and flight level (Bergner & Hassa, 2012).

The next section provides an overview of human error, followed by a discussion of human factors' contribution to human error in the context of air traffic control.

2.8 Human Error and Human Factors

2.8.1 Defining human error

Making errors is part of the human condition (Harris, 2011). The term *human error* implies that the cause of the incident was due to an insufficient interaction of one or more of several human operators with the technical system. Human error comprises all elements of the technical and organisational conditions that led to a certain insufficient interaction of one or more human operators with a system (Sträter & Van Damme, 2002; Goeters, 2004).

ATCOs are expected to make up a mental model of the situation, which must be stored in memory (Bisseret, 1997). Their performance is influenced by systemic, psychological, and physiological factors. Kontogiannis and Malakis (2009) recognise that human error cannot be completely eliminated, due to the increase in complexity of technical systems. A study of aviation safety reporting systems incidents found that the persons in error were able to detect only 24% of their own errors; thus, most of the errors were detected by other ATCOs (Sarter & Alexander, 2000). The next section discusses how human factors play a role in the safety performance of ATCOs.

2.8.2 Defining human factors

A branch of psychology emerged around 1915 (Koonce, 1984) to assist with the promotion of safety within aviation, whereby psychological principles and techniques are applied to the specific situations and problems of aviation (Martinussen & Hunter, 2010).

In this field, the terms *human factors* and *human ergonomics* are used interchangeably. Human factors as a discipline is relatively new, and draws on psychology, sociology, physiology, medicine, engineering, and management science. Human factors as a concept can be split into physical and cognitive ergonomics.

Physical ergonomics is directly related to the cognitive function of the human operator. People differ, which is why it is essential that the workplace be designed to accommodate these differences. Designing the workplace to optimise physical ergonomics, for example, ensuring that the ambient temperature is comfortable (not too hot or too cold) has to take into account that the operator has a propensity for mental and physical fatigue while operating (Harris, 2011).

Cognitive ergonomics, on the other hand, considers the ATCO as an information-processing component within a broader system. One of the anticipated challenges is the ATCO being required to process multiple pieces of information simultaneously. The manner in which information is presented to the ATCO will impact on situation awareness (Harris, 2011). With regard to the current research, the construct of workload was considered in terms of the cognitive system being heavily loaded.

Human factors practitioners are expected to deal with human performance in tasks that are primarily physical or perceptual, as well as to consider human behaviour in highly complex cognitive tasks (Endsley, 1995). The study of human factors is the application of scientific information on humans to the design of objects, systems, and environments for human use (Harris, 2011). The understanding is then translated into design, training, policies, or procedures to help humans perform optimally (Endsley, 1995). Studying human factors entails the gathering information about human abilities, limitations, and other characteristics, and then applying the information to tools, machines, systems, tasks, jobs, and environments to ensure safe, comfortable, and effective human use.

The range of problems confronting human factors practitioners continues to grow. With the continual development of technology, many complex, dynamic systems have been created that tax the abilities of humans to act as effective, timely decision-makers in operating these systems (Endsley, 1995). The focus on human factors has grown in the aviation industry, as human error, rather than mechanical failure, underlies most aviation accidents and incidents (Graeber, 2018). In aviation and air traffic management, the portion of safety incidents attributed to human factors varies from 70% to 90% (Sträter, 2016).

In aviation, studies on human factors are dedicated to better understanding how humans can most safely and efficiently be integrated with, specifically, technology (Graeber, 2018). That understanding is then translated into design, training, policies, or procedures to help humans perform better. Studying human factors involves gathering information about human abilities, limitations, and other characteristics, and applying it to tools, machines, systems, tasks, jobs, and environments, to ensure safe, comfortable, and effective human use, which approach is related to Safety-II (Graeber, 2018).

Traditionally, human factors constructs found to play an important role in the operational safety of ATCOs have fallen within a Safety-I approach, whereby causes of adverse outcomes are identified through an understanding of what went wrong that resulted in a safety incident. The next section provides descriptions of the human factors that are considered to play a role in ATCOs' performance.

2.9 Human Factors Under Study

2.9.1 Background

During their shifts, ATCOs should be mentally alert and attentive, with increased mental arousal and situational awareness. Cognitive skills such as attention, perception, planning, decision-making, judgement, information processing, and working memory are required to effectively carry out this work. This section provides a broad overview of the literature on human factors that play a role in ATCOs' safety performance.

Physiological factors that may impact their performance include diet (eating habits and hydration) and fatigue. Fatigue is defined by the FAA as "a condition characterized by increased discomfort with lessened capacity for 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 in ATCOs has become an important topic of interest, due to recent incidents of ATCOs in the USA napping while on duty (Nealley & Gawron, 2015). The FAA resolved to end the practice of single-ATCO midnight shifts by adding an additional ATCO at air traffic control towers throughout the USA (Nealley & Gawron, 2015).

A great deal of research has already been conducted in the area of ATCOs' fatigue, a field known as *fatigue risk management* (FAA, 2013, 2104; Fjare, 2015; National Aeronautics and Space Administration (NASA), 2015; National Transportation Safety Board (NTSB), 1976, 2001, 2020). Reviews of studies on ATCO fatigue and the evaluation of countermeasures were provided by Mathews, Desmond, Neubauer, and Hancock (2012) and Nealley and Gawron (2015). These authors recommend that ATCOs be adequately rested prior to going on shift, which would, firstly, require sufficient sleep.

The reduction of fatigue-related incidents is a common goal of the FAA and the NTSB. An important contributor to ATCOs' fatigue and, hence, safety incidents during the high-risk shift-handover period is scheduling practices (also referred to as *roster practices* or *shift schedule practices*). According to Nealley and Gawron (2015), the majority of ATCOs in the USA work on rotating shifts of between eight and ten hours in length. Rotating shifts do not take into account circadian rhythms (the natural internal processes that regulate sleep), resulting in ATCOs working at times when their bodies are in a sleep cycle. Research has shown that disturbances in sleep due to shift work can increase fatigue, reduce hours of sleep, and negatively affect operational performance, thus increasing the risk of safety incidents (Luna, 1997; Van den Heuvel, Fletcher, Paradowski, & Dawson, 2003).

In response to the concerns regarding the effects of fatigue on performance, the Civil Aerospace Medical Institute investigated shift-work issues related to ATCOs by conducting, amongst others, the Nationwide Shiftwork and Fatigue Survey and the Air Traffic Shiftwork and Fatigue Evaluation (AT-SAFE). Analysis of the AT-SAFE data showed that the amount of sleep obtained by ATCOs impacted their mental sharpness. Mental sharpness was then regarded as a measure of ATCO performance, and results indicated that ATCOs rated their mental sharpness as lowest at the beginning of the early morning and midnight shifts, with the ratings even lower at the end of these shifts. These shifts were also associated with the lowest average sleep prior to the shift (Nealley & Gawron, 2015).

Harris (2011) notes that poor situation awareness leads to poor decision-making. Therefore, it is essential to identify human factors that enhance mental alertness and situation awareness in ATCOs. High workload, poor situation awareness, and poor decisions reflect a poorly designed system that fails to take the human processing system into account.

In order to cope with the stress components of their particular profession, ATCOs require a certain amount of emotional stability to help them remain psychologically fit for the job. It is essential that they are able to cope with highly demanding and stressful situations in a constructive manner, such that operational safety is achieved.

In complex technological dynamic systems such as air traffic control, ATCOs have to develop a mental representation of the task environment with which they interact. Decisions on future cognitive activities and actions are based on these insights into current and then anticipated structures of the changing environment (Niessen, Leuchter, & Eyferth, 1998).

Traditionally, human factors found to play an important role in the operational safety of ATCOs are those that play a role in enhancing situation awareness, thus promoting mental alertness and mental arousal, and include mental task engagement and mental workload. On the other hand, flow is a non-traditional critical human factors construct.

While there are a myriad factors that could play a role in ATCOs' safety performance, the present study examined those traditionally considered to play a critical role (the Safety-I view), namely situation awareness, mental alertness, mental task engagement, and mental workload, as the most critical considerations in ATCOs' performance. These factors underpin higher-order psychological cognitive processes such as planning, judgement, decision-making, and problem-solving in working situations. These factors were the focus in the present study, and are discussed below.

2.9.2 Situation awareness

Situation awareness is important in a variety of contexts that confront human factors practitioners (Endsley, 2015), and has been widely researched (Baumann & Kremm, 2007; Durso, Nickerson, Schvaneveldt, Dumais, Lindsay, & Chi, 1999; Endsley, 1995; Endsley & Rogers, 1998; Endsley & Smolensky, 1998; Kaber, Perry, Segall, McClernin, & Prinzel, 2006). Situation awareness in aviation is widely recognised as critical, and much research has been conducted on the topic, focusing on pilots (Sarter & Woods, 1991) and ATCOs (Endsley & Rodgers, 1994; Mogford, 1997; Endsley & Smolensky, 1998; Kaber, Perry, Segall, McClernin, & Prinzel, 2006).

The study by Endsley and Rodgers (1994) investigated the situation awareness information requirements of specialist *en route* ATCOs, in which their definition of situational awareness included the elements of perception, comprehension, and projection. Endsley and Rodgers (1994) developed a goal-directed task breakdown (i.e. a hierarchy) for all the major decisions, tasks, and goals of ATCOs. From this, they constructed a list of all the major decision tasks and information required for situation awareness. Kaber et al. (2006) researched the effectiveness of adaptive automation to support the processing of information in a control task. This was done by measuring situation awareness. Interestingly, the results of Kaber et al.'s (2006) study showed that situation awareness was higher during manual performance than during automated performance.

Endsley (1995) places emphasis on an operator's situation awareness as a critical construct on which decision-making and performance in such systems hinge. According to Endsley (1995), there exists a relationship between situation awareness and several individual and environmental factors exist, e.g., attention, working memory, stress, and system complexity, as these factors impede operators from acquiring and interpreting information from the environment to form situation awareness. In dynamic environments, many decisions have to be made within a limited space of time, and tasks are dependent on an ongoing, up-to-date analysis of the environment (Endsley, 1995).

Many definitions of situation awareness have been proposed, and not all are applicable across different task domains. Endsley (1995) defines situation awareness as "the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future" (Endsley, 1995, p. 36). Endsley (1995) elaborates on the definition with regard to:

- perception of elements in the environment (i.e. the first step in achieving situation awareness is the perception of the status, attributes, and dynamics of relevant elements in the environment);
- comprehension of the current situation (i.e. going beyond the simple awareness of the elements that are present in order to include an understanding of the significance of those elements in light of relevant operator goals); and
- projection of future status (i.e. achieved through knowledge of the status and dynamics of the elements and comprehension of the situation enabling the knowledge and time to decide on the most favourable course of action to meet one's objectives).

For example, an ATCO is required to put together information on various traffic patterns to determine which runways will be free and where there is the potential for a safety incident. ATCOs must therefore do more than simply perceive the state of the environment (Endsley, 1995).

Kalloniatis et al. (2017) emphasise the importance of Endsley's (1995) three levels of situation awareness, and elaborate further, whereby Level I is where data are merely perceived without further processing, Level II involves interpretation of Level-I data, allowing an understanding of its relevance to tasks performed and goals attained. At this point, the operator forms a holistic picture of the operational environment, allowing him/her to comprehend the significance of objects in that environment. Operators are then able to forecast likely future states for the situation (Level III). This forecast is achievable when operators combine their own experience with Levels I and II.

Sawaragi, Fujii, Horiguchi, and Nakanishi (2016, p. 537) offer a simpler definition of situation awareness: "knowing what is happening around oneself in a complex environment, in order to take an optimal decision and is an accepted concept of cognition in complex socio-technical and dynamic environments". Situation awareness is therefore based on far more than simply perceiving information about the environment. It includes an understanding of the subjective meaning of the information in an integrated form, comparing it to operator goals, and projecting future states of the environment that are valuable in decision-making. Situation awareness can therefore be viewed as a broad construct, applicable across a variety of application areas, with many underlying (common) cognitive processes (Salas & Dietz, 2016).

Kalloniatis, Ali, Neville, La, MacLeod, Zuparic, and Kohn (2017) consider situation awareness as fundamental to decision-making in many contexts, from individual aviators, to teams in civilian safety and control systems, emergency response, and military command and control. These authors view situation awareness as critical for performance, especially in dynamic and complex situations.

Endsley (1995) notes that individual characteristics such as information-processing ability underlie and impact situation awareness. Other factors have been identified as having an impact on situation awareness (Damos & Wickens, 1980), including attention (some operators are better at dividing their attention across different tasks), perception (the ability to perceive which information is important), working memory, and long-term memory.

Stress has also been found to impact situation awareness by reducing attention (Endsley, 1995). Sarter and Woods (1991) view situation awareness as gaining attention as a performance-related psychological concept. This is especially true in the aviation domain, where it is considered an essential prerequisite for the safe operation of the complex dynamic systems.

Sarter and Woods (1991) posit that situation awareness is based on an intuitive rather than an appropriate understanding. They view definitions of situation awareness as attempting to specify its components and note that focusing on the components of a situation is not sufficient to define awareness. The authors state that the predominant component is the temporal dimension — timing. Temporal awareness requires the diagnosis of a problem that is caused or influenced by precursors in the past and prognosis and prevention of potential future problems, based on the current analysis of data.

It could be argued that definitions of situation awareness as being dependent on the context are often too general. It is important to pay attention to important issues such as the acquisition of information and effective attention-filtering in changing, data-rich environments (Sarter & Woods, 1991). Sarter and Woods (1991) recommend that, in defining situation awareness, information that is available or that can be activated should be included.

Individuals vary in their ability to acquire situation awareness given the same data input. This is hypothesised to be a function of an individual's information-processing abilities (Endsley, 1995). The individual may also possess preconceptions and objectives that can act as a filter and influence interpretation of the environment. Situation awareness could also be a function of the system within which the person operates, that is, the degree to which the system provides the needed information and the form in which it is provided. Environmental factors that could also affect situational awareness include workload, stress, and complexity (Endsley, 1995).

Woods (1991) views the distinction between situation awareness and long-term memory as blurry and questions the validity of situation awareness as a construct in addition to the already existing factors of attention and memory. Some authors who have defined situation awareness have been criticised as borrowing liberally from existing and/or traditional cognitive psychology concepts without actually explaining how these are the same or different. For example, Baumann and Krems (2007) posit that situation awareness as a concept has recently become prevalent in aviation psychology, as it describes and integrates different cognitive processes. Banbury and Tremblay (2004) include activities in which cognitive and physical tasks are performed in a complex system in their definition of situation awareness.

With regard to the current research, situation awareness that is considered to be necessary for ATCOs to operate safely embraces a broader view, whereby the dynamic, cognitive, temporal, and spatial aspects of the task at hand are considered as essential components to achieving situation awareness. Optimal situation awareness is considered to enhance mental alertness and arousal, promoting the reduction of safety incidents during shift handover.

ATCOs need to be aware of the position and location of all aircraft in a particular sector. This situation awareness is a mental representation of the current and future traffic situation (Niessen, Leuchter, & Eyferth, 1998). Situation awareness relies on memory as a cognitive function to form accurate mental pictures. Shorrock (2005) found that 38% of memory errors in air traffic control take the form of failure to complete an intended action. ATCOs rely on working memory (temporary storage of recently activated information occupying consciousness) and long-term memory. Working memory allows the encoding, storage, and retrieval of information relating to the aircraft being controlled. ATCOs are required to absorb information (aircraft frequency, callsigns, routes, flight level, speed, heading, aircraft type, and location, and projected location) and keep the information in their working memory (Bradley &Tenenbaum, 2013; Shorrock, 2005). Situation awareness is extremely important in the complex cognitive task of controlling air traffic and, thus, ATCOs' operational safety.

The above literature can therefore be summarised as follows. Situation awareness is an individual's knowledge of the environment at a given point in time. It is also temporal in nature, whereby it is acquired over time, rather than only instantly, whereby the dynamics of the situation over time are used to project the state of the environment in the near future. Specifically with regard to ATCOs, situation awareness also requires, and is informed by, spatial reasoning, whereby ATCOs have to be aware of the spatial relationships amongst multiple aircraft.

Optimal situation awareness is fundamental to effective decision-making. According to Endsley (1995), acquiring and maintaining situation awareness becomes increasingly difficult as the complexity and dynamics of the environment increase. In dynamic environments, such as air traffic control, where ATCOs have to monitor a busy radar screen, many decisions are required within a fairly narrow space of time. The tasks required are dependent on constant analysis of the environment. ATCOs need to understand the integrated meaning of every perception, which understanding then informs their decision-making (Endsley, 1995).

In the current research, psychological factors such as stress, anxiety, and depression were considered in examining factors that may impede or enhance situation awareness. Situation awareness was considered a construct separate from decision-making and performance, as well as separate from other cognitive psychological concepts that may influence operational performance, such as working memory, workload, and stress (Endsley, 1995). In the current study, situation awareness is defined as the ability to continually assess a dynamic and complex environment. It is considered a crucial human factor component that has to be achieved and maintained at an optimal level in order to promote safety in air traffic control, in order to prevent safety incidents.

ATCOs are required to project the paths of ever-increasing numbers of aircraft in order to maintain minimum separation and ensure an ongoing sequences of safe and efficient landings and take-offs. In this taxing environment, ATCO require situation awareness to perform constant assessments of rapidly changing locations of aircraft in three-dimensional space and maintain aircrafts' current and projected locations relative to each other, all wile considering parameters such as speed, routing, and destination, and maintaining communication.

The focus of the current research is to consider different ways of assisting the ATCOs to facilitate enhanced situation awareness in the best possible way before commencing shift, ending a shift, and re-commencing shift after a break (shift handover), the limitations of operators manifesting in impeding situation awareness, as well as to identify mechanisms in the form of interventions that may assist in enhancing ATCOs' situation awareness, with the objective of reducing safety incidents. The current research investigated whether ATCOs who are able to achieve a high level of situation awareness are more likely to be mentally alert, thereby reducing the likelihood of a safety event.

As noted earlier, situation awareness is critical to effective decision-making. Therefore, it is important to incorporate the concept into studies on human factors (Endsley, 1995). Decision-making is discussed in detail in the following section.

2.9.3 Decision-making

Decision-making is referred to by Wickens, Gordon, and Liu (1998) as a task in which there are a number of choices confronting an individual, who must then select one of the choices. Zsambok and Klein (1997) characterise aeronautical decision-making as being carried out in dynamic and complex environments with ill-structured problems, copious amounts of information, uncertainty, competing goals, time constraints, high levels of risk, and collaboration or task-sharing among multiple individuals.

Klein, Calderwood, and Clinton-Cirocco (1986) found that expert decision-making entails first classifying and understanding a situation, and then immediately proceeding to action selection. Situation awareness plays a critical role in decision-making, especially in complex and dynamic environments. Critical cognitive components required in decision-making include selective attention, working memory, long-term memory, cue reception and integration, together with generating, evaluating, and selecting hypotheses and selecting and generating actions (Wickens & Hollands, 2000). Reason (1990) notes the cognitive limitations to decision-making as the individual's knowledge of the situation, working memory capacity, attentional resources, and the ability to retrieve the relevant information.

In order for ATCOs to perform optimally and make decisions in the highly complex and dynamic air traffic control environment, situation awareness is crucial. Cognitive psychological functions such as the ability to attend to appropriate critical cues and predict future states of the situation are made possible when ATCOs attain situational awareness.

(Endlsey, 1995; Kalloniatis, Ali, Neville, La, MacLeod, Zuparic, & Kohn, 2017; Sarter & Woods, 1991; Wickens, 2008). A model of decisions that incorporate situation awareness and goals was proposed by Eurocontrol (2009). This model can be described as a decision-making loop, whereby:

- the task's goal informs the planned action;
- the planned action incorporates perception, understanding, and forethought; which, in turn,
- informs the anticipated result, leading to an action and a result.

The result then feeds back into the goal, perpetuating the decision-making loop.

The air traffic control environment is considered to be complex and dynamic, as it is constantly changing. A multitude of decisions are required within a fairly narrow space of time. Tasks are dependent on an ongoing and up-to-date analysis of the environment. ATCOs' understanding of a situation as a whole will therefore enhance decision-making (Endsley, 1995).

2.9.4 Mental task engagement

Mental task engagement, also known as *mental alertness*, is considered critical to performance in the profession of air traffic control (Cañas, Ferreira, Puntero, López, López, & Góme, 2017; Desmond & Hoyes, 1996; Signal, Gander, Anderson, & Brash, 2009; Bernhardt, Jorgenson, Carlson, Drechsel, Iseminger, Poltavski, Ferraro, & Petros, 2017). Workers who are mentally engaged are experience less of the stress caused by long hours and increased workload (Britt et al., 2005).

Kahn (1990) conceptualised work involvement and commitment in the form of cognitive, affective, and physical engagement. Kahn (1990) went on to define involvement in work as personal engagement that harnesses employees' selves to their work roles. Kahn (1990) also characterises personal engagement as the emergence of one's true self, which is expressed within one's role. Self and role are therefore seen to exist in a dynamic relationship, in which the person drives personal energies into role behaviours, displaying the self through self-expression. When individuals are engaged, they express themselves physically, cognitively, and emotionally, and for mental task engagement to occur, it is essential that the situation involves meaningfulness, safety, and availability.

Meaningfulness refers to a function of work elements, such as the nature of the task and the role played. *Safety* is created by the social system, for example, the predictability, consistency, and non-threatening nature of group dynamics and interpersonal relationships. *Availability* refers to physical and psychological resources to process emotions and invest effort into the work (Kahn, 1990).

Schaufeli et al. (2002) define mental task engagement as a positive, fulfilling, work-related state of mind that is characterised by vigour, dedication, and absorption. When mentally engaged with the task, the person may have difficulty detaching himself/herself from the work.

Mental task engagement has been found to be related to social support from peers and co-workers, feedback, job control, task variety, training (Demerouti, 2001), task variety, feedback, and autonomy (Rapayana, 2008). Mental task engagement is further associated with high levels of self-efficacy. Engaged workers are more satisfied with their jobs and feel more committed to the organisation and their occupation (Demerouti, Bakker, Janssen, & Schaufeli, 2001). They are also more likely to work overtime and perform well (Rapayana, 2008). Demerouti (2001) found that engaged workers have higher levels of productivity and increased motivation to learn, and take more initiative.

Mental task engagement is often confused with both work involvement (Kanungo, 1982) and work commitment (Morrow, 1993). Work involvement is defined as being dedicated, enthusiastic, and inspired by one's work, while work commitment contains elements of mental task engagement, and is characterised by being engrossed and attached to one's work. The terms *mental task engagement*, *involvement*, and *commitment* have previously been used interchangeably (Kanungo, 1982), despite the fact that they are conceptually different. Hallberg and Schaufeli's (2006) research highlighted that they are different concepts, and that mental task engagement extends beyond involvement and commitment. Involvement is a cognitive and psychological identification with one's work, whilst commitment is an attitudinal and affective identification with one's work (Meyer & Allen, 1997).

Mental task engagement is a health psychology concept that has components of vigour and energy, which go beyond involvement and commitment (Hallberg & Schaufeli, 2006). Mental task engagement is therefore defined as a persistent and pervasive affective-cognitive state that is not focused on any particular object, event, individual, or behaviour (Schaufeli & Salanova, 2002).

Mental task engagement has been linked to air traffic control work. Pop, Stearman, Kazi, and Durso (2012) explored the extent to which increasing mental task engagement negates vigilance decrements in monitoring air traffic. *Vigilance decrement* refers to a reduction in performance over time, which leads to decreasing efficiencies, due to slower detection times (Lanzetta, Dember, Warm, & Berch, 1987). The results of their study showed that engaging the ATCO may alleviate the vigilance decrement, although this was noted to occur only after practice. Sawin and Scerbo (1995) postulate that a decrease in performance most commonly occurs after the first 20 to 35 minutes of ATCOs starting their shift. ATNS found that the majority of safety events take place within the first 30 minutes of a shift. This may be due to vigilance decrement during the high-risk handover period. However, De Reuck (2014) postulates that, if the occurrence of safety events is predominantly within the first 30 minutes on shift, it is unlikely to be due to a vigilance decrement, as the decrement decreases performance over time; therefore, safety events would occur later in shifts, rather than within the first 30 minutes.

Sustained attention is important, due to the fact that an ATCO is required to remain perpetually vigilant during the task of controlling, in order to prevent errors. In order to remain vigilant, the ATCO must maintain focused attention and remain alert to stimuli over a prolonged period of time (Warm, Parasuraman, & Matthews, 2008). Vigilance is defined by Donald (2008) as a capacity for sustained effective attention during the process of monitoring a situation or display for critical signals, conditions, or events to which the operator must respond. ATCOs encounter situations whereby vigilance, i.e. sustained attention, is necessary to allow both frequent and infrequent events to be monitored in order to achieve optimal safety.

From the above, it is clear that, in order to promote operational safety, it is essential that ATCOs are engaged in the task of controlling. This will allow them to maximise the cognitive elements necessary for mental task engagement, most importantly, sustained attention, focus, and concentration, and the ability to function in a dynamic environment. Many tasks that ATCOs are confronted with have elements that are different to those of the previous task. Previously acquired knowledge therefore needs to be applied differently (Salden, Paas, Broers, & Van Merriënboerr, 2004).

Air traffic control is a complex and dynamic task, with situations changing rapidly and often. In the current research, the capacity of an ATCO to engage mentally with the task of controlling was considered an essential skill. It was hypothesised that the more elevated the ATCO's level of mental engagement with the task of controlling is, the better the ATCO's performance will be, whereby the ATCO will have the ability to effectively resolve a conflict situation that poses a safety risk.

The cognitive aspects within the concept of mental task engagement that were examined in the current research are: attention/focus (particularly the ability to sustain attention, thereby achieving vigilance) and concentration.

2.9.5 Mental workload

Workload is acknowledged in the literature as a significant multi-dimensional concept encompassing the complexity of the task, together with the components of both the physical and mental effort (Brooker, 2003; Collett, Averty, Delhomme, Dittmar, & Vernet-Maury, 2003; Eurocontrol, 2003; Farmer, Belyavin, Tattersall, Berry, & Hockey, 1991; Hilburn, 1997; Kirwan et al., 1998; Van Acker et al., 2018). Workload covers an extensive spectrum of human activity; however, the current research's scope was limited to mental workload, i.e. the mental capacity of the ATCO to meet and co-ordinate task demands.

Advances in technology have resulted in complex work systems in which operators are required to adapt their performance to suit the dynamic environment, coupled with concurrent task demands, time pressure, and tactical constraints (Sheridan, 2002). It is therefore essential to consider mental workload in these complex systems, of which air traffic control is a good example (Loft, Sanderson, Neal, & Mooij, 2007). Throughout the history of studies on human ergonomics and human factors, the concept of mental workload has been considered to play an major role (Van Acker, Parmentier, Vlerick, & Saldien, 2018). Air traffic volumes are increasing worldwide (Loft, Sanderson, Neal, & Mooij, 2007), which is why is considered advisable that the mental workload of ATCOs be monitored.

The focus on *mental* workload is a fairly recently development. Previous research (Kirwan et al., 1998; Van Acker et al., 2018) found that, the greater the complexity of the operator's mental operations is, the more mental processing capacity would be required, with a greater impact on physiological variables (e.g., heart rate), resulting in a subjective experience of a higher workload. A relationship exists between an operator's limited and multidimensional cognitive resources and the cognitive work demands to which he/she is exposed.

Van Acker, Parmentier, Vlerick, and Saldien (2018), in critically analysing the concept of mental workload, note that various definitions exist, and that these include different variables related to workload. The literature offers random selections of defining variables and descriptions of these on different levels of abstraction and mediator and moderator variables. The construct is often misused conceptually, and is not always underpinned by established theory (Van Acker et al., 2018).

Gaillard (1993) notes that workload requires the capacity to process information in a task situation, and that this processing capacity is dependent on the availability of attentional resources and the state of the organism. While mental work overload negatively impacts performance, Desmond and Hoyes (1996) and Saxby, Matthews, Warm, Hitchcock, and Neubauer (2013) note that the converse also holds true — mental work underload can also lead to a decline in performance.

In the context of air traffic control, Brooker (2003) and Todorov and Petrov (2017) investigated the role of mental workload in measuring airspace sector capacity in air traffic control, which is the maximum number of aircraft that can be serviced in a given sector for a particular period of time by the system or one of its components while the ATCO is experiencing his/her upper limit of workload. The research and literature on workload and airspace capacity is vast (Arad, 1964; Janic, 1997; Ratcliffe, 1969; Zhang, Shan, Liu, Yu, & Yu, 2016).

Hopkin (1995) defines mental workload as a function of task demands that are placed on an ATCO and the aptitude of the ATCO to meet those demands. Brooker (2003) posits that it is essential to consider the pattern of flow in terms of volume of air traffic through the hour, as it has been found to dramatically impact mental workload. Air traffic flow management is a service established to contribute to a safe and expeditious flow of air traffic by maximising ATCOs' capacity and ensuring that the volume of air traffic is compatible with the capacities as declared by the relevant air traffic services authority (ATNS, 2016). The coupling of air traffic flow management with capacity management is done to exploit the full capacity of the air transport system without causing safety risks due to mental work overload (ATNS, 2016).

The management of air traffic flow is not new in South Africa (ATNS, 2016). The Central Airspace Management Unit (CAMU) was established at O R Tambo International Airport's air traffic control centre in 2001. Within the South African sovereign and delegated air space, CAMU is responsible for the management of air traffic flow and capacity, with the goal of maximizing capacity and optimising the flow of air traffic. CAMU is also tasked with assisting various air traffic services units to plan for and manage future workload, in anticipation of increased traffic flow within South African airspace. The goal of effective air traffic flow management is to alleviate ATCOs' high mental workload, thereby decreasing their levels of stress during control operations (ATNS, 2016).

The highest mental workload levels generally arise from short-term peaks in traffic, when task load is considered to be at its highest. The frequency of these high task load periods can be noticeably reduced by the flow of air traffic being regulated by, for example, controlling aircraft departure times, thereby preventing peaks and troughs in traffic (Brooker, 2003).

ATCOs' performance can vary according to mental workload (Sperandio, 1978). During high traffic flow, ATCOs adopt more economic strategies in operating methods, in order to prevent mental work overload. However, during very low traffic flow rates, there is the concern that mental work underload could result in boredom, and coping behaviours may then result in an increase in errors (Hopkin, 1988).

Loft et al. (2007) consider ATCOs' cognitive resources (e.g., information processing) as important factors in managing mental workload and define mental work overload as the task demands of the air traffic situation exceeding operator capacity. Levels of subjective mental workload vary according to ATCOs' level of skill and experience, as well as the complexity of different task demands (Loft et al., 2007). Mental workload may therefore be strongly connected to an ATCO's ability to manage his/her cognitive capacity. ATCOs also have differing abilities to keep their workload at a manageable level, and some are considered to be passive regarding the management of their workload (Loft et al., 2007).

From the literature discussed above, it is clear that increases in air traffic density and complexity lead to substantial increases in ATCOs' mental workload. High workloads could lower operational performance, increasing the risk of safety incidents (Moon et al., 2011; Wickens et al., 1997). Research by Endsley and Rogers (1998) found that ATCOs were significantly less likely to make mistakes when the experience lower levels of subjective mental workload than high levels. Research has also shown that an individual's performance is likely to decrease when workload increases (Wickens, Gordon, & Liu, 1998), which, in the context of the current research, translates into a higher risk of errors, leading to safety incidents.

Air traffic control is an environment in which the complexity of operations could rapidly cause mental overload, potentially impairing ATCOs' decision-making. In this environment, ATCOs' cognitive state is critically tied to their performance (Desmond & Hoyes, 1996; Signal, Gander, Anderson, & Brash, 2009), and if mental work overload Impacts the ATCO's performance, it could place aircraft at risk (Wickens, Mavor, & McGee, 1997).

In air traffic control, mental workload is influenced by the number of aircraft the ATCO is responsible for, which requires interaction between task requirements and task demands, together with the ATCO's skill level and mental and physical effort needed to successfully perform the task.

In the current study, mental workload is defined as the amount of work assigned that needs to be completed within a particular time frame, as posited by Brooker (2003), Stein (1998), and Stramler (1992). Thus, it is the amount of mental effort required to achieve an operational goal per system demands (task load), in accordance with the required standard of performance.

The current research considered the link between ATCOs' subjective view of mental work overload and safety incidents during the high-risk shift handover period, to gain insight into which, if any, aspects of mental workload impact ATCOs' performance. The aspects of mental workload investigated in the current research were: mental demands, physical demands, and temporal demands, as well as the ATCO's own levels of performance, effort, and frustration.

Understanding mental workload in ATCOs requires an understanding of the cognitive strategies ATCOs use to meet task demands. The cognitive strategies identified from the literature that are relevant to the current research include attention and concentration, decision-making, and information processing. These cognitive functions are essential to an ATCO's ability to meet task demands, and are related to an ATCO's skill level, which impacts the ATCO's subjective experience of mental workload. In exploring the impact of an increased mental workload on ATCOs' performance the physiological variable measured was the ATCO's heart rate.

The next section provides an overview of the final human factor under study, namely flow.

2.9.6 Flow

In moving towards incorporating a Safety-II approach into researching human factors in aviation, the current research examined the construct of flow. The positive psychology roots of flow are elucidated below.

Mihaly Csikszentmihalyi, considered one of the co-founders of positive psychology, was the first to identify and research flow. Flow is being in a state of optimal experience (Csikszentmihalyi, 1988), where one feels alert, in effortless control, unselfconscious, and that one is performing at one's best. During this state, there is no sense of time passing or of emotional problems; there is a feeling of transcendence and oneness with the activity. The term *autotelic* was coined by Csikszentmihalyi (1988) from the Greek work *auto*, meaning 'self', and *telos*, meaning 'end', indicating intrinsic motivation. The activity is seen as rewarding in itself, as opposed to it being a means to and end such as a product or an extrinsic reward (Nakamura & Csikszentmihalyi, 2002).

Csikszentmihalyi (1997) refers to flow as exceptional moments in which one's consciousness is full of experiences, and these experiences are in harmony with each other. In these moments, what one feels, what one wishes, and what one thinks are in harmony. Exceptional moments are characterised by there being no room in one's awareness for conflict or contradictions. Flow is also referred to as being 'in the zone'.

Csikszentmihalyi's (1988) focus was on the quality of the experience. The autotelic experience, that is, engaging in an activity for intrinsic rewards, remains very similar, regardless of context (Csikszentmihalyi, 1975). The experience of flow is so desirable and rewarding that one wishes to repeat it as often as possible. The consciousness starts to seek out those experiences that provide flow. The autotelic personality is defined by Csikszentmihalyi (1997) as a person who is able to confront life with such involvement and enthusiasm as when the person is in flow. Such individuals generally do things for their own sake, as opposed to doing something to achieve an external goal or reward. An autotelic person experiences flow in work, family life, in interacting with others, or when alone. An autotelic person is less dependent on the external rewards that motivate others. Autotelic people are more autonomous and independent, but still very much involved with everything around them, as they are fully immersed in the current aspects of their life.

Positive psychology postulates a shift in the focus of psychology from the pre-occupation with disease and pathology to recognising the experience of well-being, for example, facilitating satisfaction at work (Seligman & Csikszentmihalyi, 2000). The positive psychology model moved away from the disease model of human functioning towards the study of strength and virtue, thereby nurturing what is best. Positive psychology encompasses valued subjective experiences such as well-being, contentment, insight, optimism, love, growth, courage, skill, faith, work ethic, responsibility, perseverance, tolerance, originality, creativity, play, and flow. Positive psychology also emphasises satisfaction (with reference to the past), hope and optimism (with reference to the future), and flow and happiness (with reference to the present). Positive psychology was applied to the current research through consideration of human factors that enhance ATCOs' operational safety; thus, what went right during their normal, everyday operations, with a focus on flow.

Dietrich (2004) highlights how, more recently, the fields of cognitive science and neuroscience have brought the concept of the flow experience into focus. Flow is a psychology construct, and the flow state is characterised by effortless processing of information. There is much support in literature for the concept of flow enhancing performance (Bakker, 2005; Csikszentmihalyi, 1975, 1988, 1992, 1997; Moneta, 2012; Nakamura & Csikszentmihalyi, 2002; Rupanya, 2001).

Nakamura and Csikszentmihalyi (2002) posit that flow tends to occur when a person faces a clear set of goals that require appropriate responses. A person in flow is completely focused. There is no space in consciousness for distracting thoughts and irrelevant feelings. Self-consciousness disappears. The sense of time is distorted, whereby hours seem to pass by in minutes; time is forgotten. During flow, a sense of control develops, which allows one to deal with the situation and its challenges (Nakamura & Csikszentmihalyi, 2002). Once a person has experienced flow, he or she becomes more likely to experience flow again. Flow can lead to personal growth, as the flow experience encourages a thirst for learning and developing new skills (Jackson & Eklund, 2002).

Bakker (2007) defines flow as comprising three elements:

1 absorption;
2 enjoyment; and
3 intrinsic motivation.

Absorption is a state of total concentration, whereby one is totally immersed in one's work. During this state of absorption, time passes quickly, and everything around one tends to be forgotten. Outside stimuli are not noticed, as one's attention is fully focused on the task (Csikszentmihalyi, 1990; Jackson & Eklund, 2002; Nakamura & Csikszentmihalyi, 2002).

Enjoyment is a state in which workers enjoy their work and tend to make positive judgments about the quality of their working life (Veenhoven, 1984). This enjoyment or happiness is the outcome of cognitive and affective evaluations during the flow experience (Diener, 2000).

Intrinsic motivation refers to performing a certain work-related activity with the aim of experiencing the inherent pleasure and satisfaction of the activity, rather than for the sake of extrinsic motivation, such as financial rewards (Deci & Ryan, 1985). Intrinsically motivated workers are interested in their work. They are motivated by the aspects of their work tasks, tend to want to continue their work, and demonstrate a fascination for the tasks they perform (Harackiewicz & Elliot, 1981).

Researchers have found evidence of flow during the performance of a large number of different activities (Csikszentmihalyi & Csikszentmihalyi, 1998; Kowal & Fortier, 1999). Significant consequence of the flow experience are enjoyment and pleasurable absorption. Csikszentmihalyi (1997) posits that such a peak experience may emerge in any situation in which there is activity.

Rupayana (2008) conducted research on flow in the workplace, and found it to be linked to several important outcomes, such a positive mood and physical and psychological wellbeing. Csikszentmihalyi (1975, p. 9) defined flow as "the holistic sensation that people feel when they act with total involvement in their activity". Csikszentmihalyi (1988) found that almost any activity in daily life can produce a flow-like experience. Flow is similar regardless of the context, and has been found to occur in work, education, and leisure settings, and has been observed in artists, school children, athletes, chess masters, rock climbers, dancers, school basketball and tennis players, composers, poets, dancers, and writers, to name a few. Later research by Csikszentmihalyi (1997) found that people experience flow more often in work settings than during leisure time.

Clarke and Haworth (1994) found that the occurrence of flow is most likely to occur when a balance is perceived between the challenge of a situation and one's own skills to deal with the challenge, i.e. when the individual's professional skills match the job demands. In addition, flow tends to occur when the individual's skills are fully involved in overcoming a challenge.

On the other hand, Boniwell (2008) warns that activities whereby flow is achieved have the potential to become addictive. Csikszentmihalyi (1992) also warns that flow has a potentially negative effect, whereby the individual desires a certain kind of order and is unwilling to cope with the ambiguities of life. Flow theory has been criticised as being ethereal and bordering on mystical, and that there is no explicit explanation of how to achieve the state of flow (Carl, 2013). With regard to the context of the current research, no studies on the impact of flow in aviation or air traffic control could be found.

Being fully in flow makes for excellence (Csikszentmihalyi, 1997). A significant consequence of the flow experience is enjoyment and pleasurable absorption. In other words, ATCOs who are totally engrossed in their task, passionate about what they do, and experience enjoyment when they are engaging with the task of controlling are more likely to experience happiness and higher levels of motivation at work.

In the current research, flow was regarded as a short-term peak experience characterised by absorption, enjoyment, and intrinsic motivation. It is proposed that ATCOs achieving a state of flow would enhance their performance, thereby decreasing the risk of safety incidents, especially during the high-risk handover period.

The core cognitive processes that link to flow and that were measured in the current study were: attention, concentration, motivation, memory, perception, planning, and the processing of complex information, all of which arguably become effortless during the flow state. In addition to the cognitive components of flow being considered, outputs of flow were also be taken into account, that is the subjective experience of absorption, enjoyment, and intrinsic motivation (Bakker, 2007).

2.9.7 Psychophysiological arousal

Psychophysiological arousal is both a physical and a psychological or state. The physical component is evident in aspects such as body posture and orientation appropriate to the reception of sensory information and a sufficient degree of muscle tension to be ready to respond quickly. The psychological component is evident in aspects such as the process of freeing the mind of inessential thoughts and ruminations, and keeping all channels of sensory influx equally available to receive and process information in accordance with task demands or the goals to be achieved. The construct has also been linked to other characteristics, e.g., drive, motivation, and goal-directed behaviour, and could be reflected in cognitive functions (Lindsley, 1988). Dienstbier (1989) explains that psychophysiological arousal is triggered when an individual is confronted with a stressful or challenging scenario.

Lindsley (1988) describes mental arousal as awakening from drowsiness and mobilisation to action, interest, motivation, and effort in the performance of a task or duty. Attention is required in order to obtain the required level of mental arousal. It is one of the cognitive processes necessary for perception, memory, thought, communication, and action in both simple and complex tasks. It is effortful concentration of thought and alerted and sustained vigilance, requiring increased cognitive effort and a predetermined mindset to detect, isolate, and integrate temporal-spatial and sensory cues and sensory qualities, yielding metacognitive processes of perception and memory as outcomes. These processes are subject to oscillations due to boredom, fatigue, and distracting stimuli (e.g., interruptions and stress).

Psychophysiological arousal has been studied in research in aviation and air traffic control (see David, Mollard, Cabon, & Farbos, 2000; Rodrigues, Paiva, Dias, Aleixo, Filipe, Paulo, &

Cunha, 2018; Wilson & Russell, 2003). The mental arousal required of ATCOs is selective and focused, as opposed to attention that can be generalised and unfocused (Lindsley, 1988).

Cherry (2018) discusses the mental arousal in terms of motivation, whereby individuals are motivated to attain and maintain higher levels of mental arousal in order to deliver high performance. According to Rodrigues et al. (2018), in a situation where there is pressure to respond rapidly, as is the case in air traffic control, there is a trade-off between speed and accuracy. In commenting on arousal, Oken, Salinsky, and Elsas (2006) reference vigilance decrement, which is a decline in attention-related performance over an extended period. At low levels of arousal, performance is low and sensitivity to input decreases, which may lead to errors due to fatigue, lack of stimulation and/or motivation, a low workload, and a lack of complexity, which, in air traffic control, occurs when air traffic is constant and unchanging.

However, performance can become impaired if arousal levels become too high due to very high levels of complexity or workload. It is therefore important to establish optimal arousal. From a psycho- and physiological perspective, mental arousal is the non-specific activation of the cerebral cortex in relation to sleep–wake states (Oken, Salinsky, & Elsas, 2006). Mental arousal is a state of the nervous system being able to receive and process information at an optimal level (Rodrigues et al., 2018). Rodrigues et al. (2018) considered the impact of stress on psychophysiological arousal of stress on ATCOs' performance and error rates.

In the present research, psychological arousal is defined according to the Yerkes-Dodson law (Yerkes & Dodson, 1908), which holds that there is an empirical relationship between pressure and performance. Physiological and psychological arousal enhance performance, but only up to the point when optimum arousal has been achieved. Thereafter, additional levels of arousal will result in decreased performance.

According to Rodrigues et al. (2018), several physiological modifications can be observed when the body is under stress beyond optimum arousal. The autonomic nervous system is activated, the parasympathetic nervous system is withdrawn, and the sympathetic nervous system is triggered. Stress-related hormones are secreted, leading to many physiological responses, e.g. increased heart rate, decreased heart-rate variability, increased blood pressure and breathing rate, vasoconstriction of blood vessels, and increased muscle tension.

A review of extant literature, Charles and Nixon (2019) conclude that there is no single physiological measure that can offers sensitivity, diagnosticity, reliability, and ease of use.

However, a growing body of literature supports the inclusion of physiological measures in studying human factors.

There are six main measures of psychophysiological arousal (Charles & Nixon, 2019): heart activity (heart rate and heart-rate variability as measured using an electrocardiogram), respiratory activity (breath rate), ocular activity (blink rate, pupil size), dermal activity, blood pressure, and brain activity (measured using electroencephalograms (EECs) and event-related potential). Such data can be collected discreetly, whereby arousal is measured without interference with the primary task, or it can be collected intrusively, where the data are collected with some level of interference with the subject performing a task. For the purpose of the current research, the psychophysiological response of heart rate was selected as the indicator of level of psychophysiological arousal. The data were collected in an unobtrusive manner whereby the participants could continue with their task of controlling as would be the case when the researcher is not present.

The above discussion elucidated the constructs under study. However, the boundaries between these factors of performance are not absolute; there is some conceptual overlap. Furthermore, the factors play roles in conjunction with each other, and have interactive effects. The next section provides an overview of these conceptual overlaps and interactions.

2.10 Conceptual Overlaps and Interactions Between the Human Factors Under Study

Performing the task of air traffic control in a safe and efficient manner involves the co-ordination of concurrent cognitive tasks. ATCOs achieve this by building and maintaining a mental picture of the air traffic situation. They have to control complex and dynamic situations, forming mental representations of the changing situations, together with flexible co-ordination of the concurrent cognitive tasks. ATCOs also have to resolve potential conflicts, based on different sources of information (e.g., radar screens, flight progress strips, and headphone communication with pilots) in situations characterised as dynamic and complex, with time constraints. ATCOs have to perceive, comprehend, and anticipate multiple considerations regarding many aircraft, while new incoming aircraft create new traffic relationships for evaluation (Niessen, Leuchter, & Eyferth, 1998).

A shift in psychology occurred from the traditional study of cognitive functions (i.e. situation awareness, mental task engagement, and mental workload), to studying cognitive functions such as flow) in an information-processing context. These cognitive constructs are also human factors, and are arguably vital to operations in any complex system such as air traffic control.

The is conceptual overlap between the cognitive constructs *arousal*, *alertness*, and *attention*, and the constructs are difficult to separate and define. Lindsley (1988) explains this difficulty as the result of each term having a variety of meanings and implications. The terms alertness, vigilance, and attention are also often used interchangeably. However, a case can be made for differentiation of these constructs, even though they may share some properties under certain conditions.

Workload can be separated into physical and mental workload, thereby overlapping with alertness. Optimal mental alertness requires interest, effort, and motivation. Lindsley (1988) sees attention as an extension of mental alertness, with mental alertness and arousal being closely related. However, *mental alertness* is no longer the preferred term in psychology literature. When exploring the concepts of mental arousal and mental alertness in air traffic control, mental fatigue must be recognised as impairing mental alertness, leading to errors. Accurate performance needs to be sustained over a shift; therefore, mental alertness needs to be maintained. Mental fatigue leads to a decreased ability to concentrate and identify important information, poor judgement, slower decision-making and reaction time, and carelessness.

Task engagement and flow have been identified as important psychological constructs in understanding workers' interaction with their work. An increasing body of research has identified mental task engagement and flow as related to critical work outcomes such as performance (Harter, Schmidt, & Hayes, 2002), lower stress (Salanova, Bakker, & Llorens, 2006), and increased commitment to work and the organisation (Schaufeli & Bakker, 2004). Both flow and mental task engagement incorporate aspects related to individuals' interactions with their work. According to Schaufeli and Salanova (2007), these two concepts have been identified as similar in the literature; however, the construct *flow* is defined as activity-specific, while the construct *mental task engagement* is defined on a more general level. This definition of Schaufeli and Salanova (2007) contradicts Csikszentmihalyi's (1997) postulation that the experience of flow can be found in all aspects of a person's life, and is therefore not limited to one specific activity.

Rupayana (2008) considered the concepts of mental task engagement and flow, and how they relate to one another. Rupayana (2008) researched whether flow and engagement are measures of the same underlying construct — work involvement. According to Kahn (1990), mental task engagement is the underlying factor of flow. Mental task engagement can therefore be seen as underlying effort, involvement, mindfulness, flow, and intrinsic motivation. Flow might therefore be regarded as the peak experience of mental task engagement (Rupayana, 2008).

Shernoff et al. (2003) assert that mental task engagement occurs when a person experiences flow while working. Macy and Schneider (2008) propose that an autotelic personality is a manifestation of flow, and can therefore be conceptualised as trait engagement. However, this would contradict the overlap between flow and mental task engagement.

Flow as an autotelic experience is an intrinsically motivated activity, while mental task engagement is characterised by dedication, which is defined as being strongly involved and having a sense of significance, enthusiasm, and pride in one's work. Autotelic individuals are less concerned with themselves. It follows that they have more energy available to invest in their work activity.

Engaged workers are more likely to identify intrinsic reasons for being in their jobs, such as the nature of the job itself and its meaningfulness. Both flow and mental task engagement have a component of intrinsically motivated activity, and both are pleasurable experiences (Rupayana, 2008).

The concepts of mental task engagement and flow are therefore similar, including in their definitions, resulting in differing viewpoints in the literature with regard to whether engagement results in flow, or whether flow causes engagement. Flow and mental task engagement have been defined in similar ways and are often used interchangeably in the literature. Empirical evidence is lacking with regard to whether there is a causal relationship between the constructs, or whether the use of both is a redundancy (Shernoff, Csikszentmihalyi, Schneider, & Shernoff, 2003).

Similarly, mental task engagement has been found to be positively related to social factors such as performance feedback and job control. Mentally engaged workers value feedback as an important part of their engagement. Engagement and flow both have the component of requiring unambiguous feedback (Rupayana, 2008). Rupayana (2008) posits that mental task engagement cannot be differentiated from the flow experience.

Rupayana (2008), in commenting on literature on the construct *engagement*, notes that it has been found to affect important outcomes, such as satisfaction (Britt, Castro, & Adler, 2005) and productivity (Harter, Schmidt, & Hays, 2002). Bakker (2005) refers to the concept of flow as being similar to mental task engagement, and that it is increasingly linked in research to positive outcomes in the workplace.

According to Tsang and Vidulich (2006), the constructs *mental workload* and *situation* *awareness* were developed to describe certain task demands faced by the human operator. Although mental workload and situation awareness are concepts that aid understanding of human reaction to interacting with a system to achieve an identified goal, they are separate concepts (Tsang & Vidulich, 2006). These two concepts vary independently, but mental workload may have a negative effect on situation awareness in certain situations (Endsley, 1993). A high workload is needed to maintaining high situation awareness (Tsang & Vidulich, 2006). The relationship between situation awareness and performance is not always direct (Endsley, 1995). For example, a person's performance may be poor despite high situation awareness when the correct action for the identified situation is not known, or when time or other factors limit the individual's ability to carry out the correct action (Endsley, 1995).

Pew (1994) posited that the term *situation awareness* has replaced of the term *workload*. However, Wickens (2001, p. 446) argues against this replacement, despite these constructs being affected by the same human variables (e.g., task demands):

> *Mental workload is fundamentally an energetic construct, in which the quantitative properties (how much) are dominant over the qualitative (what kind) properties. In contrast, situation awareness is fundamentally a cognitive construct in which the critical issue is the operator's accuracy of ongoing understanding of the situation (a qualitative property).*

The conceptual overlap between flow and situation awareness is not addressed in the literature. One of the overlaps between flow and situation awareness identified by the present researcher is the temporal nature of both situation awareness and flow, whereby situation awareness is acquired over time, without the individual necessarily being aware of the construction of reality. With flow, however, there is a distortion of the perception of time passing. Engagement and flow are measured similarly with regard to their dimensions (Rupayana, 2008). For example, absorption in work is present in both flow and mental task engagement. Absorption in mental task engagement can be more pervasive in mental task engagement than in flow, as absorption is only indirectly represented in the flow experience, through the loss of self-consciousness, time distortions, and concentration on the task (Jackson & Eklund, 2002). Individuals who experience flow also show intense concentrating on the task at hand, which can be referred to as absorption. Mental task engagement and flow have elements of absorption and loss of self-consciousness.

As is clear from the preceding discussion, there are many conflicting views regarding definitions of the constructs used in the present study. Therefore, for the sake of clarity, the definitions used in the present study are reiterated below.

Situation awareness:	the ability to continually assess a dynamic and complex environment;
Mental task engagement:	the cognitive aspects of attention/focus (particularly the ability to sustain attention, thereby achieving vigilance) and concentration;
Mental workload:	the amount of work that needs to be completed within a particular time frame;
Mental arousal:	mobilisation to action, interest, motivation, and effort in the performance of a task;
Flow:	a state of absorption, enjoyment, and intrinsic motivation.

In researching the effects of the concepts discussed above on performance, human error frameworks and investigation schemes have been developed. These frameworks aid examining of causes of incidents related to human factors. The aim in the development of these frameworks and schemes, discussed in the next section, was the development of more effective prevention strategies.

2.11 Human Error Frameworks

The current research undertook to analyse safety incident reports that were based on the HERA-JANUS Technique (Eurocontrol, 2003). It is therefore necessary to understand the rationale behind human reliability assessment and the analysis tools that are used. Human reliability assessment involves computing the likelihood or probability of an error. The goal of the assessment is to gain an understanding of all potential risks to the system, including human error. The outcome of such an assessment is the determination whether the system is safe, which is ultimately determined by the identification of human error.

Human performance contributes to risk, but is difficult to predict. Kirwan (1998) refers to the shift to a focus on considering context in human reliability assessment, as opposed to merely descriptions of operational procedures. The impact of human error and error recovery on a system is considered by Kirwan (1998) to be determined by identification of human error.

Following human reliability analysis, it is important to reduce the possibility of an error occurring, as well as reducing the impact of an error. This is referred by Kirwan (1998) as ‘error reduction analysis’.

There are a number of human error analysis methods, referred to as *human error identification* approaches or techniques (Kirwan, 1998), e.g., Systematic Human Error Reduction and Prediction Approach (SHERPA), Generic Error Modelling system (GEMS), Potential Human Error Causes (PHECA), and the Human Error in Air Traffic Management (HERA) Technique are some of the older techniques, with newer techniques being System-Theoretic Accident Model and Process (STAMP), Accimap, Functional Resonance Accident Model (FRAM), and Cognitive Work Analysis (CWA). Techniques applicable to the aviation industry include Human Factors Analysis and Classification System (HFACS), Human Error Assessment and Reduction Technique (HEART), and Technique for Human Error Rate Prediction (THERP). The most widely used human factors accident analysis framework is the HFACS (Harris & Li, 2011). "It is a generic human error-coding framework, originally developed for US naval aviation as a tool for the analysis of the human factors aspects of accidents" (Harris & Li, 2011, p. 109). It is important to emphasise that HFACS was one of the earlier human reliability analysis tools used for the compilation of the incident reports in the current research study.

Kirwan (1998) classified the techniques as (i) taxonomies that present checklists or error modes to be interpreted in context (THERP), (ii) psychology-based techniques, relying on understanding factors affecting performance, characterised by tools that consider error causes and/or mechanisms (SHERPA, GEMS, and PHECA), (iii) cognitive modelling of cognitive aspects of performance, bringing cognitive psychology into the arena, (iv) cognitive simulations, which are computer simulations of operator performance and are considered "the most sophisticated human error identification area, often relying on expert system-type frameworks to predict performance and error" (Kirwan, 1998, p. 159), and (v) reliability-oriented techniques, which stem from the reliability approaches that have proven their worth in analysis of non-human reliability problems.

The Human Error in Air Traffic Management Project (HERA-JANUS), a joint effort by Eurocontrol and the FAA, is concerned with how the examination of human errors in air traffic management can be improved to enhance safety and efficiency in European operations. The HERA-JANUS project aimed to increase the effectiveness of error recording and analysis. This work has arisen out of the increasing recognition of the consequences of human error, error recovery, and error reduction in air traffic management. The effective analysis of incidents in air traffic management has become more important as traffic levels increase and operational centres make more use of computerised support and automation (Eurocontrol, 2003). HERA analysis, developed by Eurocontrol, is a technique for analysing airspace events retrospectively and prospective system development. Narratives of airspace incidents are analysed to determine human error in relation to contextual factors (such as task and equipment). The HERA-JANUS Technique is also retrospective, and its development was aimed at "standardising terminologies, simplification of the analysis, the reduction of taxonomies for easier use, and refined methodology to assist understanding" (Eurocontrol, 2003, p. 4).

The HERA-JANUS method classifies human error in air traffic control into several taxonomic groups, including tasks, equipment, contextual conditions, error/violation types, error detail, error mechanisms, and information processing levels. The technique offers a logical, structured, and complete framework, together with a more objective approach, to the analysis of all components of the incident situation. The technique allows comparison of data and the sharing of experiences sharing between units and countries, as well as trend analyses and processing of statistical data.

The technique also allows the inclusion and in-depth analysis of the human factors. The technique is aimed at encouraging a blame-free culture (Eurocontrol, 2003). The HERA-JANUS Technique of analysis of safety incidents was utilised in the current research to qualitatively and quantitatively analyse safety incidents.

Critique of the HERA-JANUS technique (Eurocontrol, 2003) includes that the training to use it is a lengthy process, human error is difficult to identify (especially when it involves cognitive processing), using the technique is time-consuming, the analyst having a background in human factors is essential, and the technique cannot be used for all cases. Within to the context of the current research, the technique can be critiqued as following solely a Safety-I approach, to the exclusion of important Safety-II considerations. However, it could be argued that the positives outweigh the negatives, as the HERA-JANUS Technique is a comprehensive technique suitable for the identification of human error in aviation settings (Eurocontrol, 2003).

In line with the present study's focus on combining the Safety-I and Safety-II approaches, two interventions were conducted to investigate whether these may enhance 'what goes right'. These are discussed below.

2.12 Interventions

2.12.1 Music and mindfulness

Music and mindfulness were selected as interventions to be utilised in the current study, to test whether these could enhance the cognitive processes of flow, mental task engagement, and situation awareness. The applicability of the interventions was measured through their impact on the psychophysiological arousal of ATCOs. The ultimate aim was to enhance the desired cognitive processes that may lessen the occurrence of safety incidents.

2.12.1.1 Music

Music, according to Lingham and Theorell (2009), is a social endeavour that is uniquely human. To recognise and respond to music is neurologically and genetically programmed into the hard wiring of our brains (Peretz & Zatorre, 2005). Music amplifies and provokes emotions, and hormones, autonomic activities, and cerebral functioning may be altered during listening to music (Peretz & Zatorre, 2005).

Listening to self-selected music can produce stimulative or sedative (relaxing) effects (Blood & Zatorre, 2001). Neurobiological research has shown that self-selected music may have strong stimulatory effects on heart rate, breathing rate (respiratory rate, i.e. the number of breaths per minute), and skin conductance, as well as a stimulatory effect on those parts of the brain associated with reward (Blood & Zatorre, 2001). Lingham and Theorell (2009) refer to heart rate and breathing rate as psychophysiological reactions. There is evidence that self-selected music correlates with a number of social and psychophysiological variables, such as biological arousal.

Research has shown that preferred music may have psychophysiological effects that differ from those of non-preferred music (Davis & Thaut, 1989; Gregory, 1994; Paskin & Bakker, 1994). Lingham and Theorell (2009) refer to two studies that presented diverging results regarding the effects of self-selected music. Allen and Blascovich (1994) found that surgeons had decreased physiological arousal when listening to self-selected music, while Davis and Thaut (1989) found that anxiety significantly decreased, while, at the same time, there was an increase in heart rate of subjects who listened to preferred music.

A general theme in the literature in this domain is that preferred — not prescribed — music is critical to achieving the desired outcome. For example, Davis and Thaut (1989) concluded that preference, familiarity, or past experiences related to the music may have an overriding effect on positive behaviour change, rather than the genre of music. This was also evident in a study on computer systems developers, in which it was found that individual choice of music was important in reducing negative affect and improving positive affect (Lesiuk, 2008). The quality of participants' work was also seen to improve over time. When the music evoked a pleasant mood state and increased arousal, the participants performed better (Lesiuk, 2008).

Lingham and Theorell (2009) explored possible effects of preferred and self-selected music, both stimulative (uplifting, faster) and sedative (relaxing, slower) on psychophysiological reactions (heart rate and breathing). These authors defined stimulative music as music that is fast, uplifting, happy, and high-spirited, while sedative music is relaxing, slow, and gentle. It was emphasised that both pieces were the participants' favourites, in other words, preferred and familiar. Stimulative music was found to increase heart rate and respiration rate, and decrease carbon dioxide in exhaled air. This was indicative of increased sympathetic nervous system activity and, hence, increased arousal. Stimulatory music increased feelings of joy, elated mood, and energy. Physiologically, the effects were much more pronounced for stimulatory than sedative music. Relaxing music did not significantly decrease heart rate.

Robb (2000) notes increasing evidence that listening to music can produce physiological arousal, with a simultaneous reduction in psychological measures of anxiety. Further studies are, however, needed to determine how music mediates emotion, mood, and arousal.

A number of authors suggest that happy, exciting, and stimulative music produces higher levels of anxiety, physiological arousal and aggression when compared with sad, calming, and sedative music (Smith & Morris, 1977; Carlson, Saarikallio, Toiviainen, Bogert, Kliuchko, & Brattico, 2015; Karreman, Laceulle, Hanser, & Vingerhoets, 2017; Saarikallio, 2016; Wood, 2015; Zoteyeva, Forbes, & Rickard, 2016). Given the importance of arousal and/or activation in most music theories of persuasion and information processing, there is a need for greater understanding of how music can be harnessed to effect psychological arousal (Dillman, Carpentier, & Potter, 2007).

There are different approaches of music psychology. Dillman et al. (2007) highlight the numerous debates that exist within the literature on music psychology, specifically how the process is best conceptualised and approached from an empirical point of view (Bever, 1988; Gaver & Mandler, 1987; Juslin & Sloboda, 2001; Dillman et al., 2007). According to Scherer and Zetner (2001), the two main schools are:

(i) the cognitivist school of thought, which holds that the cognitive recognition of cues within the music produces an emotional response; and

(ii) the emotivist school of thought, which discards any consideration of cognitive recognition. Emotivists consider emotions that are felt when listening to a musical composition, and hold that there is a cultural and/or social influence on how the piece of music is interpreted (Peretz, 2001).

Dillman et al. (2007), however, posit that there is a conceptual chasm between emotion being expressed and emotion being elicited by a piece of music. A variety of different empirical approaches have been adopted in the field of music and emotion (Dillman et al., 2007). Distinct basic emotional states are the focus of some researchers (Ortony, Clore, & Collins, 1988; Thayer, 1989; Dillman et al., 2007), while other researchers investigated human reactions to music (Dillman et al., 2007).

According to Dillman et al. (2007), some studies (specifically those conducted by emotion scholars) focused on the extent to which different feeling states have common factors, while other studies focused on the 'discrete identifier' assigned to a certain feeling state by the listener. The dimensions *valence* and *arousal* have received the most research attention (Dillman et al., 2007).

The current research focused on music that has a mentally arousing effect on the ATCO. The focus was therefore on cognitive processes, specifically mental arousal, rather than emotional states. Specifically, the current research explored whether an increase in mental arousal in response to the stimulative effect of music would lead to enhanced mental engagement and flow in ATCOs.

The results of research on the effects of music on arousal tend to be fairly consistent across studies (Juslin & Sloboda, 2001). The relaxation potential of music has been noted, whereby, for example, muscle tension was measured, and was found to have been reduced (Dillman et al., 2007). The musical compositions utilised in these studies were either pre-tested to confirm that they were relaxing, or were identified by the participants as having a relaxing effect. Bartlett (1996, as cited in Dillman et al., 2007). Rickard (2004) combined self-reports of emotional impact, enjoyment, and familiarity with psychophysiological measures (skin conductance responses, chills, skin temperature, and muscle tension) in evaluating arousal effects of music. The results revealed that the greatest increases in skin conductance and chills were found in participants who self-identified the music as emotionally powerful.

Dillman et al. (2007) highlight how numerous studies have attempted to distinguish exactly which characteristics of music (for example, tempo and mode) produce increased states of arousal in listeners. Mode, i.e. major or minor key, was found to affect self-reported mood, while increased tempo caused increased self-reported arousal (Kellaris & Kent, 1993).

Dillman et al. (2007) conducted two experiments to investigate whether a certain tempo increased activation of the autonomic nervous system, thereby elevating the listener's arousal. Dillman et al. (2007) were interested in investigating if individual musical beats resemble other auditory structural features that activate the sympathetic nervous system when their tempo was increased. They found that increasing the tempo of the music could heighten arousal. Research by Potter (2007) showed that increasing frequency of onset for certain auditory structural features, i.e. those that cause cardiac-orienting responses and a resulting allocation of cognitive processing to message encoding lead to increased self-reported and psychophysiological arousal. The results of Dillman et al.'s (2007) two experiments concluded that the presence of any fast or slow music leads to an increase in arousal in the sympathetic nervous system. It is therefore feasible to conceptualise musical beats as auditory structural features capable of activating sympathetic arousal.

Lingham and Theorell (2009) note the need for studies looking at the psychophysiological effects of everyday listening to favourite music and the extent to which arousing music can activate biological systems. Lingham and Theorell (2009) explored the effects of listening to two selected pieces of favourite music (stimulatory and sedative) on both arousal (sad/joyful, listless/energetic, worried/elated) and relaxation (tense/relaxed, anxious/calm). They assessed emotions by means of physiological outcomes such as heart rate and breathing rate. Participants were asked to select their favourite stimulative and sedative piece of music. Participants listened to the self-selected music in random order. Lingham and Theorell (2009) found that stimulative music resulted in aroused physiological responses, such as increased heart rate and breathing rate. It also resulted in increased arousal feelings (i.e. joyous, elated, and energetic). However, no sedative effects on emotions (i.e. calm and relaxed) were found.

The literature on music and arousal suggests that preferred music improves performance (Schellenberg, 2005). Many studies have shown that listening to music that one likes can improve performance over the short term (Schellenberg & Hallam, 2005). These studies emanated from the widely reported study by Rauscher, Shaw, and Ky (1993), in which spatial intelligence quotient (IQ) increased by eight to nine points when the individual listened to classical music for ten minutes. "Any stimulus that is capable of increasing someone's mood and arousal, music being just one example, should boost performance in the short term" (Thompson, Schellenberg, & Hussain, 2001, as cited in Perham & Sykora, 2012, p. 3).

Lesiuk (2008), in a study in the context of air traffic control, explored the impact of preferred music on ATCOs' stress levels. Lesiuk (2008, p. 1) emphasised the high levels of workplace stress with regard to the occupation of air traffic control, and sought to identify "stress coping strategies … that reactivate air traffic control personnel in a quick, effective and sustainable way". Lesiuk (2008) concluded that state anxiety levels significantly decreased over time when air traffic control personnel listen to music. The self-reports indicated a relationship between the degree of liking the music and its effectiveness in stress reduction. Lesiuk's (2008) research utilised self-selected sedating music, whereas, the current research, self-selected uplifting music was used to investigate whether it improved mental arousal, alertness, and attention in ATCOs.

One ATCO in Lesiuk's (2008) study noted that complete relaxation is not a desirable state for ATCOs. This is an essential insight with regard to the current study, whereby "the requirement to attend to several simultaneous stimuli during on-task work time necessitates that stress (i.e. over-arousal) must be managed and alertness maintained. Thus, the role of music for some ATCOs, at least during work time, may be to maintain alertness or to increase arousal" (Lesiuk, 2008, p. 9).

The potential effect of music were investigated in the current research, whereby the arousal effect of music on ATCOs was explored, to determine whether it is an effective tool to enhance ATCOs' arousal high-risk handover period. In line with the method of Rauscher, Shaw, and Ky (1993), ATCOs listened to preferred music for ten minutes. Little research exists on the ability of laymen to select the type of music that may have a stimulatory or sedative differential and psychological and biological effects. This was the rationale for the present researcher compiling a list of uplifting songs with a fast tempo, from which the ATCOs were tasked with selecting their preferred music, specifically music they perceived as stimulative.

A study by Kellaris and Kent (1993) found that an increase in tempo led to more self-reported arousal and pleasure. An interesting finding of their study was that self-reported pleasure was higher when participants listened to classical music, while self-reported arousal was higher when they listened to popular (pop) music. In the current research, the prescribed list of music contained both classical and pop music.

The current research sought to explore the impact of music, self-selected by ATCOs, on the psychophysiological state of mental arousal and attention. The psychophysiological measure utilised in the current study to assess this was heart rate, measured as the number of heart beats per minute. This was recorded by the ATCO wearing a Fitbit (an armband or smartwatch used to track steps, heart rate, and more) on his/her wrist. An increase in the ATCO's heart rate is a preferred state, as it is evidence of increased arousal. Should ATCOs become more aroused as a result of listening to self-selected music, this would potentially assist in the reduction of safety events during shift handover, as an increase in arousal could lead to an increase in an ATCO's ability to be in flow and to mentally engage with the task. On the other hand, it is important to not over-stimulate the ATCO and cause stress. The optimum state of arousal would differ for each ATCO, and can be assessed from the heart rate — the higher the heart rate, the higher the level of arousal. However, research is lacking on the optimum heart rate for effective functioning in ATCOs. The current research sought to investigate whether listening to self-selected music during the period prior to shift handover has the potential to stimulate an ATCO such that the desired level of mental alertness, mental arousal, and attention is achieved.

2.12.1.2 Mindfulness

Cresswell (2017) notes that there is much scholarly dialogue around the definition of mindfulness. Mindfulness is a process of attending, with awareness, to one's present moment experience, in contrast to the day-to-day experience of our minds wandering, 'running on autopilot', and suppressing unwelcome experiences (Killingsworth & Gilbert, 2010; Bargh & Chartrand, 1999; Kang et al., 2013). The current research considered whether ATCOs achieving a mindfulness state would lead to an increased capacity to attend to present-moment experiences, which would, in turn, lead to a higher state of mental alertness and arousal. ATCOs may then have an increased ability to be situationally aware and in flow. The capacity to openly pay attention to moment-to-moment experiences can be developed and deepened by mindfulness interventions (Cresswell, 2017).

Killingsworth and Gilbert (2010) found that people's minds tend to wander 47% of the time. Brown and Ryan (2003) found that having the capacity to be mindful enhances wellbeing. Cresswell (2017) highlights two features of mindfulness that are considered to be the most important: (1) the grounding of attention and awareness in one's present-moment experience, including one's body sensations, emotional reactions, mental images, mental talk, and perceptual experiences; and (2) adopting an attitude of openness or acceptance towards an experience, whereby even the most challenging experiences are embraced (Cresswell, 2017). Some theorists view the concepts of mindfulness and flow as identical, while other view these as discrete constructs (Komagata & Komagata, 2010).

Siegel (2007) describes flow as a state of being immersed in an experience in a non-self-conscious manner, which indicates a lack of mindful awareness. The process of mindful self-awareness is described by Bryant and Veroff (2007) as disruptive to the process of flow. According to Komagata and Komagata (2010), mindfulness and flow are connected; however, the concepts are not the same, in the sense that mindfulness cannot be sustained beyond access concentration, and flow involves both mindfulness and a level of concentration beyond that of access concentration. The authors further posit that flow is not a state, but rather an experience across time. Bishop, Lau, Shapiro, Carlson, Anderson, Carmody et al. (2004) postulate that self-regulation, an essential aspect of mental ability, facilitates the peak performance of flow.

Few studies have been conducted on the relationship between flow and mindfulness (Kee & Wang, 2008). Clarke (2002) investigated the impact of mindfulness (defined as self-regulated attention control) on the time spent in flow, using a sample of graduate students. The results demonstrated that mindfulness interventions may be more beneficial to some than others in increasing the time spent in flow.

The relationship between mindfulness and mental task engagement has also been explored (Malinowski & Lim, 2015; Zheng, Gunasekara, & Blaich, 2018; Leroy, Frederik, Dimitrova, & Sels, 2013; Malinowski & Lim, 2015), and higher levels of mindfulness were reported to be conducive to mental work engagement and mental well-being in the workplace. Zheng, Gunasekara, and Blaich (2018) found that mindfulness interventions lead to increased levels of mindfulness, thereby mediating the effect of mindfulness on mental task engagement. The goal of mindfulness interventions is to reduce stress and increase mental task engagement (Leroy et al., 2013).

According to Malinowski and Lim (2015), mindfulness is a resource that leads to high levels of work engagement. Hulsheger, Alberts, Feinholdt, and Lang (2012) found mindfulness to be negatively related to emotional exhaustion, allowing employees to cope more effectively with challenging work situations, ultimately lowering the risk of burnout. Mindful employees tend to have a heightened self-image and are more positive, and are therefore more willing to engage in their work (Malinowski & Lim, 2015). Leroy et al. (2013) hypothesises that mindfulness is positively related to work engagement via two channels: first, by directly developing an employee's attention and focus while (second) increasing internal awareness. Therefore, mindfulness is essential in strengthening the personal resources necessary for mental work engagement.

Mindfulness interventions are aimed at developing the ability to pay attention to and maintain awareness of present-moment experiences (Cresswell, 2017). Interest in mindfulness interventions has increased over the past three decades, fuelled by reports describing the potential benefits, such as enhanced mental and physical health, improved cognitive abilities and affect, and healthier interpersonal relationships (Ludwig & Kabat-Zinn, 2008; Brown et al., 2015). Mindfulness interventions are also increasingly being administered in institutional and workplace settings. Cresswell (2017) notes the varied reactions in the scientific community to utilising mindfulness interventions, ranging from scepticism to fanaticism.

Cresswell (2017) and Jensen et al. (2012) argue that mindfulness interventions might aid a variety of positive attention-related outcomes, such as sustained attention, task-switching ability, and enhanced working memory. Taylor et al. (2015) researched how mindfulness-based interventions could reduce stress in teachers, and found that these interventions yielded an enhanced ability to cope with job stress.

Meland, Ishimatsu, Pensgaard, Wagstaff, Fonne, Garde, and Harris (2015) researched the impact of mindfulness interventions on stress and attention in a military context. They concluded that mindfulness alleviates some physiological stress responses and subjective mental demands during periods of high workload. These findings are supported by those of the study by Taylor et al. (2015). Kontogiannis and Malakis (2009) emphasise that operators have to maintain a state of alertness and mindfulness, which are complex cognitive processes involving deliberate planning for the unexpected and self-introspection with regard to task progress. Bishop et al. (2004) view mindfulness as a psychological intervention that could improve situation awareness without compromising alertness (Eclache & Goldman, 2006; Tang, Holzel, & Posner, 2015).

Bishop, Lau, Shapiro, Carlson, Anderson, Carmody, and Devins (2004, p. 232) operationalise mindfulness as "consisting of two facets:
(1) the self-regulation of attention, so that it is maintained on immediate experience, allowing for increased recognition of mental events in the present moment; and
(2) an orientation toward experience in the present moment that is characterised by curiosity, openness and acceptance".

Cullen (2011) defines mindfulness as paying attention to whatever is occurring within the stream of consciousness. This is done without reacting on an emotional level or being mentally rigid or denying and/or rejecting what is taking place. Weick et al. (1999) consider cognitive processes as important in attaining high reliability, which implies a focus on preventing failures. Mindfulness is operationalised as the joint capability of a rich awareness of discriminatory detail and a capacity for action (Weick et al.,1999). Awareness, according to Weick et al. (1999), becomes heightened through concerns that have the potential to cause a catastrophe. This then facilitates appropriate corrective action to prevent escalation of the problem (Rochlin, 1989).

Mindfulness is both attention and the conservation of attention, i.e. what people do with what they notice after having noticed something (Weick et al., 1999). Vaughan (1986) explains this by noting that mindfulness involves interpretation, differentiation, and reframing, in order to enlarge what is known about what has been noticed.

Studies on mindfulness interventions in the workplace reported a reduction in employees' stress and an increase in job satisfaction (Choi & Koh, 2015; Vaculik, Prochazka, & Zalis, 2016). Weick et al. (1999, p. 61) postulate:

> *Mindfulness facilitates the discovery and correction of anomalies that could cumulate with other anomalies and grow into a catastrophe. Mindfulness, with its rich awareness of discriminatory detail enables people to manage juxtapositions of events they have never seen before".*

They add that mindfulness increases the comprehension of complexity, and is considered critical in countering potential accidents (Weick et al., 1999).

Weick et al. (1999) further elucidate the meaning of mindfulness by describing mindlessness. A mindlessness state occurs when there is a reliance on autopilot or a fixation on a single perspective, coupled with failing to recognise any differences in a situation that may have consequences. Miller (1993) posits that people who are mindful about success tend to simplify and adhere to existing performance routines. They also tend to comply with inherited job descriptions to the point of mindlessness.

In criticizing research on mindfulness, Cresswell (2017) identified methodological limitations, including small sample sizes, a lack of control groups, and limited use of high-quality measurement instruments. These limitations prevent definitive conclusions about the efficacy of mindfulness interventions (Cresswell, 2017). Cresswell (2017) proposes formal measurement of mindfulness during and after an intervention, as well as testing the effectiveness at a later point in time, i.e. longitudinal studies. Cresswell (2017) focuses attention on the risks of mindfulness interventions, particularly 'secularised' forms and interventions that lack ethical and compassion-related techniques. According to Cresswell and Lindsay (2014), more affluent, healthy people tend to seek out and use mindfulness practices, while low-income individuals with poorer health do not utilise such practices. It is their view that, ironically, low-income, highly stressed individuals with compromised health would benefit more from mindfulness interventions (Cresswell & Lindsay, 2014).

Few empirical studies have been conducted on mindfulness in the context of air traffic control. Weick, Sutcliffe, and Obstfeld (1999) studied mindfulness techniques in high-reliability organisations, of which air traffic control is an example (La Porte, 1988). High reliability organisations offer critical services under taxing conditions (Weick et al., 1999). Cresswell (2017) highlights the need for mindfulness intervention studies to move from clinical settings to institutional settings, of which air traffic control is an example.

Mindfulness interventions do not only train attention, but develop the skill of maintaining an open and accepting attitude toward experience, which may be important for emotion regulation and affective outcomes (Cresswell, 2017). Mindfulness interventions have been shown to reduce negative affect outcomes such as depression and anxiety (Cresswell, 2017).

During mindfulness, there is then a sense of being centred and grounded, knowing what is happening, and when (Cresswell, 2017). In the present study, a mindfulness intervention was administered to ATCOs to examine whether it would enhance their awareness — of being in the present moment. Cresswell (2017) explains that there is a subtle interplay between distraction and mindfulness. As soon as a person notices that he or she is distracted, there should be a sharpening of his or awareness. Everyone has the capacity for mindfulness, but default methods of attending to familiar tasks may let the mind wander, engaging in self-criticism, ruminating about the past, or worrying about the future. Formal mindfulness intervention exercises encourage individuals to make deliberate efforts to sustain attention as a moment-to-moment experience (Cresswell, 2017).

The current research examined whether mindfulness training will assist ATCOs to develop skills to intentionally focus their attention on present-moment somatic, mental, and social experiences, evident in bodily sensations, feelings, mental images, and thoughts. The ultimate aim was to enhance the cognitive processes that would allow for optimal flow and mental task engagement, particularly during the high-risk shift handover. In line with Cresswell's (2017) recommendation, participants' heart rate was measured before and after the intervention.

2.13 Chapter Summary

The literature review provided an overview of the theory that informed the current research. An explanation of the profession of air traffic control and the roles and responsibilities of

ATCOs were explained. The chapter provided and overview of aviation psychology, with special reference to safety the different types of safety incidents. Human factors and human error were discussed in detail, followed by an elucidation of the concepts of workload, mental task engagement, flow, and situation awareness. Thereafter, interventions in the form of music and mindfulness were discussed as having the potential to enhance these attributes. The rationale for the choice of these two interventions was the results of Kee and Wang's (2008) research, which considered the relationship between mindfulness, flow, and mental ability. Their study was based on the assumption that adopting a present-moment focus is conducive to achieving peak performance. Kee and Wang (2008) hypothesised that those who display mindfulness characteristics are more likely to score higher in measurements of flow and mental ability. They concluded that individuals with the propensity to be mindful have a higher likelihood of experiencing flow. In the current study, the aim was to investigate whether these interventions could assist ATCOs to achieve a state of flow that would allow increased mental arousal and mental task engagement during the high-risk shift-handover process.

This chapter represents achievement of *RO2: Investigate the theoretical basis for the occurrence of safety incidents in the handover period beyond simply attributing any error to cognitive limitations*.

The next chapter provides a detailed discussion of the methodology followed in the present study.

CHAPTER 3: METHODOLOGY

3.1 Introduction

This chapter describes the approach and design, including the population, sample, and the research instruments, used in the present study. The procedures carried out during the study are then explained, including data gathering and analysis.

The research population consisted of all fully certified civil South African ATCOs. ATCOs who were students or still in training were excluded. Three air traffic services units within South Africa were selected as the focus of the research study: O R Tambo International Airport, Lanseria Airport, and Wonderboom Airport. These three units were selected to be included in the research study, as they are considered the busiest with regard to air traffic, and therefore have the largest number of ATCOs and the highest traffic volumes. They were also preferable because they utilise both radar control and tower operations. The smaller units were excluded from the research study due to the fact that they typically make use of tower operations only, without any radar control operations.

Control towers and air traffic services units are highly restricted areas, due to these areas being designated as national key points, meaning only authorised personnel are permitted entry. This is to maintain security standards to ensure the safe, expeditious, and efficient management of air traffic.

The researcher obtained permission from the relevant authorities at ATNS prior to commencing the research. A non-disclosure agreement was compiled by ATNS and signed by the researcher and the Head of the School at the University of the Witwatersrand. The non-disclosure agreement was required by ATNS in order to enable the researcher to complete research requiring information relevant to ATNS's safety performance and safety incident investigation reports. All information released to the researcher was used for the sole purpose of this research project.

The research was conducted in three phases:

Phase 1: Review and analysis of safety incident reports;

Phase 2: Examination of flow, mental task engagement, and mental workload; and

Phase 3: Interventions (music and mindfulness).

3.2 Research Approach

The research approach of the current research study was a mixed-methods approach The mixed methods research design was selected due to the quantitative and qualitative data being available and accessible to the researcher in order to investigate the pattern of increased safety events, identified by ATNS as occurring within the high-risk shift handover period.

Cresswell et al. (2003) note that qualitative and quantitative methods are used to offset any weakness inherent in one design with the strengths of the other method. The design integrates the results of the two methods during the interpretation phase.

The mixed-methods research paradigm is referred to by a number of different names, such as blended research (Thomas, 2003), integrative research (Johnson & Onwuegbuzi, 2004), multimethod research (Hunter & Brewer, 2003), multiple methods (Johnson et al., 2007), triangulated studies (Sandelowski, 2003), ethnographic residual analysis (Fry et al., 1981), and mixed research (Johnson & Christensen, 2004). "An advantage of the broader term mixed research, as well as integrative research, is that there is no limitation of mixing to methods only" (Johnson et al., 2007, p. 118).

The term *methods* more broadly refers to methodology (e.g., questionnaires, interviews, and observations utilised for data collection), methods of research (e.g., experiments), and philosophical issues (e.g., epistemology). Johnson et al. (2007) examined the questions of both where (at which stage) and why mixing is carried out in research. Mixing can occur at either or both the data-collection stage and/or data-analysis stage. Mixing of research paradigms provides a deeper understanding, a more complete picture, and a more elaborate and comprehensive description and understanding. In addition, there is a greater level of confidence in the conclusions reached. According to Johnson et al. (2007), mixed-methods research yields richer, more meaningful, and more useful answers to research questions.

Qualitative research cannot be subjected to the same criteria as quantitative research; however, there are methods of analysis that should be applied rigorously to the data. Criteria for conducting good qualitative research exist (Elliot, Fischer, & Rennie, 1999). Qualitative research is able to "contribute to a process of revision and enrichment of understanding" from the participant's perspective (Elliot et al., 1999, p. 216). Qualitative research has limitations; some considered it not 'real research', as 'anything goes', making the validity of such studies questionable (Labuschagne, 2003). However, qualitative research gives participants a voice and an opportunity to share their lived experience, while simultaneously allowing deeper insight to be obtained into the distinct experiences of individuals (Roberts, 2017). In the current study, this insight could be applied to enhancing the safe operations of ATCOs during the high-risk shift handover process.

Mixed-methods research seeks to provide balanced research results, acquired through the process of collecting and analysing both quantitative and qualitative data in a single study, in which the data are collected concurrently or sequentially. Greene and Caracelli (1997) propose that a mixed-methods research approach could strengthen a research study by enabling triangulation of data.

Table 3.1, below, highlights the essential elements of a mixed-methods approach.

Table 3.1

Mixed-methods Approach

Mixed-methods approaches tend to or typically…
Use these philosophical assumptions:
Pragmatic knowledge claims: consequences of actions, problem-centred, pluralistic, and real-world practice oriented
Employ these strategies of enquiry:
Sequential, concurrent, and transformative
Employ these methods:
Both open- and closed-ended questions Both emerging and predetermined approaches Both qualitative and quantitative data and analysis
Use these practices of research as the researcher:
Collects both quantitative and qualitative data Develops a rationale for mixing Integrates the data at different stages of inquiry Presents visual pictures of the procedures in the study Employs the practices of both qualitative and quantitative research

(Creswell, 2014)

Greene and Caracelli (1997) consider the mixed-methods approach as having the potential to strengthen a research study. According to Johnson, Onwuegbuzie, and Turner (2007), mixed-methods research is becoming increasingly recognised as the third major research paradigm, together with quantitative and qualitative. Johnson et al. (2007) characterise mixed-methods research as the synthesising of quantitative and qualitative methods of data collection and analysis in a single research study. Mixed-methods research seeks to provide balanced research results, acquired through the process of collecting and analysing both quantitative and qualitative data in a single study.

There are several important criteria when considering a mixed-methods research paradigm, for example, whether the focus will be qualitative or quantitative data. While such research is aimed at including insight from both quantitative and qualitative data, pragmatism is considered the primary philosophy of mixed methods (Johnson et al., 2007). Quantitative data dominated the current study, with the qualitative data collected represented in a pseudo-quantitative manner.

Orientation of mixed-methods research is either a bottom–up, approach "whereby the research question drives the mixed methods research" (Johnson et al., 2007, p. 122), or a top–down approach, where the "mixed methods approach is not driven by the research question; rather it is driven by the researcher's quest to conduct research that is emancipatory, anti-discriminatory and participatory, and the like" (Johnson et al., 2007, p. 122). Mixed-methods research, therefore, recognises the importance of traditional quantitative and qualitative research while offering a third paradigm choice, one that strives to provide the most informative, complete, balanced, and useful research results (Johnson et al., 2007).

3.3 Research Philosophy

Research is informed by the researcher's philosophical worldview (Creswell, 2014). In the current research, the decision to formulate exploratory research questions rather than hypotheses was due to the researcher's pragmatic philosophical worldview. Philosophical ideas tend to be hidden in any research, and have an impact on the research process (Slife & Williams, 1995, as cited in Creswell, 2014). Pragmatism can be explained as a philosophical worldview; that rather than arising out of antecedent conditions, it arises out of actions, situations, and consequences (Creswell, 2014). According to Creswell (2014), the foremost pragmatic worldview elements are: consequences of actions, problem-centred, pluralistic, and real-world practice oriented.

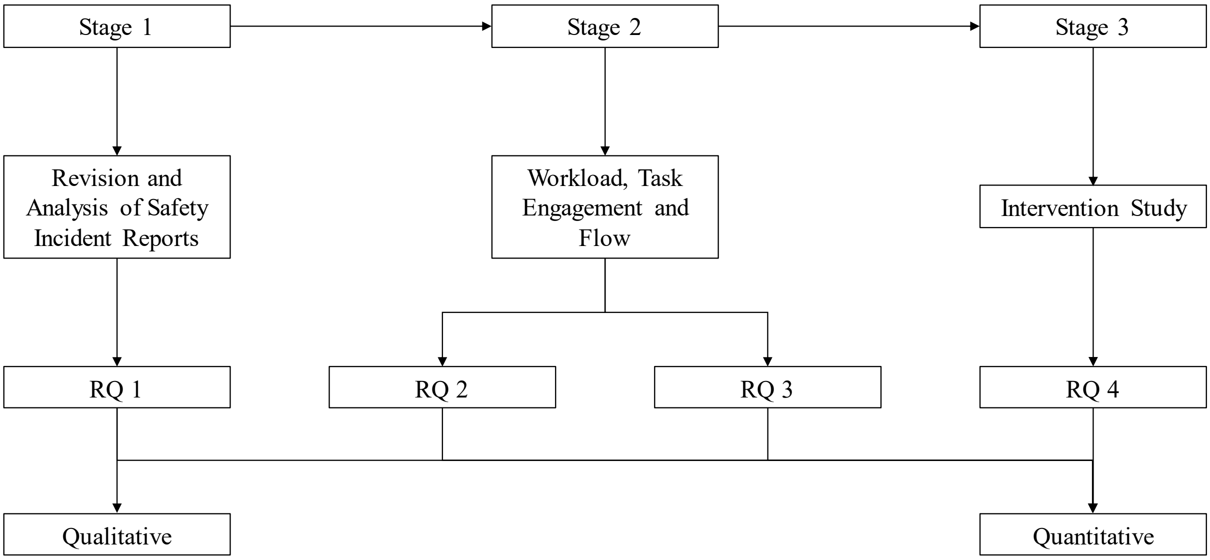
3.4 Research Design

The research questions in the present study are essentially exploratory, representing new and innovative ways of approaching the research problem. Quantitative hypotheses were therefore not formulated for the current research. The entire research design was based on exploring phenomena, rather than testing hypotheses.

The diagram below summarises the three phases in which the current study was conducted.

Figure 3.1

The Three Phases of the Study



Phase 1 links to Phase 2 and Phase 3. Safety events are likely to be minimised when an ATCO's situation awareness is achieved such that he/she is mentally engaged, reducing the potential for human error, due to being mentally aware during the high-risk shift-handover period. These concepts were selected to be further explored in the current research as they were identified from both the qualitative and quantitative analysis conducted on the safety incident data in Phase 1 and Phase 2 to have an impact on the operational safety of ATCOs during the high-risk shift-handover. Phase 3 was the administering of interventions that could assist in reducing the likelihood of safety incidents during the high-risk shift-handover, in the form of music and mindfulness.

3.5 Data Collection

Data were collected sequentially (in each phase), with the subsequent phase building on the previous phase. In a sequential design, it is challenging to know a priori which method of data collection and data analysis would be most appropriate for the following phase, until data from the previous phase had been collected and analysed. Therefore, the best method of data collection and analysis was only determined upon completion of each phase.

In triangulation, more than one method is selected in order to validate the outcome (results) of the current research (Campbell & Fiske, 1959). Triangulation is therefore the convergence of findings from the use of more than one method (Bouchard, 1976). In the present study, the findings from the qualitative and quantitative data were triangulated through corroboration and cross-validation, which enhances the trustworthiness of a study (Schoonenboom & Johnson, 2017). Webb, Campbell, Schwartz, and Sechrest (1966) consider the confirmation of a research question(s) by more than one method to greatly diminish any uncertainty with regard to research findings, leading to increased confidence in the findings.

Application of the theoretical concept of triangulation to the current research enabled the researcher to uncover different aspects of the same phenomenon. The phenomenon being researched can be summarised as the acquisition of a deeper understanding of human factors, with an emphasis on cognitive factors that contribute to safety incidents during the high-risk shift-handover period.

3.6 Data Analysis

3.6.1 Analysis of qualitative data: Thematic analysis

The choice of method of analysis should be driven by research questions as well as broader theoretical assumptions (Braun & Clarke, 2006). Thematic analysis was used to analyse the qualitative data in the present study. It is one of the most common methods of data analysis within qualitative research, whereby patterns of meaning (i.e. themes) within a data set are identified, analysed, and interpreted. Braun and Clarke (2006) that thematic analysis could provide a rich and in-depth description of the entire data set, giving the reader a sense of predominant or important themes. These themes should be an accurate reflection of the content of the entire data set. Thematic analysis is considered particularly useful in researching an under-researched area and in studies with participants whose views on the topic are unfamiliar. Thematic analysis can also be used to provide a more detailed and nuanced account of one particular theme, or a group of themes, within the data.

Thematic analysis is defined by Braun and Clarke (2006) as a method for identifying, analysing, and reporting patterns or themes within data. This way of analysing data minimally organises and describes the data set in rich detail. Nowell, Norris, White, and Moules (2017) note that thematic analysis needs to be conducted meticulously and methodically in order to produce meaningful and useful results. This requires that the data be analysed accurately and consistently through a process of systematising and recording.

Thematic analysis is a relevant and accepted method of analysis of qualitative data (Nowell et al., 2017). However, according to Braun and Clarke (2006), it is a poorly demarcated and rarely acknowledged qualitative analytic method within psychology. Despite this, it is widely used in psychological research. Braun and Clarke (2006) support thematic analysis, stating that it adds value by offering an accessible and theoretically flexible approach to analysing qualitative data. They add that it is a method in its own right. An advantage of thematic analysis is its flexibility as a tool, which enables the researcher to provide a rich and detailed account of complex data. The critique of qualitative research has always related to a lack of clear guidelines for its use. Advantages of thematic analysis, according to Nowell et al. (2017), include summarising the key aspects of a large data set, while disadvantages include a lack of coherence when developing themes (Holloway & Todres, 2003).

Tashakkori (2006) notes that, in analysing a data set, the bottom–up or top–down approach is a continuum. Most engineering or technological studies focused on error prediction apply a bottom–up approach, in the sense that they consider how individuals function, how components of a system may fail, and how these failures may propagate to lead to a consequence (Eurocontrol, 2004). This was the case in the current research; the bottom–up approach was followed in ordering and analysing the data to draw high-order conclusions.

In the current research, the qualitative data were collected from two different sources: safety incident reports and interviews with ATCOs. Using thematic analysis, common themes were identified from the safety incident reports and the interview transcripts. The aim of the analysis was to identify emergent themes. Thematic analysis can be used to analyse most types of qualitative data, including qualitative data collected through interviews, as was done in the current research in Phase 2. It is frequently used in a mixed-methods research, where the focus is on the subjective experiences of participants (Guest, MacQueen, & Namey, 2012). Anderson (2007) emphasises the importance of minimising interpreting the data, and advises researchers to rather make every reasonable attempt to use the actual words of the research participants. This was done in the present study through the findings being reported with supporting quotes from the interviews with the ATCOs.

In conducting thematic analysis, the researcher adopted an objective epistemological stance. Recurring themes in the data were identified and then categorised. The thematic analysis provided insight into the most factors, from both a Safety-I and a Safety-II perspective, that may affect mental alertness, mental arousal, attention, situation awareness, and flow in ATCOs. The theoretical concepts of situation awareness, flow, mental task engagement, and mental workload were identified from a review of the literature. These concepts overlap with mental alertness and theoretically underpin higher-order, cognitive psychological processes such as decision-making and problem-solving in active working situations (Brooker, 2003; Csikszentmihalyi, 1997; Endsley, 1995; Jackson & Eklund, 2002; Kahn, 1990; Kalloniatis et al., 2017; Loft et al., 2007; Rapayana, 2008; Sarter & Woods, 1991; Van Acker, 2018).

Thorne (2000) explains that researchers should identify themes that capture something important about the data in relation to the research question. Themes also represent some level of patterned response or meaning within the data set. A theme might be given considerable space in some data items and little or none in others. It is important the researcher use judgment in determining what constitutes a theme. Data often contain overall themes and subthemes. The importance of a theme is not necessarily dependent on quantifiable measures, but on whether it captures something important in relation to the overall research question (Braun & Clarke, 2006). However, thematic analysis sometimes has limited interpretive power. Thematic analysis can, however, be successfully used across a range of epistemologies and research questions to identify, analyse, describe, organise, and report themes within a data set (Nowell et al., 2017).

Thematic analysis involves repeatedly reading through the raw data in order to gain an understanding of the responses and become familiar with the nature of the data. The data are then arranged in a meaningful and systematic way, in order to understand and make sense of the data (Maguire & Delahunt, 2017). This advice was adhered to in the present study. Throughout the process of familiarisation with the data, the researcher identified recurring patterns through significant and common sentences, phrases, and words that related to the research questions. Thematic analysis requires a continuous interaction with the data; therefore, the present researcher repetitively read the safety incident reports and was able to develop new insights each time, which were noted down, as recommended by Braun and Clarke (2006) and Smith and Osborn (2007).

Analysis of safety incident reports provided insight into human factors that may contribute to safety incidents occurring. A number of themes and subthemes emerged from the thematic analysis, and the present researcher was able to identify relationships between the themes (see Braun & Clarke, 2006). The relationships between the themes were then developed into broader themes that contributed to answering the research question (Maguire & Delahunt, 2017). The researcher needed to make sure that the themes were prevalent and that they made sense, as noted Maguire and Delahunt (2017). Themes identified were then defined and given a descriptive (see Maguire & Delahunt, 2017). This was done through writing up a detailed analysis of each individual theme, along with compiling a list of phrases that resorted under each theme and supported the existence of the theme. Throughout the write-up, the researcher included direct quotes relating to the themes in order to allow for transparency for the readers, as recommended by Fossey et al. (2002). Inter-item correlation was performed on the qualitative data, in order to assess any questions that undermine the overall reliability (J. Möller, personal communication, February 2020).

The themes identified by the researcher emerged naturally and were not guided by prior theory, i.e. they emerged from the data. This resulted in the identification of themes that are not evident in existing theory. Themes that were not useful in answering the research questions were discarded from the analysis.

3.6.2 Analysis of quantitative data: Statistical analyses

The statistical approach adopted in the current research was used to analyse quantitative data, and the analysis was mainly exploratory. Exploratory analysis refers to a set of techniques originally developed by John Tukey between 1971 and 1977 and refined from 1991 to 1995 to display data in such a way that interesting features become apparent. Exploratory analysis differs from traditional methods of statistical analysis, which start with an assumed model for the data. Exploratory analysis techniques, on the other hand, are used in a manner whereby models are suggested by the data that may be more appropriate. Exploratory analysis refers to the critical process of performing initial investigations on data to discover patterns, spot anomalies, to test hypothesis, and to check assumptions with the help of summary statistics and graphical representations (Patil, 2018). According to Behrens (1997), exploratory analysis assists in the development and refinement of research questions. In the current research, quantitative data from the incident reports and questionnaires were analysed using summary statistics and appropriate graphs. Summary statistics provides the mean, median, and standard deviation, and can be reported using bar charts, stacked bar charts, pie charts, line graphs, box-and-whisker plots, and scatter plots.

With regard to the questionnaires administered, reliability analysis was carried out in order to establish the consistency of respondents' responses to the different questions pertaining to the individual items which the questionnaires were meant to measure. Cronbach's alpha is the most commonly reported estimate of reliability, and reflects the outcome of the reliability analysis measuring internal consistency reliability, i.e. the degree to which responses are consistent across the items within a single measure (Kline, 2005). If internal consistency reliability is low, "the content of the items may be so heterogeneous that the total score is not the best possible unit of analysis for the measure" (Klein, 2005, p. 59).

The sections below a discussion of the research procedure per phase of the study.

3.7 Phase 1: Review and Analysis of Safety Incident Reports

Phase 1 entailed the qualitative and quantitative analysis of data related to safety incidents, gleaned from the safety incident reports obtained from the ATNS. The data informed the researcher with regard to critical human factors that have been reported to lead to human error, and therefore contribute to safety events from a Safety-I perspective.

The aim of Phase 1 was to address *RQ 1: What human factors can be identified from the safety incident reports as significantly impacting the operational safety of South African ATCOs?*

3.7.1 Phase 1 sampling

Phase 1 consisted of an analysis of five years' safety incident reports collected by the safety department of ATNS at all airports in South African airspace. Each incident report was an analysis by safety investigators at ATNS of an incident reported as the result of a civil South African ATCO having contravened airspace regulations. The reports of all airports under South African airspace under the control of ATNS were included. A total of 123 reports were submitted, dated 2008 through 2012: 19 reports for 2008, 26 reports for 2009, 26 reports for 2010, 27 reports for 2011, and 25 reports for 2012. The decision to review safety incident reports spanning five years was made in consultation with two human factors specialists at ATNS. In their view, reviewing five years' reports would yield sufficient data, due to the number of incidents per year.

While all reports submitted for the years under study were included in the sample, the number of incidents may not be an accurate reflection of the actual number of safety incidents that took place each year. ATCOs avoid reporting incidents for fear of the consequences, which could include suspension and, at worst, losing their licence to work as an ATCO. Furthermore, not every report provided the same information. Reports became more sophisticated and refined over the years, which resulted in more comprehensive information being available on incidents in the later years. Each safety incident report provided detailed descriptions of safety events taking place in South African airspace with regard to errors by ATCO.

3.7.2 Phase 1 data collection

The safety incident reports include analyses by ATNS investigators, conducted using the HERA Technique (Isaac, Shorrrock, & Kirwan, 2002). This technique was applied by investigators in analysing the safety events of 2009. The HERA-JANUS Technique is the preferred technique, as it demonstrates high levels of inter-rater reliability (Lyons, Boive, & Van Damme, 2003). In the HERA-JANUS Technique, errors are classified as either error or context. *Error* refers to what took place, (i.e. the type of error), how the error occurred (i.e. the error mechanism), and why the mechanism failed (i.e. level of information processing). With regard to context, the safety investigator gains an understanding with regard to when the safety incident took place, which parties were involved, the type of task that was being performed, and the timing and sequence of events (Eurocontrol, 2004). Every safety incident analysis is consolidated into a final report (see template in Appendix A), which contains recommendations with regard to concerns to be addressed and proposed remedial action (Eurocontrol, 2003).

The researcher collected qualitative data from a Safety-I perspective from the safety incident reports, specifically the human factors that have a significant impact on ATCOs' operational performance. As the incident reports contain frequencies of types of incidences, the researcher was also able to collect quantitative information to corroborate the quantitative findings. In order to ensure that data was collected ethically, the researcher assured anonymity and confidentiality by not using any specific ATCO's name, rather reporting grouped data.

3.7.3 Phase 1 data analysis

The qualitative data were analysed using thematic analysis to identify trends in terms of the human factors related to safety incidents. The data were first reduced by labelling phrases of text according to predefined categories, similar to the approach taken by McAlister, Lee, Ehlert, Kajfez, Faber, and Kennedy (2017). A Master's student in organisational and industrial psychology at the University of the Witwatersrand reviewed the reports for the years 2010 to 2012, while the researcher reviewed the reports for the years 2008 to 2010. The year 2010 was reviewed first, and by both reviewers, to achieve consensus on coding, before continuing with other years' data. Any discrepancies were discussed amongst the reviewers until consensus was reached.

The dataset of the safety incident reports was not complete, as the data available were not consistent across safety events. This was more pronounced in the reports produced in the earlier years. The report formatting changed in 2008. Pre-2008, reports were not compiled according to the HERA-JANUS reporting format, which made comparison difficult. Two different researchers having analysed and summarised the data may also have contributed to a variance in the results, although concerted efforts were made to standardise the analyses.

The large volume of data that had to be classified and compared resulted in too many coding categories to reliably calculate inter-rater reliability statistics, such as Cohen's Kappa, to rate each observation. Due to the heterogenous nature of the data, it was decided to compare the conclusions drawn from each category by each reviewer, to determine whether there was agreement on the conclusions drawn from the text associated with a specific label. Similar to the process discussed by McAlister et al. (2017), the proportion of agreement between the outcomes was calculated. In total, 383 three items were compared, of which 320 were classified as giving rise to the same conclusion. The proportion of agreement was calculated at 83.55%, with a 95% confidence interval (79.84%; 87.26%). The level of agreement was deemed satisfactory for the purposes of the current research study. It is important to note that the qualitative data were taken as captured in the reports; therefore, the inter-rater reliability analysis is applicable to the qualitative data only.

The human factors that emerged as playing the most central roles in the operational safety of ATCOs were cognitive in nature, and included, but were not limited to, mental workload and mental task engagement. The researcher also extracted the theme *flow*, related to the Safety-II perspective, as playing a key role in the operational safety of ATCOs. Flow was therefore included in Phase 2.

3.8 Phase 2: Examining Workload, Task Engagement, and Flow

Based on the findings of Phase 1, the researcher decided to collect data from a Safety-II perspective in the next phase of the study. This was done by interviewing ATCOs and administering questionnaires during the interview process. The aim of Phase 2 of the research was to answer *RQ2: To which systemic, psychological, and physiological factors do South African civil ATCOs attribute their safe functioning at work?* and *RQ3: What is the impact of mental task engagement, mental workload, and the state of flow on the occupational safety of*

South African civil ATCOs during the shift-handover process?

3.8.1 Phase 2 sampling

The total population of ATCOs available to be interviewed was small, and therefore a sample of ten participants was considered a relatively good representation of the population. Ultimately, a total of 11 ATCOs were interviewed in the current research study.

Sample size is an important consideration in any research study. Francis, Johnston, Robertson, Glidewell, Entwistle, Eccle, and Grimshaw (2010) propose that sample size be specified *a priori*. In the current research, a minimum of ten interviews was the desired number. Bunce and Johnson (2006) and Eccle and Grimshaw (2010) propose interviewing research participants until data saturation is achieved. However, there does not appear to be any agreement with regard to when data saturation has been reached. Ryan and Barnard (2004) posit that the volume and complexity of the data, researcher experience, and fatigue, together with the number of analysts reviewing the data, will assist in determining data saturation. Guest et al. (2006) propose conducting the fewest number of interviews needed to gain a solid understanding of the phenomenon under study. It is their view that data saturation is likely to occur earlier in the process. Bertaux (1981) argued that 15 is the smallest acceptable sample size in qualitative research, while Morse (1994) recommends at least six participants in phenomenological studies. Cresswell (1998) recommends between five and 25 interviews for a phenomenological study. Guest et al. (2006) found that data saturation had occurred by the time they had analysed 12 interviews. It is their view that 12 interviews should suffice. Numerous studies provide researchers with guidelines to consider when determining sample size (Bernard, 1995; Flick, 1998; Morse, 1995; Patton, 2002; Rubin & Rubin, 1995).

In the present study, the sample size of 11 was considered sufficient, as data saturation was reached by the tenth interview, evident in similar comments and statements and no new information being elicited. The sample is considered a non-random sample obtained from a closed pool of participants, which, although appropriate for a study in the context of civil South African air traffic control, may limit the generalisability of the results.

The sample of 11 ATCOs who volunteered to participate in the study consisted of nine men and two women. Seven ATCOs were based at Johannesburg International Airport, two at Lanseria Airport, and two at Wonderboom Airport.

Table 3 provides the demographic details of the participants.

Table 3.2

Demographics Details of Sample in Phase 2

ATCO	**Age**	**Gender**	**Airport**	**Position**	**Years validated as an ATCO**
1	30	Female	O R Tambo	Area	7
2	31	Male	Lanseria	Ground/Tower	1
3	55	Male	Lanseria	Tower	36
4	31	Male	O R Tambo	Area	4
5	43	Male	O R Tambo	Radar	24
6	37	Female	O R Tambo	Approach	12
7	31	Male	O R Tambo	Tower	7
8	40	Male	O R Tambo	Radar	15
9	32	Male	O R Tambo	Radar	7
10	30	Male	Wonderboom	Ground/Tower	4
11	25	Male	Wonderboom	Tower/Approach	4

3.8.2 Phase 2 Data Collection

The researcher collected qualitative data by conducting semi-structured interviews with 11 ATCOs. ATCOs were interviewed at their workplace. The aim was to collect data from which to identify the human factors they consider vitally important in operating optimally, including factors that make things go right (Safety-II).

The interview schedule was formulated based on the findings from analyses of the safety incident reports in Phase 1. Participants were questioned about occurrences in a typical day, i.e. what happened when the ATCO commenced shift, during the shift, at the end of a shift, during breaks, as well as how the ATCO slept, what the ATCO did before coming to work, on the way to work, and when he/she arrived at work. The interview also gained data with regard to what happens when the ATCO's shift is over, what happens on the way to work and on the way home, ways in which the ATCO relaxes and de-stresses after work, as well as the ATCO's relationships at home and typical coping mechanisms. Participants were also questioned regarding any disruptors to their typical patterns of behaviour. The researcher did not impose a time limit on the interviews.

The interview schedule was tested in a pilot study. The pilot study was carried out at Cape Town International Airport. The ATCOs were invited to participate in the pilot study via an email, and four ATCOs, two men and two women, indicated their willingness to participate. The participants did not report any problems in understanding the questions and formulating responses.

The interviews for Phase 2 of the study were conducted at Johannesburg International Airport, Lanseria Airport, and Wonderboom Airport, all in the Gauteng Province of South Africa. Participants were invited via an email from the human factor's specialist at ATNS to participate in the research study. The researcher established rapport with the ATCOs prior to commencing the interviews, which included providing a description of and the rationale for the research.

The interviews were audio-recorded with the permission of the participants. The audio-recordings were then transcribed by High Tech Transcription Services. The accuracy of the transcripts was verified by the researcher taking a random sample of three transcripts and checking these against the original audio recordings for accuracy (see Appendix C).

The interview schedule was divided into the following sections: Biographical Information, General Information, Shift Handover, Psychological Factors, Flow, Situation Awareness, and Mental Alertness (see Appendix D).

The participants identified cognitive psychological aspects, metacognitive processes, and physiological aspects relevant to the high-risk shift-handover process. Using thematic analysis, three human factors were identified from the qualitative interview data: *mental task engagement*, *mental workload*, and *flow* (this is discussed in detail in Chapter 4; the results are merely mentioned here to clarify the subsequent steps in the procedure followed in the study).

The next step in Phase 2 of the present research was to collect quantitative data by administering questionnaires to the 11 participants on the identified human factors. The quantitative data gathered through the measurement instruments were used to corroborate the findings from the qualitative data. In order to ensure that data were collected ethically, informed consent was obtained from the participants, who completed a participant information sheet and a consent form. Only ATCOs who had volunteered to participate were interviewed. Anonymity and confidentiality were assured by using a code and by grouping data into emergent themes.

The instruments used to measure *mental task engagement*, *mental workload*, and *flow* are discussed below.

3.8.3 Phase 2 measurement instruments

3.8.3.1 NASA Task Load Index (NASA-TLX)

Mental workload was measured using the **NASA Task Load Index (NASA-TLX)** (Hart, 2006). Special permission had to be obtained directly from NASA to utilise this instrument in the current study.

The NASA-TLX is a multidimensional rating procedure that yields an overall *Workload* score based on a weighted average of ratings on six subscales: Mental Demand, Physical Demand, Temporal Demand, Own Performance, Effort, and Frustration (NASA, 2003). Each subscale is described below.

The **Mental Demand** subscale assesses how much mental and perceptual activity is required to perform a task, e.g., thinking, deciding, calculating, remembering, looking, and searching, as well as whether the task is easy or demanding, simple or complex, and exacting or forgiving.

The Physical Demand subscale assesses how much physical activity is required to perform a task, e.g., pushing, pulling, turning, activating, as well as whether the task is easy or demanding, slow or brisk, slack or strenuous, and restful or laborious.

The **Temporal Demand** subscale assesses how much time pressure is felt due to the pace at which the task has to be performed, e.g., whether the required pace is slow and leisurely or rapid and frantic.

The **Effort** subscale assesses how hard the respondent works, both mentally and physically, to achieve his/her level of performance.

The **Own Performance** subscale assesses how successful the respondent thinks he/she was in accomplishing the task goals set by the researcher. Respondents are also assessed in terms of how satisfied they are with their performance in accomplishing the tasks.

The **Frustration** subscale assesses how insecure, discouraged, irritated, stressed, annoyed versus secure, gratified, content, relaxed, and complacent the respondent felt during the task performance.

The degree to which each of these six factors contributed to the workload of the specific task to be evaluated from the raters' perspective is determined by their responses to pair-wise comparisons among the six factors. Magnitude ratings on each subscale are obtained after each performance of a task or task segment. Ratings of factors deemed most important in creating the workload of the task are given more weight in computing the overall *Workload* score, thereby enhancing the sensitivity of the scale.

The NASA-TLX workload evaluation procedure is a two-part procedure requiring the collection of both weights and ratings from the respondent and the manipulation of collected data to provide weighted subscale ratings and an overall *Workload* score. The original computer version of the NASA-TLX consisted of three separate computer programs: one to collect weights, one to collect ratings, and a third to process the raw data and provide an overall *Workload* rating. The current version, which was utilised in the present study, uses only the first two functions. The third function, the derivation of overall *Workload* score, is no longer provided (NASA, 2003).

The first requirement was to collect the participants' Sources of Workload options. There are 15 possible pair-wise comparisons of the six scale elements. Participants selected which element they felt contributed the most to the workload of the specific task. A tally was calculated of the number of times each of the elements was selected, which could range from *0* (*Not relevant*) to *5* (*Most relevant*). The second requirement is to obtain numerical ratings for each scale element that reflects the magnitude of that factor in a given task. In the current study, the task of controlling was rated. The weighted workload rating for each element in a task was simply the weight (tally) for that element, a number between 0 and 5, multiplied by the magnitude of load, a number between 0 and 100. Overall workload for a particular task was determined by summing the weighted workload ratings for an individual respondent for a particular task, divided by 15.

With regard to the psychometric properties, the NASA-TLX has shown good reliability and validity, and may be used to assess mental workload (Bourne & Yaroush, 2003; Byers, Bittner, Hill, Zaklad, & Christ, 1988). Researchers (e.g., Sharek, 2011) have validated its administration via computer. The re-test reliability, split-half reliability, Cronbach alpha coefficient, and correlation coefficients between item score and total score were used to test the instrument's reliability. Good internal consistency was found between the two scales. Results of the two scales were also shown to have good consistency (Sesar, 2006). With regard to test validity, factor analysis showed that the two scales had good structure validity (Sesar, 2006). Xiao et al. (2005) concluded that the NASA-TLX has good reliability and validity, and is a valid tool with which to assess mental workload. Based on the reports in the literature, the NASA-TLX was considered a valid research instrument to assess ATCOs' mental workload during the high-risk shift handover period, in order to assess the impact of workload on their safety performance.

Each rater is required to evaluate the contribution of each factor, that is, it's weight, to the workload of a specific task. These weights account for two potential sources of between-rater variability: differences in workload definition between raters within a task and differences in the sources of workload between tasks. The weights themselves can also be considered to provide diagnostic information about the nature of the workload imposed by the task. There are 15 possible pairwise combinations of the six subscales. As respondents can give ratings quickly, it is possible to obtain these in operational settings. However, it was established that little information was lost when ratings were given retrospectively (Hart, Battiste, Chesney, Ward, & Mc Elroy, 1986). High correlations were found between ratings that were obtained online and those that were obtained retrospectively. The NASA-TLX has been tested in a variety of experimental tasks, ranging from simulated flight, to supervisory control simulations, laboratory tasks, such as the Sternberg memory task, choice reaction time, critical instability tracking, compensatory tracking, mental arithmetic, mental rotation, target acquisition, and grammatical reasoning, to name a few. The NASA-TLX has also been successfully utilised in research on air traffic control (Metzger & Parasuraman, 2001; Averty, Collet, Dittmar, & Vernet-Maury, 2003; Averty, Dittmar, Collet, & Vernet-Maury, 2004; Averty, 2004). The results of the first validation study were summarised by Hart and Staveland (1988). The derived *Workload* scores were found to have substantially less between-rater variability than unidimensional workload ratings, and the subscales provided diagnostic information about the sources of load (Hart & Staveland, 1988).

The NASA-TLX has proven to be reasonably easy to use and reliably sensitive to experimental manipulations over the past 20 years. Its use has spread far beyond its original application (aviation), focus (crew complement), and language. Hart and Staveland (1988) documented an extensive research programme assessing the reliability and validity of the NASA-TLX, which demonstrated that it is less sensitive to individual differences than other workload measures, such as the Subjective Workload Assessment Technique (SWAT). Hart and Staveland (1988) conducted a multi-dimensional survey of the NASA-TLX *Workload* scores, and Hart (2006) retrospectively surveyed 550 studies of the first 20 years of the NASA-TLX's use, in which the NASA-TLX was used or reviewed in order to provide a summary of environments in which it has been applied, the types of activities the raters performed, other variables that were measured, methodological issues, and lessons learned. Subsequent to the 2006 survey by Hart, there have been extensive studies in air traffic control in which the

NASA-TLX was used to measure mental workload. A meta-analysis of NASA-TLX global workload scores was carried out by Grier (2015), who presented a descriptive analysis of over 1 000 NASA TLX scores from over 200 publications.

In the present study, the instructions given to the participants were per the computerised program Version 2.1.2, developed by David Sharek (2011). Participants were asked, immediately after their shift, to give their opinion on how high their workload had been during the task of actively controlling. There are two parts to the computerised program, i.e. ratings and weights. Ratings are obtained following the completion of a task, while weights are determined by the user's choice of the subscale that is most relevant to workload from a pair of choices. The respondent provides a rating for each of the six subscales (Cao, Chintamini, Pandya, & Ellis, 2009). The respondent then selects one of two subscales presented in 15 pairs. The use of the NASA-TLX was limited to the high-risk shift handover period.

This stage of the research contributed to answering *RQ3: What is the impact of mental task engagement, mental workload, and the state of flow on the occupational safety of South African civil ATCOs during the shift-handover process*.

3.8.3.2 Work-Related Flow Inventory (WOLF)

Flow was measured using the Work-Related Flow Inventory (WOLF) (Bakker, 2007). The scale was adapted to conform to the purposes of this study. See Appendix E for the complete scale as adapted by the researcher to use a seven-point scale to rate each item.

With regard to reliability and validity, Bakker (2008) showed that *Absorption*, *Work enjoyment*, and *Intrinsic work motivation* correlate moderately highly with each other. The correlations ranged from 0.44 for *Absorption* and *Intrinsic work motivation* to 0.82 for *Work enjoyment* and *Intrinsic work motivation*. The reliability of the three dimensions of flow were found to be good; the Cronbach alpha was found to be high for *Work enjoyment* (0.90), acceptable for *Absorption* (0.80), and satisfactory for *Intrinsic work motivation* (0.75) (Bakker, 2008). This means that flow can be measured reliably. Bakker (2007) further concluded that each dimension had good test-retest reliability. Empirical support for convergent validity of the WOLF was found if each of the three dimensions correlated positively with the general Flow index. Bakker (2007) also established construct validity and predictive validity.

In the present study, flow was measured using the original set of 16 items formulated by Bakker (2008). *Absorption* was measured using four items, *Work enjoyment* was measured using four items, and *Intrinsic work motivation* was measured using five items. The administering of the WOLF in the current study followed the instructions of Bakker (2008). The ATCOs were requested to indicate how often they experienced elements of flow during the high-risk shift handover period, immediately after their shift. The data gathered through this instrument contributed to answering *RQ3: What is the impact of mental task engagement, mental workload, and the state of flow on the occupational safety of South African civil ATCOs during the shift-handover process?*

3.8.4 Phase 2 data analysis

Data collected from the interviews were in the form of transcribed interviews. The interviews were transcribed by a professional transcription company, High Tech Transcription Services. The accuracy of the transcripts was verified by the researcher taking an original audio recording and comparing it to the transcript (see a sample excerpt in Appendix C). Thematic analysis was used to analyse the transcripts to gain insight into the subjective experience of ATCOs, particularly during the high-risk shift handover period.

The NASA-TLX was scored via a computerised program, while the Flow scale was scored by hand. Averages and frequencies were then calculated. The quantitative data are described, rather than having been statistically analysed, due to the limitation of the small sample.

3.9 Phase 3: Interventions

Phase 3 was the final phase of the research study, and was developed from the results of Phase 2. Phase 3 was the testing of interventions to determine whether these could enhance ATCOs' operational safety performance by enhancing mental arousal, mental alertness, situation awareness, and attention, and alleviate stress.

Two interventions were selected by the researcher: music and mindfulness, as these are relatively straightforward to implement and test, without significant disruption of the ATCOs' task performance.

Phase 3 addressed *RQ4: Does a music intervention or mindfulness intervention improve flow and mental task engagement, that is, work performance in civil South African ATCOs?*

3.9.1 Phase 3 Sample

All ATCOs at O R Tambo International Airport were invited to participate in Phase 3. A total of 15 ATCOs volunteered, who were then randomly assigned to one of three groups (five ATCOs per group). One group underwent the music intervention and one underwent the mindfulness intervention, while the third group took part in neither, thereby serving as the control group. The table below provides the demographic details of the sample.

Table 3.3

Demographic details of Sample per Intervention: Phase 3

Intervention	Age	Gender
Music		
ATCO1	42	Male
ATCO2	31	Male
ATCO3	48	Female
ATCO4	31	Female
ATCO5	31	Female
Mindfulness		
ATCO1	30	Male
ATCO2	38	Male
ATCO3	31	Female
ATCO4	26	Male
ATCO5	34	Male
Control		
ATCO1	32	Male
ATCO2	56	Male
ATCO3	38	Male
ATCO4	32	Male
ATCO5	32	Male

3.9.2 Phase 3 data collection

For each intervention, the ATCO wore a Fitbit, a smartwatch able to monitor heart rate, on the wrist of his or her non-dominant hand. The Fitbit was linked via Bluetooth to the researcher's smartphone. Each ATCO's heart rate was recorded at one-minute intervals (an instantaneous measure), while the researcher sat within close proximity to the ATCO.

With regard to the music intervention, the researcher compiled a list of songs (see Appendix I) with a faster tempo, as such music was considered likely to have a stimulative effect and lead to increased psychophysiological arousal. ATCOs were given the list and requested to select five songs they considered uplifting. The ATCOs were given headphones and informed that they would be able to listen to the selected songs for ten minutes. They were not required to do anything for the duration of that time, other than to listen to the music they had selected. In most cases, the ATCOs did not listen to the entire playlist within the allotted ten minutes.

With regard to the mindfulness intervention, ATCOs were given a drawing to colour in (see Appendix J), together with a selection of pencils and crayons. They were requested to complete the task within ten minutes. Colouring-in as a mindfulness intervention has been previously utilised in research studies (Carsley & Heath, 2018; Mantzios & Giannou, 2018). The quick colouring-in task was chosen for the mindfulness intervention because it would cause minimum disruption of the ATCOs' work activities, rather than a mindfulness intervention that would be time-consuming, such as meditation.

In order to measure the effects of the interventions, ATCOs in all three groups were given the Short Stress State Questionnaire (Helton, 2004) to complete (see Appendix L).

The process was as follows. All participating ATCOs completed the Short Stress State Questionnaire prior to going on duty. Wearing Fitbits, they then went on duty (active controlling) in the radar hall, while the researcher unobtrusively recorded their heart rate for the first 20 minutes of active duty. The ATCOs continued controlling until the scheduled end of their shift. At the end of his or her shift, each ATCO was again given the Short Stress State Questionnaire to complete (see Appendix M). Upon the second completion of the questionnaire, the heart rate monitor was removed. The researcher ensured that the data were collected ethically by administering a participant information sheet as well as a consent form to each participant. Only ATCOs who had volunteered to participate were utilised, and any physical discomfort was reduced by utilising a wrist heart-rate monitor. Codes and grouping of data assured anonymity and confidentiality.

3.9.3 Phase 3 measurements

In measuring the effect of the interventions, the researcher had to determine the stress levels of the ATCOs. The next paragraph provides a brief overview of stress. Considering the high-pressure work environment of ATCOs, the description contextualises and justifies the selected measurement instrument.

Task performance is frequently stressful, especially when the task imposes high cognitive demands (Matthews et al., 2013). Tasks may be intrinsically demanding if they impose a high workload, time pressure, or carry the likelihood of failure. The environment in which the task is performed and social factors may also be sources of stress. Task-related stress may have a variety of consequences, such as acute emotional responses, performance impairment, and long-term impacts on the health and wellbeing of the operator. The subjective response to stress is multidimensional, and different types of tasks demand elicit different patterns of response. Stress is the result of a relationship between the person and his or her environment. Individuals experiences stress when they appraises the relationship as taxing or exceeding their resources and endangering their well-being (Lazarus & Folkman, 1984). Stress may also influence information processing and cognition (Hockey, 1997).

As mentioned in the previous section, the researcher chose the Short Stress State Questionnaire (SSSQ) (Helton, 2004) to measure ATCOs' stress prior to going on duty and again afterwards. The instrument is discussed in detail below.

3.9.3.1 Short Stress State Questionnaire (SSSQ)

The SSSQ was developed from the Dundee Stress Sate Questionnaire (DSSQ) (Helton, 2004; Matthews, Szalma, Panganiban, Neubauer, & Warm, 2013) and has been employed in studies investigating stress states in performance contexts (Carretta & French, 2012, cited in Helton & Näwell, 2015). The DSSQ (Matthews et al., 2013) assesses 11 dimensions of subjective state response in stressful environments within the domains of affect, motivation, and cognition.

The DSSQ is a reliable measure, and has been employed effectively in a number of recent studies investigating the subjective stress of demanding tasks (Helton et al., 2003; Temple et al., 2000). However, the DSSQ has a serious limitation in the form of its length. The most recent version of the DSSQ contains 90 items, usually administered pre-task and post-task. This means that respondents have to respond to 180 items. Not only does the length pose the risk of fatigue, which may skew results, it is impractical to administer such a lengthy instrument in an operational setting (Helton, 2004). The present researcher therefore chose to employ the shorter SSSQ (Helton, 2004).

The three factors of the SSSQ — motivation, affect, and cognition — show sensitivity to task stressors, and it is a useful tool in studying the relationships between conscious states and variables such as task performance physiological variables. The SSSQ may also be useful in assessing subjective state reactions to task manipulations (Helton, 2004). While there are slight differences in how the primary three factors are construed, the overall structure and results of the SSSQ (Helton, 2004) appear similar to those of the DSSSQ (Matthews et al., 2013). Helton and Näwell (2015) provided evidence of the measurement properties and theoretical utility of the SSSQ. According to Helton and Näwell (2015), the 24-item SSSQ appears to be an effective short stress state inventory, demonstrating sensitivity to task stressors. Research in air traffic control utilising the SSSQ is lacking, and the use of this instrument in the present study therefore makes a contribution to the literature in this domain.

3.9.3.2 Heart rate

Heart rate was utilised in the present study as a measure to assess the impact of the music and/or mindfulness intervention on each ATCO's mental alertness and psychophysiological arousal during the task of controlling. Heart rate, measured as the number of beats per minute, was recorded, whereby an elevation in heart rate over an individual's basal heart rate was considered to indicate an increase in mental alertness and arousal. The association between vigilance and increased heart rate is long accepted (Mendelowitz, 2014).

Heart rate is also an indication of workload (Vogt, Hagemann, & Kastner, 2006; Chen & Lee, 1998; Leo, 1973). Many studies have shown that an increase in heart rate is a response to an increase in workload (Kastner et al., 1998; Lindholm & Cheatham, 1983; Rohmert & Rutenfranz, 1972; Rose, Jenkins, & Hurst, 1978). In studies of German ATCOs, cardiovascular variables showed the highest correlation with air traffic load (Hagemann, Vogt, Biskup, Kastner, & Kalveram, 1999; Lewis, Directo, Kim, & Dolezal, 2016; Rohmert & Rutenfranz, 1972).

In the current study, a Fitbit Charge HR was used to measure heart rate. Fitbit is a wireless wristband that offers automatic, continuous heart-rate and activity tracking. It is one of the most popular brands of wearable fitness trackers, and is utilised for recording steps, calculating energy expenditure, and measuring heart rate (Hargis, Powell, & Konz, 2018). The accuracy of the Fitbit Charge HR is affected by the physiology of the individual, as well as the location of the sensor and the type of movement (Hargis, Powell, & Konz, 2018).

With regard to the reliability and validity of the Fitbit Charge HR, Evenson, Goto, and Furberg (2015), confirmed the validity of activity trackers, include criterion validity (comparing the trackers to a criterion measure of steps, distance travelled, physical activity, energy expenditure, and sleep), and construct validity (comparing the trackers to other constructs that should track or correlate positively (convergent validity) or negatively (divergent validity)).

Reliability included intra-device reliability (consistency within the same tracker) and inter-device reliability (consistency across the same brand/type of tracker, measured at the same time and worn in the same location). The validity and inter-device reliability of the measure of step counts were found to be generally high, while the inter-device reliability of the measure of energy expenditure was high. The validity of the tracker was lower than that of other devices. Evenson et al. (2015) found higher validity for the measure of steps taken, distance, and physical activity, but lower validity for the measures of energy expenditure and sleep. High inter-device reliability was found for the measures of steps taken, energy expenditure, and sleep for certain Fitbit models. A number of recent studies were carried out using the Fitbit Charge HR (Benedetto, Caldato, Bazzan, Greenwood, Pensabene, & Actis, 2018; Caldato, Bazzan, Greenwood, Pensabene, & Actis, 2018).

In the current study, average heart rate was measured, rather than continuous heart rate.

3.9.4 Phase 3 data analysis

Due to the small sample size, the data collected in this phase of the study were analysed qualitatively, and not statistically as was initially intended. The data were therefore analysed as a means to describe the data.

The SSSQ (Helton, 2004) data were scored manually, whereafter averages and frequencies were calculated. Heart rate was also recorded manually, at one-minute intervals, whereafter averages and frequencies across the ten-minute periods measured were calculated.

3.10 Ethical Considerations

Ethical clearance to conduct the study was obtained from the human research ethics committee (non-medical) of the University of the Witwatersrand (see Appendix H).

The researcher and the University of the Witwatersrand entered into a non-disclosure agreement with the ATNS, as the safety incident reports contained information of a confidential and sensitive nature. The non-disclosure agreement required that the researcher not use any identifying personal information in reporting the findings of the study. Therefore, the reports on the results and findings contain no unique identifiers, and the data were grouped. On completion of the research, ATNS will be provided with a copy of the dissertation.

Permission was obtained from NASA to utilise the NASA-TLX research tool. ATCOs who participated in the research did so on a voluntary basis. They were informed regarding the aim and nature of the study, and that they could withdraw at any time, without negative consequences. Before commencing with the interviews, research participants were given an information sheet, which explained the purpose of the study and what participating in the study would entail. Participants were then given two consent forms to sign (see Appendix B), one giving consent to be interviewed and another giving consent to be audio-recorded. They were also given the opportunity to ask any questions arising from the participant information and consent forms.

Participants were also assured that participation was anonymous, as pseudonyms would be used, and that no identifying data would be included. As part of the consent forms, ATCOs were informed that there were no benefits to taking part in the research, and that they would not be harmed in any way. Both documents and audio-recordings were saved in a password-protected folder on the researcher's laptop.

3.11 Chapter Summary

This chapter provided a description of the mixed-methods research design utilised in the current study. As the research was conducted in three phases, a description of samples and processes involved, together with methods of analysis and ethical considerations, was delineated for each phase.

Phase 1 allowed the researcher to verify the claims of ATNS that safety incidents occur during the high-risk shift handover period (i.e. 30 minutes after the start of shift, after a shift break, and 30 minutes before the end of a shift). Phase 1 also allowed the researcher to look for alternative explanations in the incident data. The approach taken in Phase 1 was a Safety-I approach; however, analysis of the safety incident reports also allowed the researcher to identify flow, mental task engagement, and mental workload as essential factors in promoting ATCOs' ability to operate optimally, such that things go right (Safety-II).

Phase 2 explored the explanations and themes emerging from Phase 1. A combination of a Safety-I and a Safety-II approach was used in Phase 2 in order to obtain a more holistic view of ATCOs' performance. Phase 2 therefore assisted the researcher to examine how mental task engagement links to the state of flow, thereby ensuring operational safety.

Phase 3 was based on the explanations from Phase 1 and Phase 2, and consisted of interventions in the form of music and mindfulness, to determine whether these could be used to facilitate optimal flow, mental task engagement, and mental workload, in order to have a positive impact on ATCOs' operational safety.

The next chapter presents the results of the study.

CHAPTER 4: RESULTS

4.1 Introduction

This chapter presents the outcomes of the research. Qualitative themes are reported first, followed by the results of the quantitative analyses for each of the three phases of the research. In presenting the results, important aspects are woven into the presentation of the results, to enhance dependability (that the research process is logical, traceable, and clearly documented) and confirmability (that the interpretations and findings were derived from the data). The discussion culminates in conclusions and interpretations.

The outcomes are reported per phase of the research:

4.2 Phase 1: Qualitative Analysis of Safety Incident Reports

Phase 1 of the research was conducted to answer *RQ1: What human factors issues can be identified from the safety incident reports as significantly impacting on the operational safety of South African civil ATCOs?*

Multiple qualitative themes emerged from the analysis of the safety incident reports, providing a holistic view of trends in the human factors that impact the operational safety of ATCOs. The incident data reported became more comprehensive over the years under study: 2008 to 2012. Some inconsistencies in reporting information were also observed, for example, variables such as age and gender. Thematic analysis was conducted to identify themes, which were grouped into three categories: systemic, psychological, and physiological factors. The following themes were identified from the qualitative analysis of safety incident reports.

4.2.1 Systemic factors

Systemic factors identified were divided into the following sub-categories: Sector, ATNS Unit, Traffic Load/Complexity, Weather, Student and On-the-job Instructor (OTJI) Experience, ATCO Workload, Organisational Factors, and Environmental Factors. These sub-categories and how they link to safety events are expanded on below.

4.2.1.1 Traffic load/complexity

An overload or underload in air traffic on the day of a safety incident means air traffic volumes or sector capacity was either above or below the approved numbers. It refers to both the amount of aircraft on frequency and the complexity of managing the airspace.

Different reasons were identified in the safety incident reports that account for an increase or decrease in air traffic load and/or complexity, and both overload and underload had been noted in safety incidents. For example, an increase in traffic load and/or complexity occurred during the 2010 Soccer World Cup, when South Africa hosted the event. In some safety events, air traffic load was low immediately prior to and during the safety event. Low air traffic density was noted as causing, for example, complacency and boredom in ATCOs. In one incident during low traffic, the ATCOs were having a casual conversation with one another, which led an ATCO being distracted from the task. ATCOs drift into a state of lower mental alertness during periods of air traffic underload, while their mental alertness is higher during periods of traffic overload. Interestingly, safety events have occurred where low air traffic load was immediately followed by periods of elevated air traffic load, when the high intensity session required elevated mental alertness.

4.2.1.2 Weather

Safety incidents tended to occur during periods of inclement weather and severe thunderstorm activity. It was noted that ATCOs' alertness and decision-making are enhanced through accurate weather phenomenon displays while on duty. In other words, equipment must be in good working order at all times including weather displays.

4.2.1.3 Student and OTJI experience

It is essential that ATCOs operate at the level expected of them, to ensure safety, even if the potential risk of an incident is low. Student ATOCs and newly validated ATCOs lack experience. In the case of student ATCOs, they are not at the adequate level of skills and experience, due to insufficient hours on the job. Student ATCOs receive training from an OTJI, who allows them to gain the necessary experience.

These students and newly validated ATCOs therefor have had limited exposure and experience in working in a particular sector. As such, they are not as equipped to deal with a scenario of conflict resolution. For example, during one safety incident that involved a student ATCO, the student was not experienced in the weather avoidance operation at O R Tambo Airport.

Combined sectors of operation also place increased pressure on ATCOs, and may lead to information overload for students and newly validated ATCOs.

4.2.1.4 Pilot–ATCO interaction

This was another category of factors identified as contributing to safety incidents. The most significant pilot–ATCO factor was found to be communication: communication during a safety incident was inadequate; miscommunication occurred between pilots and ATCOs; in some cases there had been a complete breakdown in communication (e.g., a pilot entered the airspace without valid clearance); the use of non-standard phraseology by the ATCO; an ATCO not correcting a pilot's incorrect readback or not noticing an incomplete readback from the pilot; the pilot not understanding or adhering to an ATCO's instruction, or even ignoring instructions. Other factors in this category were: differing expectations and understanding of the situation by ATCOs and the pilot; ambiguous instructions transmitted by the ATCO; and ATCOs arguing with pilots and vice versa.

4.2.2 Organisational factors

The following organisational factors were found to play a role in the occurrence of safety incidents.

4.2.2.1 Processes

These sometimes took the form of proper safety filters being absent. In other incidents, approach ATCOs were not assigned sufficient shifts in the tower to remain proficient. One ATCO's previous shift in the TOWER had been three months prior to the incident, despite staff requiring at least 33% rostering in a secondary control position. One ATCO had not been subjected to a familiarisation shift as required by company protocol, which is a violation of safety filters, especially as that ATCO had not worked in that position for three cycles. Rostering and scheduling needs to account for 'sick outs', rostered leave, and ATCOs attending courses. One ATCO was working illegally, as his/her O R Tambo Airport tower validation had expired three days prior to the incident.

In some safety events, standby shifts were not rostered, leading to staff shortages. Rostering also needs to allow for effective breaks in order for ATCOs to remain vigilant in a low traffic situation for extended periods. The rostering during some safety events did not ensure that the ATCO had sufficient mental recovery breaks, which is especially pertinent in an environment with high traffic loading that requires prolonged ATCO vigilance. Safety events have occurred when the ATCO was alone in the tower on night duty.

4.2.2.2 Culture

Organisational culture also played a role in some incidents, e.g., efficiency had been placed ahead of safety; an awareness of management politics disrupted the ATCOs' functioning; and there was a perceived lack of managerial support. In several incidents, the unit's morale was low, e.g., due to rumours of resignation of management and ATCOs. There was inadequate supervision of safety behaviour and operational risk during the shift in which the safety incident occurred. The supervisor on shift should allow breaks according to task demands. An absence of supervision in the operational environment was found also to lead to the slow reporting of safety incidents and action by the unit, as there was no operational line of authority at the time. In some cases, there was a negative atmosphere at work. Team factors played a positive role here, e.g., a colleague pointing out a potential conflict scenario and good support from peers during and following an event.

4.2.2.3 Ergonomics

Ergonomics were also found to play a role in the occurrence of safety events. For example: apron floodlights were identified as contributing to a loss in situation awareness through the ATCO being denied good visibility in the vicinity of the threshold of the runway. It is not, however, known to what extent the apron lights may be a threat to safety. In one incident, the only lights available to allow the ATCO to see the aircraft during a period of darkness were the apron lights and the lights of the aircraft.

Workplace design also plays a role, e.g., limited space at the console; an angled view of the radar display resulted in an observation error; an ATCO in a seated position could not observe the entire runway, due to height of the consoles; the layout of the tower consoles in relation with the tower window made it difficult for the ATCO to execute a proper visual scan of the runway and taxiway; and a poorly placed radar display resulted in the ATCO having limited ability to observe both the radar display and circuit traffic.

Faulty or unserviceable equipment was also found to play a role in safety events, e.g., false alerts leading to a lack of trust in the system. Sub-standard or radios impair communication between ATCO and pilot. In another incident, construction and maintenance on the runway had contributed to a safety incident.

4.2.3 Environmental factors

Two environmental considerations were identified from the reports.

4.2.3.1 Rest area

ATCOs require a rest area where they can enjoy quiet time and relax without distraction. These areas tend to be inadequate. ATCOs provided input with regard to their requirements for a rest area: access to computers; physical, social, and fun activities (such as a pool table and darts); a kitchen facility within closer proximity; plants; a pleasant colour scheme; and non-aviation magazines.

4.2.3.2 Climate

Safety incidents were linked to very cold conditions in the radar hall and very hot conditions in the tower, due to air conditioners being out of order. This caused fatigue, with a negative impact on mental alertness. This was particularly pertinent during shifts on summer days and lengthy shifts. In other incidents, ATCOs noted reflected glare from the sun as a contributory factor.

4.2.4 Psychological factors

The psychological factors identified as factors in safety incidents were divided into direct and non-direct task-related psychological factors. Direct task-related factors are those psychological influences that are directly related to the ATCO's performance during the task of active controlling, while non-direct task-related factors are not directly related. Those psychological factors that have a direct impact on the ATCO's task are more traditionally focused on in the field of air traffic control, and fall within the field of cognitive psychology. These include, e.g., attention, situation awareness, and mental alertness. Psychological factors that do not have a direct influence on the task of controlling include, e.g., adherence to policies and procedures, such as not completing occurrence logs and personal stress (due to, e.g., pending emigration, moving house).

4.2.4.1 Direct task-related factors

A significant finding by the ATNS was the occurrence of safety events within 30 minutes of taking position, at the start of shift, including returning from a break, when the ATCO takes position. This can be understood by the possibility that the ATCO's psychophysiological state is one where arousal has not reached the optimal level to allow the ATCO to effectively formulate an accurate mental picture in order to deal with traffic scenarios that may or may not be complex.

According to Section 2 of the SACAA Standards and Procedures Manual, personnel handing over an operational position to another shall ensure that the successor is provided with full information on the current traffic situation and any matters of significance that have influenced the development of the situation, or may have a bearing on a situation arising during the course of the shift. When a prevailing traffic situation or other events make it desirable for personnel to complete all actions before transferring responsibility to another person, the person should remain on duty until such time as these actions have been completed. It is important that ATCOs consider the following during handover: avoid distracting ATCOs during hand-over; use checklists with the sequence of actions to be performed by both the handing-over and taking-over ATCO. The taking-over ATCO should ensure that he/she has been able to assimilate all information relevant to a safe handover, and should accept responsibility only after he/she is completely satisfied that he/she has a comprehensive awareness of the situation. The handing-over ATCO should remain available for a few minutes following the handover, particular in dynamic traffic situations, to provide clarification and assistance regarding any issues that may subsequently arise.

Factors found to contribute to a lowered psychophysiological state are the following:

4.2.4.1.1 Traffic volume

This refers to a low-intensity shift and period leading up to the incident, i.e. low traffic volumes. The ATCO needs a comprehensive understanding of the traffic situation as he/she takes control.

4.2.4.1.2 Handover period

A settling-in process is required at the start of a shift, and is facilitated during handover. ATCOs are required to exercise caution during the handover of a control position, so as not to be distracted and miss crucial information such as the correct positions of vehicles and aircraft. From the analysis of safety incident reports, time allocated to handover did not always allow the ATCO to gain the required level of mental alertness to deal with the current situation. This time is also necessary for ATCOs to complete the necessary administration for the proper execution of duties.

4.2.4.1.3 Mental alertness

A decrease in mental alertness was found in ATCOs during a safety incident, whereby the ATCO did not immediately react to the developing scenario. Mental alertness needs to be maintained before the shift and during periods of low task demands.

4.2.4.1.4 Attention and concentration

A decrease in attention and concentration was found to be commonly linked to a safety incident. Lowered attention and concentration lead to the failure of an ATCO to recognise and identify conflict situations timeously. ATCOs' failure to prioritise attention during a period when low mental alertness is requirement is referred to as a 'skill-based error'.

ATCOs were found to be distracted when continuously engaging in conversation with colleagues. Other distractions included student pilots who constantly require extra attention, loud noise emanating from radios and alarms, construction on the runway, and excessive noise levels in the tower. ATCOs on a break usually remain in the tower and converse with the ATCOs on duty. One ATCO had been elected to planner position, and had to divide his/her attention between that and providing on-the-job training.

Attention and concentration are lowered by the increase in distraction experienced during the period of settling into the operational shift. An adverse mental state was found to occur when the ATCO was distracted. An increase in distraction is categorised as an error in information processing. It occurred as a result of several factors: the ATCO had to take a telephone call while controlling, noise levels such as loud audio noise from an adjacent ATCO (shouting), intrusion by three helicopters resulting in emotional upset, distraction through double transmissions (two frequencies operating independently), one ATCO distracting another, and an unconfirmed or false short-term conflict alert.

In one safety incident, the student ATCO's frame of mind was negative due to an earlier altercation with the OTJI with regard to a difference of opinion, leading to the student ATCO feeling criticised with regard to his/her decision-making, which later interfered with his/her performance. As he/she tried to please and appease the OJTI, he/she attempted more advanced techniques, rather than easier, although less efficient, ones. The student's attempts to please the OTJI may have been a distraction from the main task. Other instances of distraction occurred as a result of the air conditioner being noisy, and one ATCO was having a casual conversation with fellow ATCOs at the time of the event. In another safety event, this resulted in the ATCO requesting a repeat of transmission on three occasions within eight minutes, on which pilots commented.

4.2.4.1.5 Perception and judgement

Faulty perception can be visual or auditory errors, and was found to contribute to safety events. An example of faulty auditory perception is a 'mishear', whereby the ATCO fails to detect an incorrect hear-back or read-back, and failed to correct it. The ICAO Manual of Radiotelephony (Doc 9432) states:

> *Read-back requirements have been introduced in the interests of flight safety. The stringency of the read-back requirement is directly related to the possible seriousness of a misunderstanding in the transmission and receipt of ATC clearances and instructions. Strict adherence to read-back procedures ensures not only that the clearance has been received correctly but also that the clearance was transmitted as intended. It also serves as a check that the right aircraft, and only that aircraft, will take action on the clearance.*

Furthermore:

> *The controller shall listen to the read-back to ascertain that the clearance or instruction has been correctly acknowledged by the flight crew and shall take immediate action to correct any discrepancies revealed by the read-back. If an aircraft read-back or instruction is incorrect, the controller shall transmit the words "NEGATIVE, I SAY AGAIN" followed by the correct version.*

An example of faulty visual perception occurred when the ATCO misperceived the actual position of the aircraft on the radar. Examples of perception and judgement errors are, e.g., the ATCO misjudging the aircraft speed and heading of an approaching aircraft, the taxi speed difference, the speed of an aircraft's descent, and the distance and closing speeds of two aircraft. Other visual perceptual errors include the ATCO misjudging the projection of an aircraft or its timing, for example, of departure readiness. An error in judgement can result in an ATCO issuing an instruction to the wrong aircraft.

4.2.4.1.6 Information processing

Errors in the processing of information can result in omission of a required action. Examples include: an instruction order was not issued by the ATCO in time to facilitate a quick response by crew; an ATCO failed to recognise the potential risk of a situation and was slow in responding to a conflict situation; and an ATCO detected visual information too late (this can occur due to an overwhelming rate of prior false alerts, leading to ATCOs losing trust in the system). Information processing errors can also be seen when there is visual or sound confusion, whereby the information is similar; for example, two call signs are significantly similar, differing by only one letter. ATCOs were found to make errors in information processing when they failed or forgot to monitor the movement of one or more aircraft, failed to check that adequate separation was maintained, and failed to recognise a potential risk. Information processing errors can cause safety incidents. In one safety event, there were emotional factors present in the tower or radar hall on the day of the incident, due to a fatal aircraft accident the previous day. The ATCO may have been preoccupied and instructed the wrong aircraft to perform an action. An information processing error occurred in one instance when the OTJI was preoccupied with other tasks and did not prioritise tasks correctly, leading to a safety incident.

4.2.4.1.7 Memory

Human memory is critical to the performance of tactical air traffic control tasks. All intelligent systems that process information require memory to direct actions and to store the results of those actions. The human memory system is subdivided into long-term memory, short-term memory, and working memory.

Long-term memory has no known capacity, is fairly permanent, and supports information retrieval with little conscious effort. Working memory capacity is limited, and requires conscious attention for the maintenance and retrieval of information. On average, people can maintain a maximum of seven plus or minus two units of information in short-term memory, without conscious attention. However, this information is forgotten in approximately 15 seconds (Zimmerman & Schunk, 2008).

Human memory recall is prone to error, and it may at times be challenging for ATCOs to remember specific information that has to be passed to crews or aircraft but is infrequently applied. Memory was found to contribute to safety incidents, whereby the ATCO had an inaccurate or no recall of information, or lapses in memory, a poor working memory, or inaccurate recall from working memory.

Memory errors can be the result of information overload when sequences keep changing. This may lead to an ATCO forgetting to monitor or to perform a planned action. Memory capacity overload was found to occur in ATCOs involved in safety events when there was too many temporary facts to keep in working memory; the ATCO was dealing with multiple conflicts; and the ATCO was unable to keep track of each task and movement as he/she had numerous things to remember. When ATCOs initially take watch, their mental alertness levels are still low, which may result in errors related to memory.

4.2.4.1.8 Planning

Planning errors, i.e. an insufficient plan, were found to be linked to judgement errors, for example, when an ATCO misjudges the distance between two aircraft or aircraft projection.

4.2.4.1.9 Decision-making

When decision-making is faulty, the ATCO selects an incorrect action. Faulty decision-making can occur when the ATCO misjudges a traffic situation. Faulty decision-making by the ATCO was found to occur when an incorrect decision or plan is made and results in, for example, the incorrect issuing of an instruction to a pilot. In another safety incident, conditional clearance was given to an aircraft while there were still other aircraft ready to land.

4.2.4.1.10 Situation awareness

It is imperative that, at the commencement of the shift, ATCOs familiarise themselves with the situation and escalate to an optimal operational level of situation awareness, such that they are able to maintain a mental picture of the traffic scenario, together with the ability to identify potential traffic conflicts. Situation awareness is required in order for the ATCO to observe a developing situation. Loss of situation awareness was identified from the safety incident reports as a psychological factor that often contributes to the occurrence of safety incidents. For example, ATCOs who had just taken over a shift and were familiarising themselves with the situation fixated on aircraft sequencing into airport, and were not fully aware of the position of other aircraft.

4.2.4.1.11 Conflict resolution

Some safety incidents were the result of ATCOs not applying conflict resolution, i.e. they did not enforce the maintenance of standard separation requirements.

4.2.4.1.12 Essential traffic information

ATCOs require essential traffic information. ICAO Doc 4444 (Chapter 5) states:

> *Essential traffic is that controlled traffic to which provision of separation by ATC is applicable… Essential traffic information shall be given to controlled flights concerned*

whenever they constitute essential traffic to each other. Thus the passing of essential traffic information is relevant to radar and non-radar environments.

From the safety incident reports, some incidents occurred when an ATCO did not pass essential traffic information or instructions to the aircraft(s). In this regard, according to the SA-CAA Standards and Procedure Manual:

aircraft should be informed of their position in the following circumstances:

a) on first identification;

b) when the pilot requests the information;

c) when the aircraft is flying off the correct track;

d) when an aircraft estimate differs significantly from the radar controller's estimate based on radar observation;

e) when the pilot is instructed to resume his own navigation following vectoring.

The SACAA Standards and Procedure Manual Section 7, ATS Surveillance Procedure Point 16 states:

Traffic information should include the following:

a) bearing from the aircraft in terms of the 12 hour clock (when an aircraft is turning direction of the unknown aircraft by compass points);

b) distance from the aircraft in miles;

c) direction in which the unknown aircraft is proceeding, e.g. "traffic is opposite direction/crossing left to right", etc.

d) height information when available, this may include the unverified mode C of unknown aircraft.

4.2.4.2 Non-direct task-related factors

4.2.4.2.1 Disappointment and guilt

Disappointment and guilt emerged as a theme. ATCOs were disappointed in themselves and experienced feelings of guilt for having made errors in the period leading up to the safety incident.

4.2.4.2.2 Personal stress

In some cases, ATCOs were experiencing one or more acute or long-term personal stressors at the time of the safety event. ATCOs do not necessarily understand the impact and extent of demanding social and personal stressors on their performance. For example, one ATCO experienced a personal trauma that was life threatening only weeks prior to safety event. This particular ATCO was still recovering from the trauma at the time the safety incident occurred.

4.2.4.2.3 Anxiety

In one safety event, the ATCO watched the situation unfold in front of him/her. He was unable to do anything to prevent the incident from occurring, leading to a feeling of a loss of control. This particular ATCO experienced feelings of helplessness, powerlessness, and immense anxiety. Anxiety was found to be common in many of the ATCOs.

4.2.4.2.4 Speech

Radio telephony phraseology should be standardised per SACAA Standards and Procedures Manual, Section 8, Communications Procedures and Standard Phraseology. For example, "I have no further traffic for you" should be "No reported traffic". When information transmitted by ATCOs is unclear and non-standard, or incorrect phraseology is used, the instructions sent to pilots are ambiguous, causing an increased likelihood of safety incidents occurring. Incorrect phraseology in communicating with the pilot may lead to a misunderstanding between the pilot and the ATCO. In one safety event, the transmissions were of a poor quality, which placed additional stress on the ATCO, who felt "bombarded" with incorrect transmissions. One ATCO utilised incorrect and shortened phraseology, due to a heavy air traffic load. Other ATCOs used non-standard phraseology, including "please", "thank you", "OK", "have a nice day", "*ja*", and "bye". Language other than English was used in some events, which was found to contribute to the occurrence of safety events. For example, in one event, pilots communicated in French, even after the ATCO had communicated in English. In another incident, the ATCO had communicated in Afrikaans. Voice tone utilised by the ATCO is important. For example, a sense of urgency should be conveyed when a risk is detected. The speed and timeliness of transmissions were found to make important contributions to the communication between ATCOs and pilots. If speech is, e.g., too rapid, the recipient may not be able to copy the instruction correctly, or may misunderstand it. Another element of speech that was found to contribute to safety events is pronunciation leading to ambiguity and confusion. Read-back and hear-back errors (incomplete or not corrected) were also found to be linked to safety events.

4.2.4.2.5 Personality

A common personality factor found in ATCOs who had been involved in incidents was the tendency to be over-confident and a need to be in control.

4.2.4.2.6 Poor habits

ATCOs who were involved in safety events were found to have developed poor habits, such as poor record-keeping, whereby they do not adhere to procedure, e.g., not signing on for duty and not completing occurrence logs. Some did not conform to directives, policies, and procedures. Other ATCOs were disorganised and lacked the ability to prioritise tasks.

According to the Operations Directive 4/2020 (ATNS SD 4/2006) Air Traffic Services Log Keeping, Section 4-4.1.2, the occurrence log must include, amongst others:

> *all appropriate information which is relevant to the recording of actual unit circumstances and unusual and abnormal events e.g.*
>
> *a) opening or closing or continuation of watch;*
>
> *b) aerodrome inspections, details of work in progress and other essential aerodrome information;*
>
> *c) time of receipt of special aerodrome reports, SIGMET reports, or any other significant meteorological phenomena;*
>
> *d) any changes to status of CNS facilities, services, and procedures.*
>
> *e) Safety Significant Events, accidents, non-compliance with regulations or ATC clearances, regardless of whether an additional, separate report is required.*

4.2.4.2.7 Call sign confusion

In some safety events, an incorrect call sign was used by the ATCO. Call-sign confusion was previously referred to as a ‘slip’ (from ‘Freudian slip’).

4.2.4.2.8 Dual role

ATCOs are, at times, required to carry out an additional role to that of controlling air traffic, such as being responsible for answering telephone calls. One safety incident took place when the ATCO was also responsible for taking telephone calls, and, on the day the safety incident occurred, there was an abnormally high volume of telephone calls.

4.2.4.2.9 Faulty assumptions

Safety incidents have occurred due to ATCOs making faulty assumptions, e.g., that adequate separation is being maintained.

4.2.5 Physiological factors

Physiological factors were found to be linked to the occurrence of safety incidents. These are discussed below.

4.2.5.1 Health

Several physical health concerns were found to have existed in ATCOs at the time of their involvement in a safety incident, which may have played a role. One ATCO was pregnant at the time, another was in the process of recovering from surgery, and another reported dull headaches for two months prior to the incident. Other physical health concerns included sinus complaints, frequent headaches, heartburn, and indigestion.

4.2.5.2 Fatigue

Fatigue in ATCOs involved in safety incidents was found to occur as a result of several factors.

Some ATCOs that did not take the mandatory leave stipulated in the ATNS HC Directive 23/2010, Section 3: "An employee must take at least ten consecutive working days annual leave for each leave cycle". Some ATCOs had not taken the ten consecutive leave for two years. In one instance, the ATCO had annual leave due to start in four days after the incident occurred. The ATCO's mental readiness may have been deteriorating in anticipation of the expected rest period.

A number of ATCOs had had inadequate rest. One had been on duty for 12 consecutive days prior to the event, while another had worked solo for 14 days. Yet another had worked 9 shifts with 4 days off. Some ATCOs had worked their shifts without a break. The International Federation of Air Traffic Controllers' Association (IFATCA) recommends a break every 2.5 hours. The analysis of the safety incident reports indicated that ATCOs at King Shaka International Airport, in Durban, work shifts with a duration of up to eight hours without a formal, planned break. One ATCO had worked an 11-hour shift (with breaks), as a colleague was off sick. In some safety events, break allocation was not sufficiently scheduled to limit fatigue, or breaks were too short to allow ATCOs to get sufficient rest. In one safety event, the ATCO had been on duty for three hours and 45 minutes without a break, and in another incident, the ATCO had been on shift for five hours and 20 minutes without a break. In another safety event, the ATCO was on night shift, with no breaks scheduled. An interesting finding from the reports is that ATCOs are not always aware that they are fatigued at the time of making an error.

4.2.5.3 Exercise and physical activity

A lack of exercise and/or participation in physical activity was found in a number of ATCOs who had been involved in safety events.

4.2.5.4 Nutrition

Some ATCOs who had been involved in safety events were found to drink insufficient water on shift, and some had poor nutritional habits. One ATCO drank five cups of coffee in a shift, and another had one meal per day. Not maintaining hydration and healthy blood sugar levels may have impacted their ability to concentrate.

4.2.5.5 Sleep

In some safety events, it was apparent that the ATCOs were sleep deprived. In other safety events, the ATCOs' sleep patterns were erratic, e.g., taking naps during the day and then being more inclined to be awake and active at night. One ATCO only got four hours of sleep. Sleep deprivation is well known to negatively impact performance (Nealley & Gawron, 2015). ATCOs experienced unusual fatigue during the FIFA Soccer World Cup, when unusual late-night shifts were rostered.

The table below provides a summary of the factors according to category that impact the safety performance of ATCOs.

Table 4.1

Summary of Factors Identified from Incident Reports

CATEGORY		FACTOR
Systemic		Traffic load/complexity Weather Student and OTJI experience Pilot–ATCO interaction
Organisational		Processes Culture Ergonomics
Environmental		Rest area Climate
Psychological	Direct task-related	Low traffic volume Insufficient time Mental alertness Attention and concentration Perception and judgement Information processing Memory Planning Decision-making Situation awareness Conflict resolution Essential traffic information
	Non-direct task related	Personal stress Anxiety Speech Personality Habits Call sign confusion Dual role Faulty assumptions
Physiological		Health Fatigue Exercise and physical activity Nutrition Sleep

The next section provides a quantitative description of the data gathered from the safety incident reports.

4.3 Phase 1: Quantitative Description

This stage of Phase 1 of the study was conducted to address *RO1: Determine whether the suspected pattern of incidents indeed conforms to the ATNS's hypothesis that the first or last 30 minutes of a shift and first 30 minutes after a break are high-risk periods.*

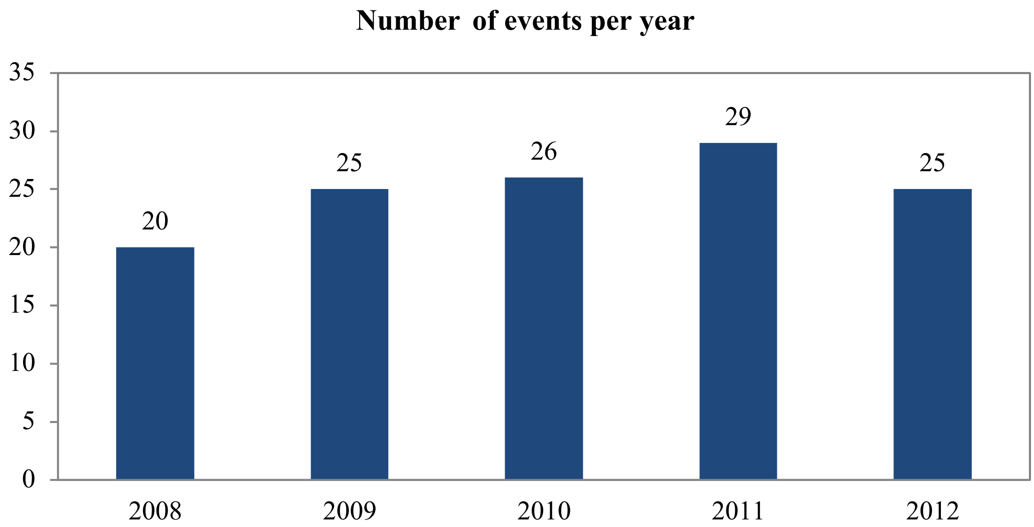
The following sections provide a quantitative description of the data for all the airports under study.

4.3.1 Events per year

The figure below illustrates the total number of safety incidents per year.

Figure 4.1

Number of Events per Year



Most safety incidents, 26, occurred in 2011, followed by 26 safety events in 2010, 25 in both 2009 and 2012, with the least number of safety events, 20, recorded in 2008. This must be seen against the steadily increasing number of scheduled flights over this period and a sharp increase in the number of flights during 2010 as a result of South Africa hosting the FIFA Soccer World Cup.

4.3.2 Timing of events

The figure below illustrates the timing of safety incidents.

Figure 4.2

Timing of Safety Incidents

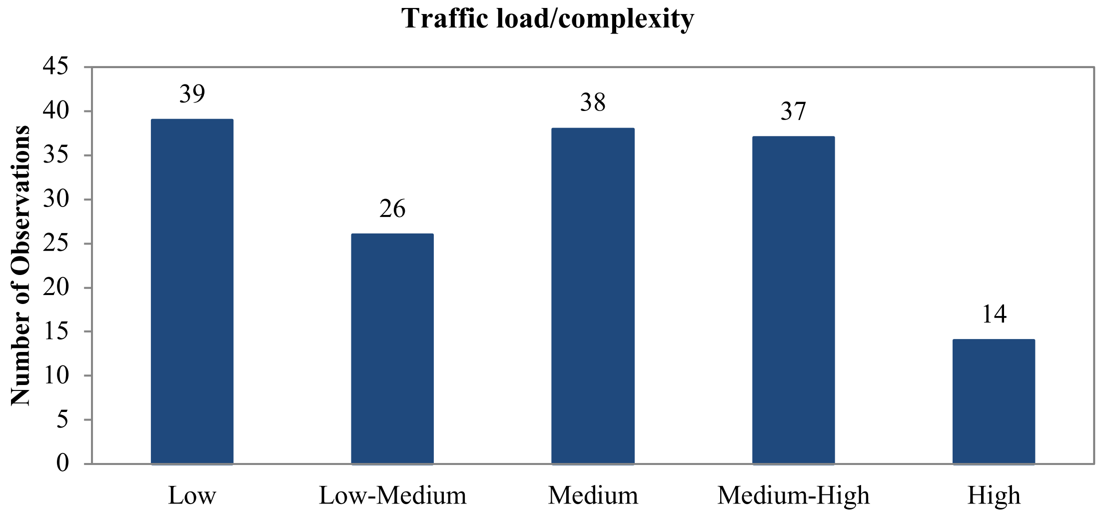
With regard to the time of day that safety events take place, the analysis of the incident reports found a pattern whereby the occurrence of safety events peaks between 05:00 and 06:00, at 08:30, and again at 12:00. This pattern can be partly explained by the morning peaks in air traffic that take place between 05:00 and 10:00. However, the peak in incidents at 12:00 does not correspond to a peak in air traffic. The next peak in air traffic is only from 16:00 to 18:00. Therefore, to explain the peak in incidents at 12:00, other factors had to be considered. One possible explanation is that the highest number of incidents occur when air traffic complexity is low. The trend of higher incidents at 12:00 may be explained by it being a midday lull in-between two very busy periods, leading to lowered alertness in ATCOs. This is illustrated in the figure below.

4.3.3 Traffic load/complexity

The figure below illustrates the number of safety incidents according to different air traffic loads.

Figure 4.3

Number of Incidents According to Traffic Load/Complexity

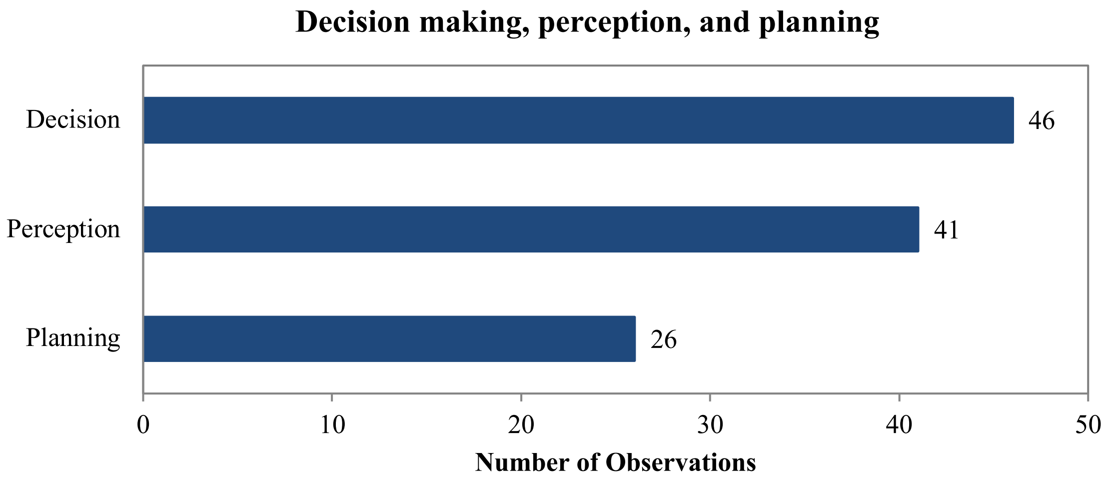


4.3.4 Decision-making, perception, and planning

The figure below illustrates the number of safety incidents ascribed to three categories of error, namely decision-making, perception, and planning.

Figure 4.4

Number of Incidents due to Decision-making, Perception, and Planning



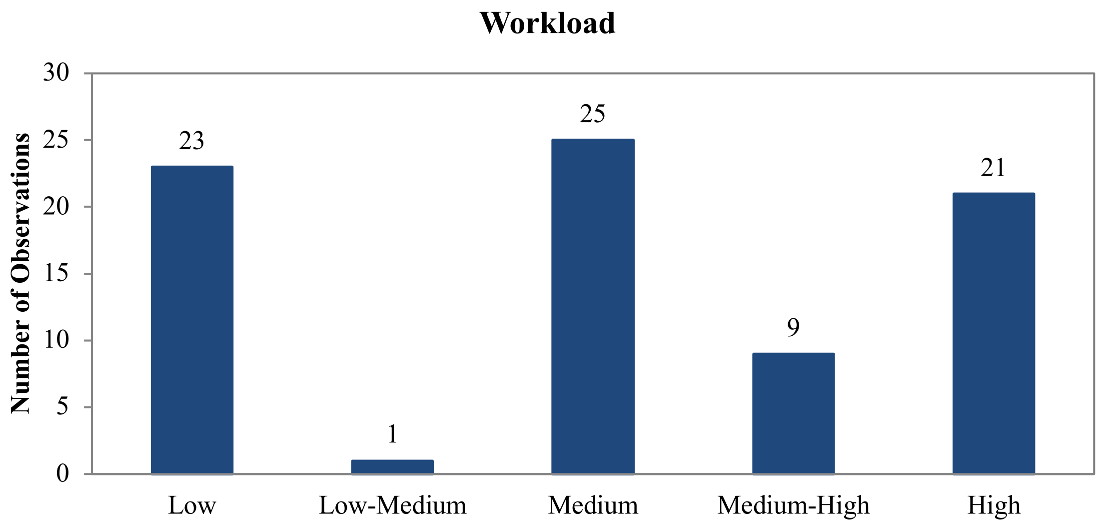
When considering direct task-related psychological causes of safety events, most safety incidents can be attributed to errors in decision-making, followed by perception errors, with the least safety incidents attributable to erroneous planning.

4.3.5 Workload

The figure below illustrates the number of safety incidents according to level of workload.

Figure 4.5

Safety Incidents according to Workload



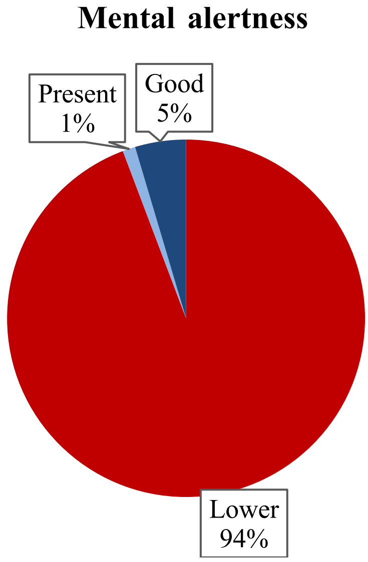
This figure illustrates ATCOs' perception of workload and the link to safety events. An ATCO's stress level and response to stress play a role here. It may be that, when the stress response in an ATCO is activated, as in periods of elevated workload, the ATCO responds more rapidly to a safety event. The traffic situation not being perceived as a threat to safety may cause decreased mental alertness (see Figure 4.6, below). The graph shows that the fewest incidents occur when ATCOs perceive their workload as low-medium and as medium-high. The notably lower incident rate (1) during low-medium workload may just be an artifact of the coding scheme. The high rate of incidents during perceived low and medium workload may be due to ATCOs' stress levels being too low to support mental alertness. The increased number of incidents during high perceived workload could be due to excessive stress, but other factors could also play a role, such as very complex traffic situations or understaffing.

4.3.6 Mental alertness

The figure below illustrates the percentage of incidents ascribed per level of mental alertness.

Figure 4.6

Safety Incidents Ascribed to Mental Alertness



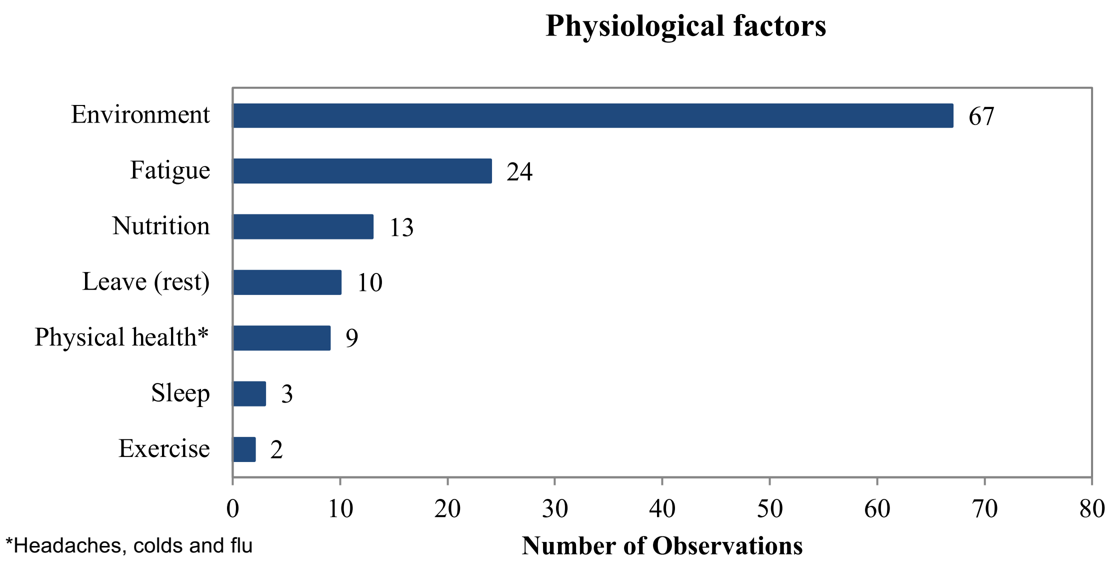
As could be expected, the large majority of safety incidents (94%) occur when ATCOs' mental alertness is lower.

4.3.7 Physiological factors

The figure below illustrates the number of safety incidents ascribed to physiological factors.

Figure 4.7

Safety Incidents Ascribed to Physiological Factors



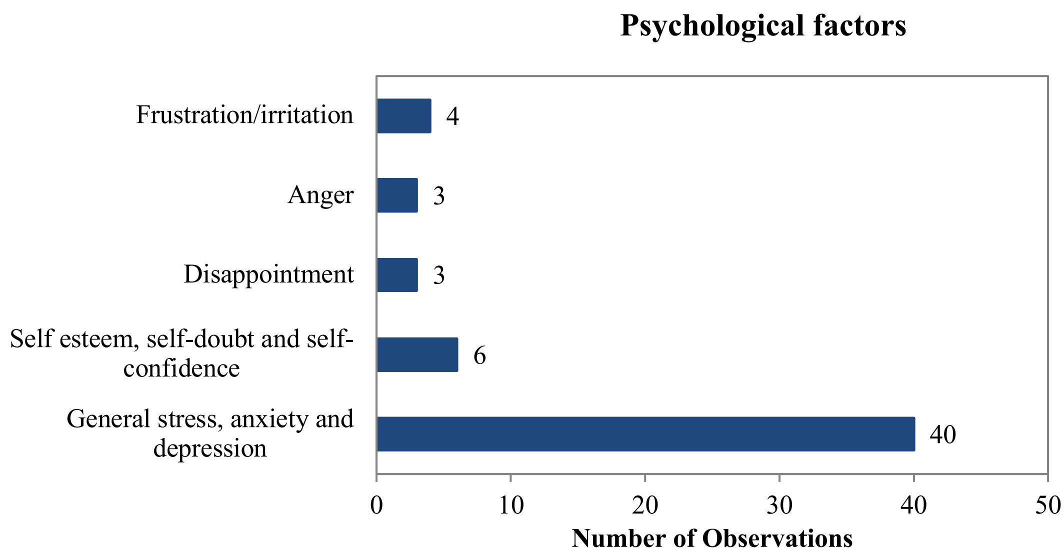
Surprisingly, with regard to physiological factors and environmental factors, i.e. inadequate rest area facilities and an unfavourable ambient temperature accounted for the highest number of safety incidents. Fatigue is the second-highest contributor, with sleep and lack of exercise making the smallest contribution.

4.3.8 Psychological factors

The figure below illustrates the number of safety incidents ascribed to psychological factors.

Figure 4.8

Safety Incidents Ascribed to Psychological Factors



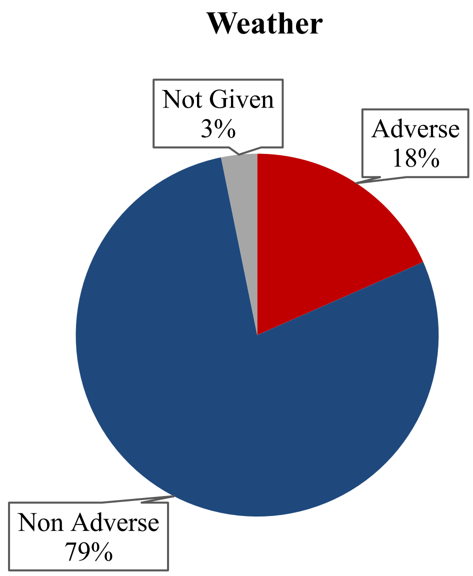
The category *Stress, anxiety, and depression* accounted for the majority of safety incidents, followed by the category *Self-esteem, self-doubt, and self-confidence*; however, the gap between the number of incidents for these two categories is large, evident in the graph above. The three categories *Frustration/irritation*, *Anger*, and *Disappointment* were found to be the least important contributors.

4.3.9 Weather

The figure below illustrates the number of safety incidents according to weather conditions.

Figure 4.9

Number of Safety Incidents According to Weather Conditions



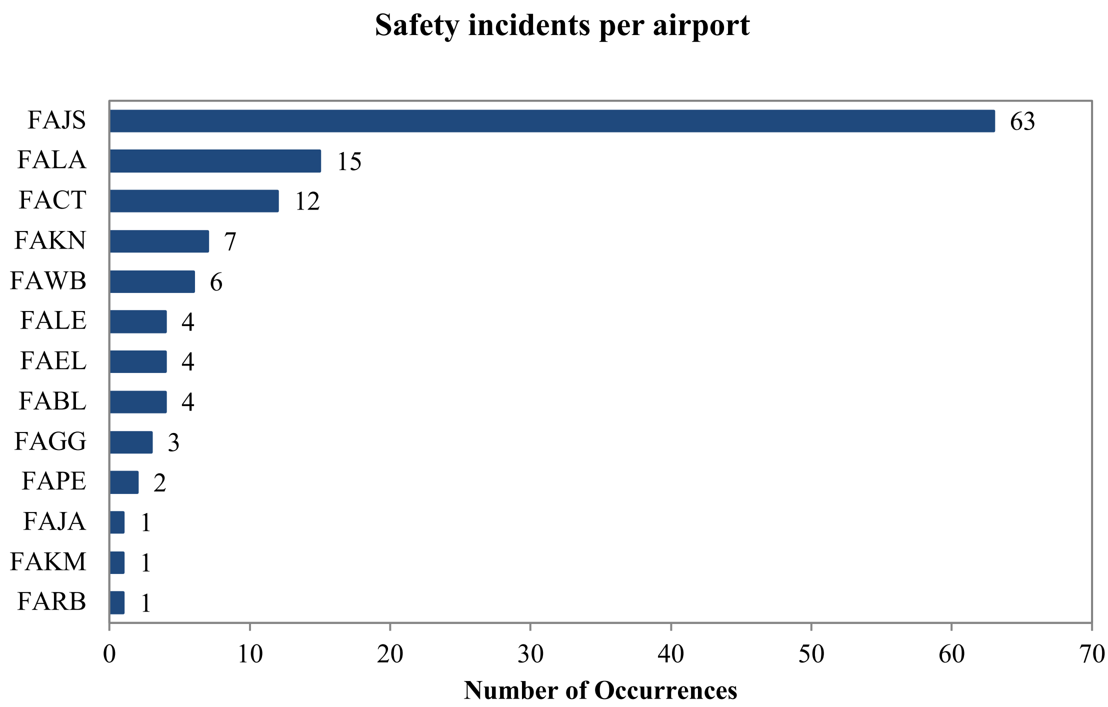
The above pie chart illustrates how weather conditions play a significant role in the occurrence of safety incidents, with by far the most safety events occurring in non-adverse weather conditions. This could be due to ATCOs experiencing lowered stress levels, and therefore lower mental alertness.

4.3.10 Safety incidents per airport

The figure below illustrates the number of safety events per airport under study.

Figure 4.10

Safety Incidents per Airport



Most safety incidents between 2008 and 2012 took place at O R Tambo, followed by Lanseria and Cape Town, with a large gap between O R Tambo and the two latter airports. The lowest number occurred at Richards Bay, and Kimberley. However, the results may have been skewed, as the amount of air traffic at each airport is not available to calculate a relative proportion.

4.3.11 Safety Incidents per Sector

The figure below illustrates the number of safety incidents per sector for all the airports combined.

Figure 4.11

Safety Incidents per Sector

Approach	ATCOs in this sector take over from the tower ATCOs as soon as the aircraft has departed.
Aerodrome	ATCOs in this sector control aircraft from the airport tower. Aircraft ready for take-off are under the control of ATCOs in this sector. Clearance for take-off is issued by ATCOs in this sector. ATCOs in this sector resume control of the aircraft when it has touched down on the runway.
Procedural	ATCOs in these sectors control air traffic without radar.
Area	ATCOs in this sector assume control of the aircraft from the approach ATCOs.
Between sectors	These control sectors are between control areas or between area- and approach sectors, or between approach- and aerodrome sectors.
Not given	Sector in which safety incident took place was not stated in the safety incident report.

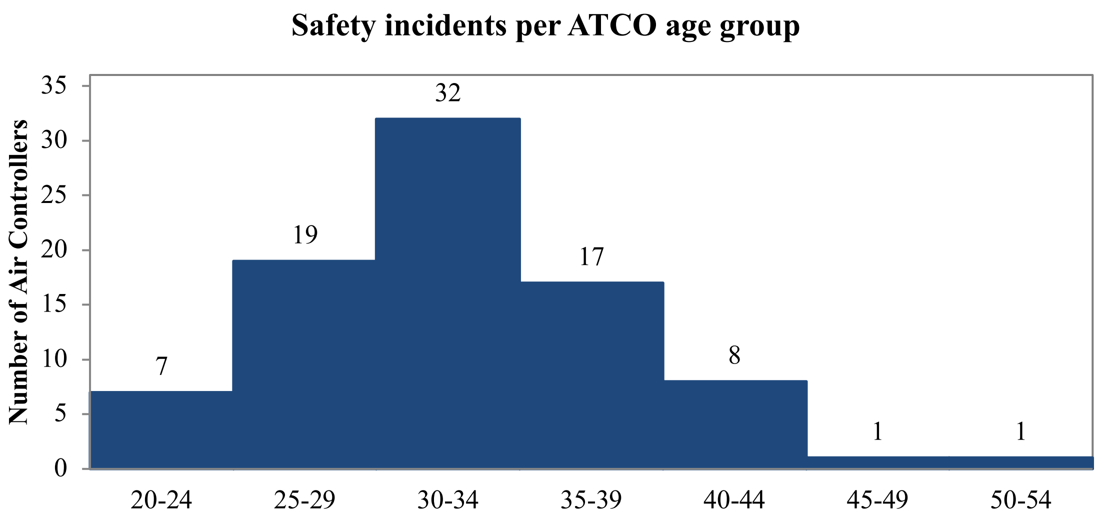
The greatest number of safety events take place in the Approach Sector, followed by the Aerodrome, and then the Procedural Sector. Area and Between Sectors show the fewest safety incidents. Approach is a complex sector, due to aircraft changing altitudes and flight paths. In the Aerodrome Sector, there is a relatively greater risk of loss of separation and runway incursions. Another consideration is that ATCOs in the Aerodrome Sector can control the traffic complexity by keeping aircraft still. Aircraft in the Approach Sector, however, are in flight.

4.3.12 Incidents according to ATCOs' age

The figure below illustrates the number of safety incidents according to ATCOs' age, per age group.

Figure 4.12

Number of Incidents per ATCO Age Group



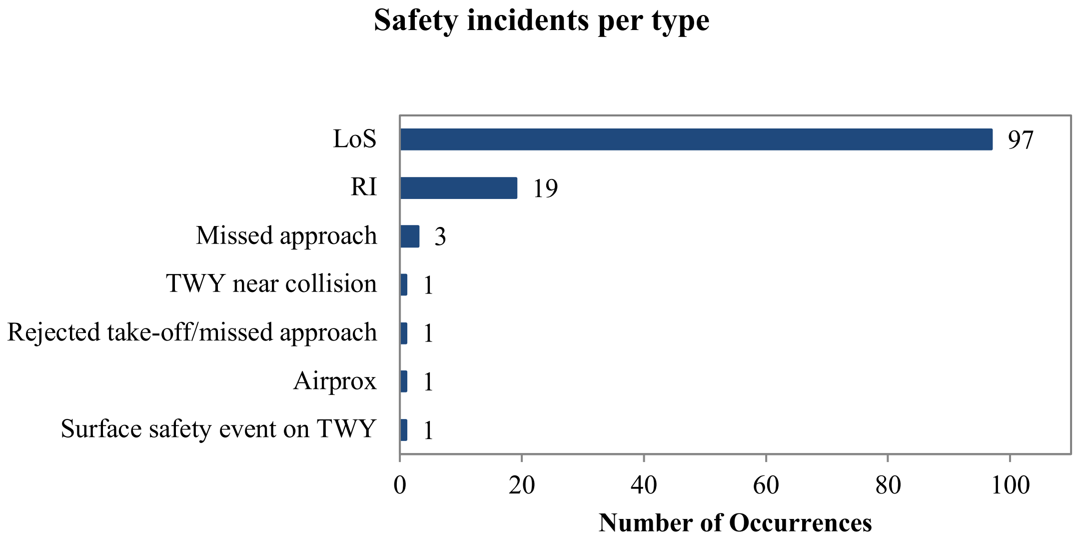
The above figure illustrates that the majority of ATCOs involved in safety incidents were between the ages of 30 and 34, with the fewest incidents occurring for those aged 50 to 54. The average age of ATCOs is in the range of 30 to 40 years. This indicate that older ATCOs are less likely to experience a safety incident, probably related to experience. Age is therefore an important factor in safety in air traffic control. ATNS uses 27 as a cut-off age for candidates selected for the training programme. This would make the oldest first qualified ATCO 30 years old. Younger ATCOs tend to be placed in an Approach position, rather than in an Aerodrome position. There is scant research on the relationship between ATCOs' age and safety. The FAA's the mandatory age for retirement for ATCOs in the USA is 56, while there is no mandatory retirement age in South Africa. Despite this, there are few older ATCOs, i.e. over 45.

4.3.13 Incidents according to type

The figure below illustrates the number of safety incidences per type of incident.

Figure 4.13

Number of Safety Incidents per Type



The research investigated the occurrence of safety incidents per type of incident. Loss of separation is by far the most common safety incident, followed by runway incursions. The occurrence of other types of safety incidents is significantly lower.

4.4 Timing of Safety Incidents

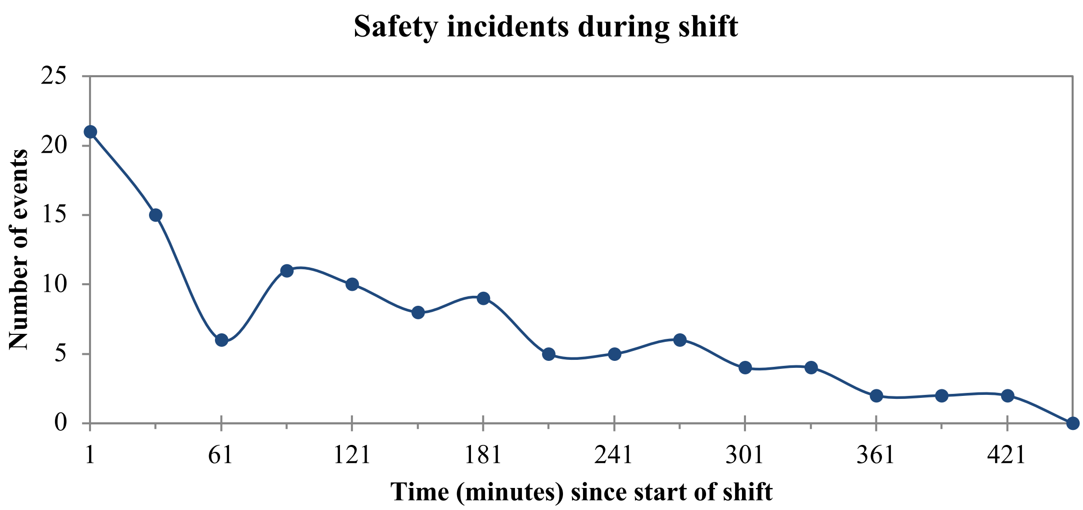
The sections below elucidate the number of safety incidents according to period, i.e. during shift, after ATCOs have taken a break, and from the time of takeover.

4.4.1 Incidents during shift

The figure below illustrates the number of safety events from start to end of ATCOs' shifts.

Figure 4.14

Timing of Safety Incidents during Shift



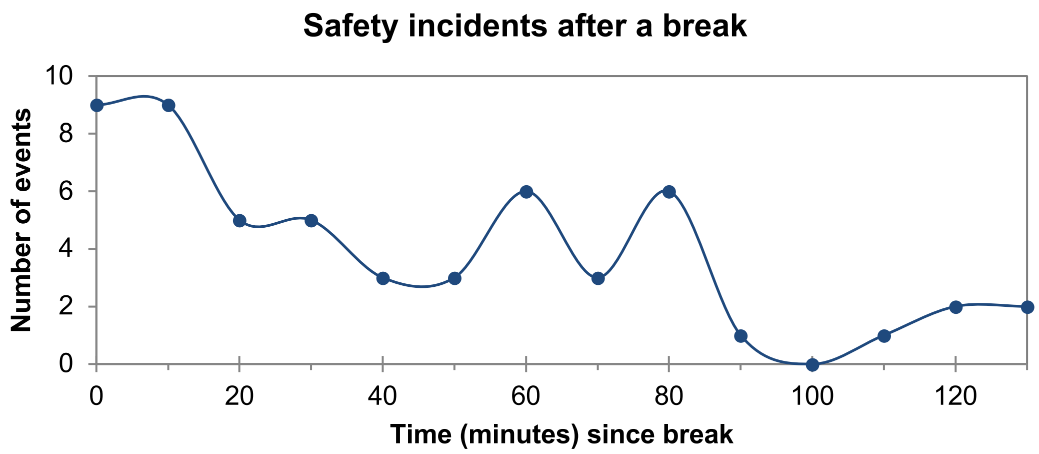
An important result of the research is that most of the safety events take place during the first 30 minutes of ATCOs being on shift. There is a steady decline in incidents up to one hour on shift, whereafter there is again a peak at 90 minutes and three hours. This is followed by a steady downward trend in incidents until end of shift, with only a small peak at the five-hour mark.

4.4.2 Incidents since break

The figure below illustrates the number of incidences and timing after ATCOs have taken a break.

Figure 4.15

Number of Events Since Break



The highest number of safety events took place within the first ten minutes following a break.

4.4.3 Incidents since shift handover

The figure below illustrates the occurrence of safety incidents after shift handover.

Figure 4.16

Number of Events After Shift Handover

The above figure indicates that there is an increase in the number of safety events after takeover. This could be due to fatigue, ATCOs' attention waning in anticipation of ending their shift, or ATCOs being distracted by the arrival and briefing of the ATCO taking over.

In summary, the most significant psychological factors identified are related to the controlling task, either in a direct manner (attention, concentration, decision making, situation awareness, mental alertness, judgement, perception, and memory) or non-direct manner (personal stress, anxiety, habits, and personality factors).

The most significant physiological factors identified in the current study were found to be fatigue, exercise and physical activity, nutrition, and sleep. The finding that safety events tend to occur when traffic load and complexity are highest corresponds with that of the ATNS. The confirmation that there is a pattern of increased safety incidents within the first 30 minutes of an ATCO commencing a shift, the first 30 minutes after an ATCO returns from a break, and the last 30 minutes of an ATCO's shift is supported by the current research.

The above discussions of findings answer *RQ 1: What human factors can be identified from the incident reports as significantly impacting the operational safety of South African ATCOs?*

RO1: Determine whether the pattern of incidents indeed conforms to the ATNS's hypothesis that the first or last 30 minutes of a shift and first 30 minutes after a break are high-risk periods, was therefore achieved.

The next phase of the present study was interviews with ATCOs, using an interview schedule based on the factors examined in Phase 1, in order to assess the impact of mental task engagement, mental workload, and flow on the operational safety of ATCOs. The results of Phase 2 of the research are reported in the next section.

4.5. Phase 2: Interviews on Workload, Mental Task Engagement, and Flow

4.5.1 Introduction

Phase 2 of the research was conducted to answer *RQ2: To what systemic, psychological, and physiological factors do South African ATCOs attribute their safe functioning at work?*

and

RQ3: What is the impact of mental task engagement, mental workload, and the state of flow on the occupational safety of South African Civil ATCOs during the shift-handover process?

The aim was to establish which factors ATCOs consider important, especially those that require attention and are amenable to improvement, on order to ensure high safety performance. Phase 2 commenced with the interviewing of 11 ATCOs. An interview schedule was compiled by the researcher, based on the themes that emerged from the thematic analysis of the safety incident data collected in Phase 1. The interviews with the ATCOs were conducted to gather information on factors that had an influence on ATCOs during the high-risk shift-handover period. Through the process of interviewing the ATCOs, insight was obtained into the ATCOs' cognitive processes during handover that may contribute to their safe operation during the high-risk shift-handover process.

4.5.2 Qualitative themes from interview data

The factors related to safe behaviour that emerged from the interview data collected in Phase 2 were classified into systemic, psychological, and physiological factors, providing a holistic view of what ATCOs consider important, and highlighting areas that require attention. The qualitative themes that emerged from the one-on-one interviews are summarised in the table below, and further detail is provided in Appendix F. The main themes that may be useful in enhancing ATCOs' safety performance, aligned with a Safety-II approach, are discussed, together with a verbatim supporting quotes from the interview transcripts (see Appendix F).

Table 4.2

Summary of Qualitative Themes

Systemic	Psychological	Physiological
Support	Attention	Sufficient rest
Equipment	Flow	Nutrition and hydration
Rostering	Situational awareness	
Management	Mental alertness	
Noise		

4.5.2.1 Systemic factors

Systemic factors that the ATCOs noted as important considerations in preventing the occurrence of safety events are discussed below (also see Appendix F for excerpts from interview transcripts).

Support:

Overall, the ATCOs were very positive about the collegial support they received.

> "At no point are you sitting by yourself … there is always an extra pair of eyes … you always have your colleagues around you if you unsure … have an agreement amongst staff to listen out and look out for each other to avoid any incidents." [ATCO1]

However, a number of ATCOs mentioned the importance of sufficient staff and support structures, especially during periods of high traffic volumes and adverse weather conditions, but also in the form of rostering and company support functions, in order that ATCOs may focus on their tasks. They highlighted the following areas for improvement.

> "Efficiency of your support, your back up, your administrator, things like computer technician, overtime claims, basic human resource factors that were efficient and not something you had to put much effort into making sure happened … you can actually be more focused on the operational job you're meant to do." [ATCO10]

> "We don't have the numbers to fill the positions. It places extra strain on everyone and sometimes you end up working without an assistant for the day." [ATCO11]

"…services that aren't doing their work." [ATCO5]

"…not being placed in positions where you have to work combined sectors or be overloaded with traffic." [ATCO1]

"Busy periods can be stressful, as you need to divide your time or give everyone attention." [ATCO4]

Safety before efficiency:

The ATCOs felt very strongly that safety is their first priority, and then efficiency. One ATCO remarked the following regarding training students:

"…but if you pass him and he is not ready, you have friends flying, and is it really safe?" [ATCO11]

There were also some concerning remarks in this regard.

"Management and colleagues don't share the same beliefs and understandings of this job, occasionally putting efficiency ahead of safety…" [ATCO7]

This ties in with ATCO's relationship with management.

Equipment:

"…systems that are not set up properly … and management blinded that it should have been or should or could be better…" [ATCO5]

ATCOs' emphasised that their equipment has to be of a high quality, user-friendly, and properly maintained. With regard to this theme, a number of concerns were raised.

"If we were able to capture more information on one screen instead of six screens … it would make for a better working environment."

"…proper binoculars … they are in the process of acquiring new ones … better pens … they're cheap, they break … actual strip boards that's made for strips … we use FPS and the new boards they sent us were made for the smaller strips … you make it work. It's not really made for us." [ATCO11]

Radar system: "…so that there is no room for interpretation, e.g., visual approach is being done differently from ATCO to ATCO." [ATCO9]

"…especially when you are relying on the serviceability of the equipment." [ATCO3]

"…unserviceabilities, broken equipment. Printer has been broken for four weeks; you can't print anything … like the weather report so that you can easily access it. Now you go to the computer, look at it, which is far away from your work station, to make decisions based on the weather … it can't be printed out and brought to you, so you have to go to the computer, which is far away from your position, in order to get information you need to do your job…" [ATCO10]

Air traffic control is a highly specialised and technical domain, and it therefore stands to reason that high-quality, fit-for-purpose equipment is essential to ATCOs' safety performance.

Rostering:

ATCOs mentioned the importance of sufficient rest to be able to function optimally, and a number of ATCOs mentioned that they would greatly value better relaxation facilities.

> "…better relaxation facilities." [ATCO3]

ATCOs also emphasised the importance of rostering that would prevent extended work hours and allow them sufficient time to rest and attend to their private life between shifts.

> "We don't have the numbers to fill the positions. It places extra strain on everyone and sometimes you end up working without an assistant for the day." [ATCO11]
>
> "…juggling the attention and needs of the children … not enough time with my kids." [ATCO5]

The ATCOs, however, indicated their satisfaction with scheduling during shifts in terms of being on frequency and taking breaks.

> "Half an hour is just enough to give you that little break and do whatever you need to do. After half an hour, come back and work, you're not totally switched off and have to re-start the process again. After half an hour, you're fine to go again. You're still kind of with the picture." [ATCO11]

Fatigue is a widely recognised as threat to performance, and it would seem that there are issues in this is an area that require attention (Nealley & Gawron, 2015).

Management:

A number of ATCOs noted the importance of a healthy relationship with management, but many noted that their relationship with management was having a negative influence on their performance, using the words "bad attitude" in describing management.

> "…tending to micromanage. It's like being in school… This doesn't work very well with adults." [ATCO1]
>
> "…unnecessary pressure from management … double standards … lack of information regarding operational issues … communication." [ATCO8]
>
> "…management's bad attitude towards you…" [ATCO10]
>
> "…bad attitude, so you can't get hold of them to change an instruction." [ATCO10]
>
> "…management to trust ATCOs more."

Another concern is the lack of guidance from management in the form of procedures.

> "…procedures that are not well written …work procedure design where you need to make another plan to be more efficient and you can save half the time … procedures should be designed to make things flow safe and efficient … often you have to fight against those improper procedures to hopefully make things safer and efficient. That gets frustrating … and you need to work harder to get going." [ATCO5]

From the interview data, it would seem that the relationship between management and ATCOs could be improved.

Environment:

A major safety concern raised was that of the tower layout not being conducive to optimal functioning.

> There is nothing I can change, I just work around it. We have pillars of invisibility; you're working the runway and it runs over here. If you have to look to your right, your final approach path, we have had quite a few incursions. If you look up and you don't see anything because it's behind a pillar. So you need to get up and move around." [ATCO11]

ATCOs mentioned that noise is an intrusive factor while they are performing their duties. A number of sources of noise were mentioned, such as visitors in the tower, other ATCOs who are on break, and loud conversations between ATCOs.

> "People on a break … still in the radar hall. Talking behind you … it's a bit loud … can go through while you are speaking." [ATCO4]

> "A colleague engages you in conversation when you're busy and will talk to you about personal things." [ATCO4]

Clear communication is vital in air traffic control, and it would seem that some disturbances could be addressed in order to enhance ATCOs' safety performance.

Another concern raised regarding the environment was climate control.

> "If there is a big fluctuation … you don't want to be working busy spells while you are shivering with cold or sweating." [ATCO8]

The work environment is an important factor in employees' optimal performance.

4.5.2.2. Psychological factors

The interview process assisted with gaining insight into the ATCOs' cognitive and metacognitive processes that were identified as the most critical psychological human factors.

Passion:

The ATCOs noted the importance of loving what you do, as the job of air traffic control requires dedication.

> "We come and do our jobs with our colleagues mostly … every day is different … it's challenging, it's fun … it's nice to be doing what we do … it's like our job is like a hobby … nice to work with … in general, it's good … everyone is providing and doing what we love doing." [ATCO 4]

The ATCOs interviewed all voiced their passion for and enjoyment of what they do, and noted that this was reflected in team dynamics. This enthusiasm represents a high level of work enjoyment, which would enhance their safety performance, and is an area that does not seem to require attention.

Attention:

A number of ATCOs iterated the importance of focused attention, to every detail, while on duty.

> "…block out what is happening around you." [ATCO9]

> "I pay enough attention … you don't really have a choice …you have to look at what you're doing." [ATCO5]

> "Cleanse your mind of anything worrying you, that is, put aside and focus on the position you taking over … be mentally prepared for the shift and focus just on the ATCO work." [ATCO3]

However, one ATCO did mention not being able to sustain the required attention.

> "Sometimes you're having a bit of a lazy day … you're not absolutely fully focused on … .safety is always there … but perhaps going out of your way to be more efficient … I could have done this better … or I could have saved a fair amount of fuel." [ATCO5]

While the comments around this point are not directly related to safety, but rather efficiency, which may be reflective of the ATCO being highly self-critical, it may be worthwhile to determine whether there are any causes underlying this scenario that could be addressed, such as distractions or fatigue, which may be related to other issues mentioned by the ATCOs. This possibility is supported by comments by other ATCOs during the interviews.

> "…stop the noise and distractions around you…" [ATCO6]

> "…from your radar screen …we have audio cues on the ground radar, but the system is not functioning 100% ... so a lot of the time, these audio cues are cancelled or dismissed without even thinking about it." [ATCO7]

The availability of a non-ATCO available to answer telephone calls could assist ATCOs to remain focused.

Situation awareness:

ATCOs were aware of the importance of situation awareness in maintaining operational safety, and noted that it was an important component of their training programme.

> "…if somebody is having a conversation and something I can add to it, but I'm busy controlling. I finish controlling and I hope they are still there when I'm done. They try and train us to be situationally aware. For me, that means if you are aware of your surroundings, what is happening around you as well as with you, so you pick up all the other stuff as well, not just work stuff." [ATCO9]

Confidence:

The ATCOs noted the importance of having self-confidence in a job with a high level of responsibility. However, their comments in some instances are cause for concern.

> "I subsequently failed my progress check … knock on your confidence … and then you have to come back and you have to do the progress check again … you are a bit apprehensive and fearful, especially since you know that might be your last shift." [ATCO9]

> "In the middle of the shift, if it is very busy and you made a bad decision and it snowballs from there, and then you have to recover … .and if you recover well, it ends up being a good day, and if you recover badly, you're left with a little bit of a down." [ATCO10]

It may be that ATCOs require some support in instances of adverse experiences, to assist them to regain their confidence and return to optimal functioning as soon as possible.

Mental alertness:

The ATCOs noted that it is essential that they reach and maintain optimal levels of mental alertness in order to minimise the risk of safety events.

> "If there is a challenging shift coming up, something out of the ordinary … reflect on it to get mental preparedness … familiarise myself with what is required." [ATCO5]

They were also asked to provide insight into factors that they perceived to impact positively and/or negatively on their levels of mental alertness and/or awareness, and some concerns were raised in this regard.

> "There is a lot of small things we have to do on top of air traffic control, which is paperwork-based … we're expected to do more and more of that type of work, which means you end up doing tons of paperwork that's not in your job description, so that someone else's job becomes easier." [ATCO10]

Some also felt that, sometimes, their shifts are too long and the breaks too short or not sufficient to maintain optimal mental alertness. This again speaks to the systemic factor of rostering that should enable ATCOs to get sufficient rest.

4.5.2.3 Physiological Factors

Physiological factors (see Table 11 in Appendix F) were identified from the interview process with the ATCOs that promote occupational safety, i.e. things going right (Safety-II) during the high-risk shift handover process.

Sufficient rest:

ATCOs noted the importance of sufficient rest, especially sleep in order to perform optimally.

> "It's quite mentally draining when you are on shift…" [ATCO9]

While this is to a great extent a personal responsibility, it again ties in with rostering that may make it difficult for ATCOs to get the necessary rest and take sufficient rest breaks and leave.

> "If you're busy or tired, then you look at the time and think of break." [ATCO5]

A tired ATCO's mental alertness will wane, causing a greater likelihood of a safety incident occurring.

Nutrition and hydration:

Adequate nutrition and hydration are noteworthy contributing factors to operational performance, and therefore have the potential to impact on ensuring the promotion of operational safety.

While ATCOs recognised the importance of proper nutrition and hydration to perform optimally, it was evident from the interviews that many have poor nutritional habits, ranging from skipping breakfast to not eating regularly, or not at all, and consuming convenience foods while on duty. ATCOs commented that they were not able to access nutritional food and healthy drinks while on shift, as there were no canteen facilities. This seemed to be especially problematic for ATCOs working on the morning shift, who may find it difficult to prepare a meal to take to work. They noted that they would greatly value the availability of nutritional food on the premises.

> "…regular, proper, healthy food." [ATCO6]

> "easier access … if you want to buy food…"

"[tea and coffee] we already drink too much." [ATCO8]

Flow:

As noted earlier, *flow*, in the present study is defined as a state of absorption, enjoyment, and intrinsic motivation. The dimensions of flow were evident in a number of comments made by ATCOs during the interviews.

… you can actually be more focused on the operational job you're meant to do." [ATCO10]

"put in one hundred and ten percent and provide the best possible service to anybody that calls on my frequency" [ATCO6]

"We come and do our jobs with our colleagues mostly … every day is different … it's challenging, it's fun … it's nice to be doing what we do … it's like our job is like a hobby … nice to work with … in general, it's good … everyone is providing and doing what we love doing." [ATCO 4]

"It is a lot of fun when you come to work." [ATCO9]

"I consider myself one of those ATCOs that's always in control … and is able to keep up with the traffic, no matter how busy it gets." [ATCO7]

"…pays attention to every detail." [ATCO5]

"…constantly be switched on … you have to be focused … whether you have one aircraft or 10 or 15 on your radar screen." [ATCO1]

"…having to be responsible and stay focused on what is happening around you." [ATCO1]

"you have to tell yourself … do your work … getting the right mental state." [ATCO5]

"Just focus on what you are doing, concentrate … not dwell on distractions such as air conditioning" [ATCO8]

"…and you need to work harder to get going." [ATCO5]

"In the middle of the shift, if it is very busy and you made a bad decision and it snowballs from there, and then you have to recover … .and if you recover well, it ends up being a good day, and if you recover badly, you're left with a little bit of a down." [ATCO10]

From the analyses of the interview data, it is evident that the ATCOs consider flow (absorption, enjoyment, and intrinsic motivation) critical to their safety performance. Certain factors are evidently promoting flow, such as positive team dynamics. The ATCOs work well with one another, without conflict, and they enjoy their jobs. It is, however, cause for concern that a number of ATCOs mentioned the factors discussed earlier as inhibiting their ability to achieve flow. In order to promote ATCOs' achievement of a state of flow, thereby promoting what goes right (SAFETY-II), these factors require urgent attention.

4.6 Quantitative analysis: Workload, Flow, and Mental Task Engagement Questionnaires

4.6.1 Introduction

Quantitative data were collected during Phase 2 in order to assess ATCOs' workload (via the NASA-TLX), flow (via the WOLF scale) and mental task engagement (via the SSSQ) on their day-to-day functioning. The results of Phase 2 differ from those of Phase 1, as the results of Phase 2 are based on ATCOs' perspectives.

4.6.2 Workload

The NASA-TLX provided an overall *Workload* score per respondent, based on a weighted average of ratings on six subscales: Mental Demand, Physical Demand, Temporal Demand, Own Performance, Effort, and Frustration. The degree to which each of these six factors contributed to the ATCO's workload was assessed.

The sample size (*n* = 11) was too small for statistical analysis, which negatively affects generalisability of the results to the broader ATCO population. The table below reports the means, standard deviations, and variances for each of the six subscales for descriptive purposes only. Box plot and whisker graphs are included in Appendix K, indicating overall scores, scale data, workload data, and weighted workload data.

Table 4.3

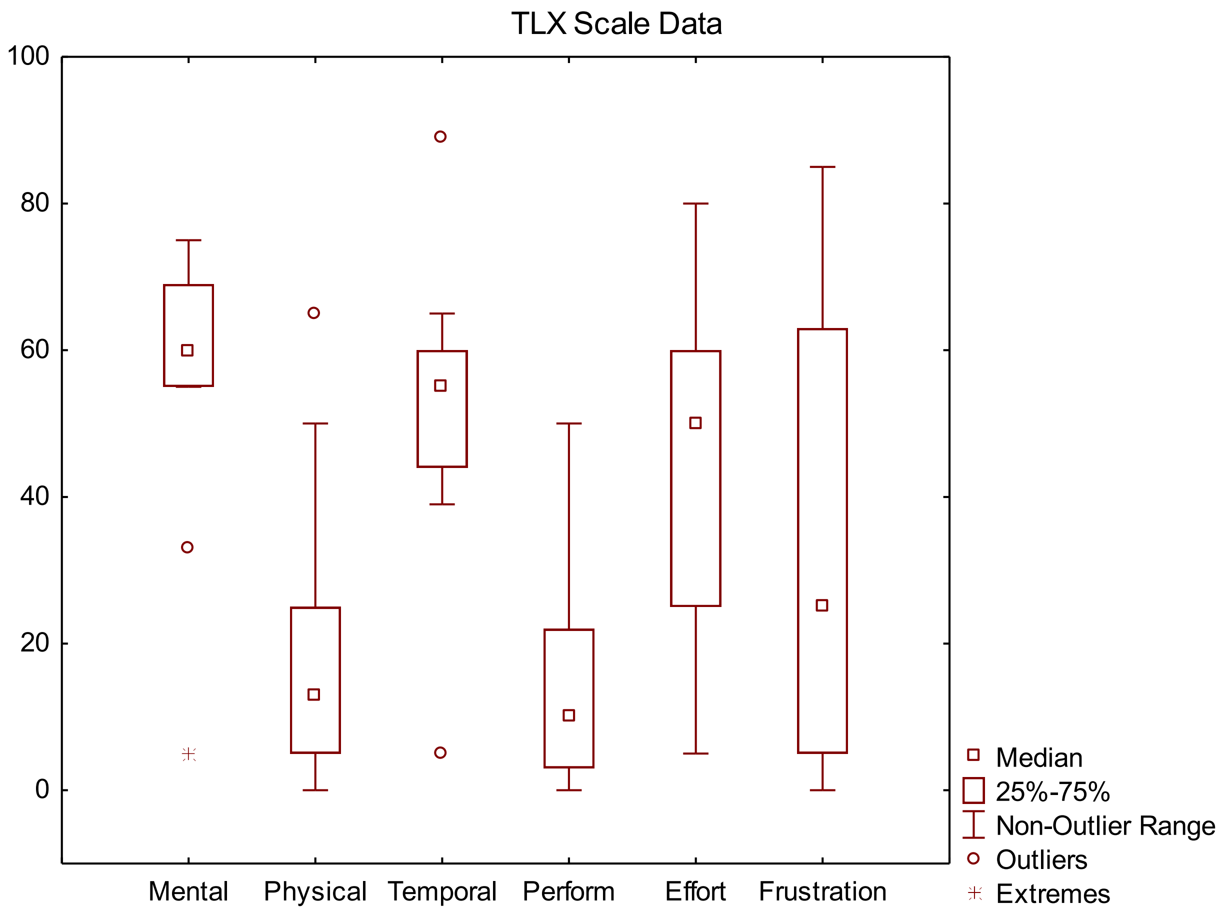
Results of NASA-TLX

Variable	Valid N	Mean	StdDev	Var	Min	Q1	Median	Q3	Max
TLX Score	11	42.74	17.31	299.70	2.99	38.33	39.93	48.34	69.66
Scale									
Mental	11	55.18	20.07	402.76	5.00	55.00	60.00	69.00	75.00
Physical	11	18.64	20.69	428.05	0.00	5.00	13.00	25.00	65.00
Temporal	11	52.64	20.35	414.25	5.00	44.00	55.00	60.00	89.00
Perform	11	14.00	14.17	200.80	0.00	3.00	10.00	22.00	50.00
Effort	11	45.36	22.17	491.65	5.00	25.00	50.00	60.00	80.00
Frustration	11	35.55	31.77	1009.47	0.00	5.00	25.00	63.00	85.00
Workload									
Mental	11	0.25	0.09	0.01	0.07	0.20	0.27	0.33	0.33
Physical	10	0.05	0.07	0.00	0.00	0.00	0.04	0.07	0.20
Temporal	11	0.19	0.06	0.00	0.07	0.13	0.20	0.27	0.27
Perform	10	0.26	0.07	0.01	0.13	0.27	0.27	0.33	0.33
Effort	11	0.16	0.08	0.01	0.07	0.07	0.20	0.20	0.27
Frustration	9	0.10	0.12	0.02	0.00	0.00	0.07	0.13	0.33
Workload Weighted									
Mental	11	14.26	7.92	62.80	1.33	8.00	18.67	20.00	23.00
Physical	11	1.72	3.06	9.39	0.00	0.00	0.00	2.00	10.00
Temporal	11	10.22	5.48	30.04	1.00	6.80	11.00	16.00	17.80
Perform	11	3.14	2.41	5.80	0.00	0.80	3.33	5.87	6.67
Effort	11	8.02	6.44	41.45	0.33	3.33	5.00	13.20	21.33
Frustration	11	5.38	9.25	85.57	0.00	0.00	0.00	8.40	24.00

The results indicate that ATCOs' workload is primarily mental, with very little physical exertion.

Figure 4.17

NASA-TLX Scale Data



The TLX scale data show that the Mental Demand subscale showed a mean of 55.18, a standard deviation of 20.07, and a variance of 402.76. With regard to the Physical Demand subscale, a mean of 18.64, a standard deviation of 20.69, and a variance of 428.05 were obtained. With regard to the Temporal Demand subscale, a mean of 52.64, a standard deviation of 20.35, and a variance of 414.25 were obtained. The Own Performance subscale had a mean of 14.00, a standard deviation of 14.17, and a variance of 200.80. The Effort subscale showed a mean of 45.36, a standard deviation of 22.17, and a variance of 491.65. With regard to the Frustration subscale, a mean of 35.55, a standard deviation of 31.77, and a variance of 1009.47 were obtained.

4.6.3 Flow

The WOLF Scale measured flow at work, which is defined as a short-term peak experience characterised by absorption, work enjoyment, and intrinsic work motivation. A summary of the results for *Absorption*, *Work enjoyment*, and *Intrinsic motivation* obtained is shown in the table below. The subsequent tables detail the results per dimension.

Table 4.4

Results of WOLF Scale: Summary

Mean = 16.05; Standard deviation = 2.49; Valid *n*:11

Cronbach alpha: 0.6571; Standardised alpha: 0.7397

Average inter-item correlation: 0.5406

	Value of statistic if item deleted					
	Mean	Variance	Standard deviation	Item total correlation	Squared Multiple R	Alpha
Absorption	11.26	2.8617	1.69	0.31	0.18	0.82
Work enjoyment	9.76	3.4413	1.86	0.76	0.71	0.39
Intrinsic work motivation	11.09	2.5145	1.59	0.52	0.67	0.49

Table 4.5

Results of WOLF Scale: Absorption

Mean = 19.18; Standard deviation = 5.12; Valid *n*:11

Cronbach alpha: 0.6366; Standardised alpha: 0.6561

Average inter-item correlation: 0.4178

	Value of statistic if item deleted					
	Mean	Variance	Standard deviation	Item total correlation	Squared Multiple R	Alpha
When I am working, I think about nothing else	14.64	19.1405	4.37	0.06	0.08	0.82
I get carried away at work	14.55	16.0661	4.01	0.40	0.31	0.58
When working, I forget everything around me	14.64	10.2314	3.20	0.74	0.88	0.27
I am totally immersed in my work	13.73	14.5620	3.82	0.65	0.86	0.43

The Absorption subscale had a mean of 19.18 and a standard deviation of 5.12. The Cronbach alpha of 0.64 shows that the scale was unlikely to be internally consistent; however, it has to be borne in mind that the sample size was very small. A standardised alpha of 0.66 was obtained, while the average inter-item correlation was 0.42. Data collected using the WOLF Absorption sub-scale fell short of being statistically useful.

Table 4.6

WOLF Scale: Work Enjoyment

Mean = 25.18; Standard deviation = 2.68; Valid *n*: 11

Cronbach alpha: 0.9137; Standardised alpha: 0.9337

Average inter-item correlation: 0.7977

	Value of statistic if item deleted					
	Mean	Variance	Standard deviation	Item total correlation	Squared Multiple R	Alpha
My work gives me a good feeling	18.55	4.6116	2.15	0.81	0.85	0.91
I do my work with a lot of enjoyment	18.64	3.8678	1.97	0.86	0.88	0.87
I feel happy during my work	19.00	3.6364	1.91	0.87	0.79	0.87
I feel cheerful when I am working	19.36	2.9587	1.72	0.83	0.78	0.91

The Work Enjoyment subscale had a mean of 25.18 and a standard deviation of 2.68. A Cronbach alpha of 0.91 indicates that the subscale was internally consistent. A standardised alpha of 0.93 was obtained, while the average inter-item correlation was 0.80. This shows that the ATCOs have a high level of work enjoyment, which contributes to flow.

Table 4.7

WOLF Scale: Intrinsic Work Motivation

Mean = 24.82; Standard deviation = 5.93; Valid *n*: 11

Cronbach alpha: 0.7795; Standardised alpha: 0.8058

Average inter-item correlation: 0.4744

	Value of statistic if item deleted					
	Mean	Variance	Standard deviation	Item total correlation	Squared Multiple R	Alpha
Received less pay	19.82	20.3306	4.51	0.60	0.59	0.72
Received less pay I find that I also want to work in my free time	22.00	17.2727	4.16	0.58	0.54	0.75
Received less pay I work because i enjoy it	18.64	24.0496	4.90	0.61	0.70	0.73
Received less pay when I am working on something, I am doing it for myself	19.73	21.1074	4.59	0.59	0.62	0.73
Received less pay I get my motivation from the work itself and not from the reward of it	19.09	25.1736	5.02	0.54	0.50	0.75

The Intrinsic Work Motivation subscale had a mean of 24.82 and a standard deviation of 5.93. The Cronbach alpha of 0.78 indicated that the subscale was internally consistent. A standardised alpha of 0.81 was obtained, while the average inter-item correlation was 0.47.

This indicates that the ATCOs had a high level of intrinsic work motivation.

Overall, the items on the WOLF Scale did not show sufficient internal consistency and reliability. There are possible explanations: the scale cannot measure overall flow, as it did not demonstrate sufficiently good psychometric properties; the ATCO's could not relate to the concept of flow (specifically absorption) in their work; or the sample was too small.

In summary, the results from the NASA-TLX showed that the ATCOs' workload is primarily mental. Overall flow could not be accurately assessed; however, the results showed that the ATCOs had a high level of work enjoyment and intrinsic work motivation.

The next section reports on the results of the Phase 3 of the study, which consisted of interventions to enhance ATCOs' performance.

4.7 Phase 3: Intervention study

4.7.1 Introduction

Phase 3 of the research was conducted to answer *RQ3: Does a music or mindfulness intervention improve flow and mental task engagement, i.e. work performance, of South African civil ATCOs?*

Due to the fact that flow could not be measured in Phase 2 of the research, it was decided to measure the ATCOs' mental task engagement in Phase 3, using the SSSQ prior to and subsequent to an intervention in the form of a music or a mindfulness intervention. The intervention was the final phase of this research. The intervention study was intended to be exploratory, rather than definitive.

As explained in detail in Chapter 3, the 15 ATCOs who had volunteered to participate were randomly and equally divided into three groups: one group for the music intervention, one for the mindfulness intervention, and a control group, which would partake in neither. The ATCOs in all three groups wore a Fitbit Charge HR on the wrist of their non-dominant hand, to enable the researcher to monitor their heart rate at one-minute intervals for 20 minutes. The music and mindfulness interventions were administered for ten minutes, whereafter the ATCOs were given the SSSQ-Pre questionnaire to complete. They then commenced their shifts. Upon completion of their shift, they completed the SSSQ-Post.

The next section provides a brief overview of the SSSQ, followed a by the results.

4.7.2 Mental task engagement

The SSSQ was used to measure the ATCOs self-reported stress state during the performance of their tasks. Three primary stress states were measured: motivation, affect, and cognition. The SSSQ may also be useful in assessing subjective state reactions to task manipulations.

Average heart rate for each group was calculated at each stage of Phase 3: during the intervention, after completion of the SSSQ-Pre and SSSQ- Post questionnaires, as well as while performing their work tasks.

The results of measuring ATCOs' heart rate are reported in the next section. The table below reports the average heart rate for all three groups during task performance, while the two subsequent figures report their heart rates after the interventions. The illustrated results are then discussed.

4.7.3 Average heart rate

Table 4.8

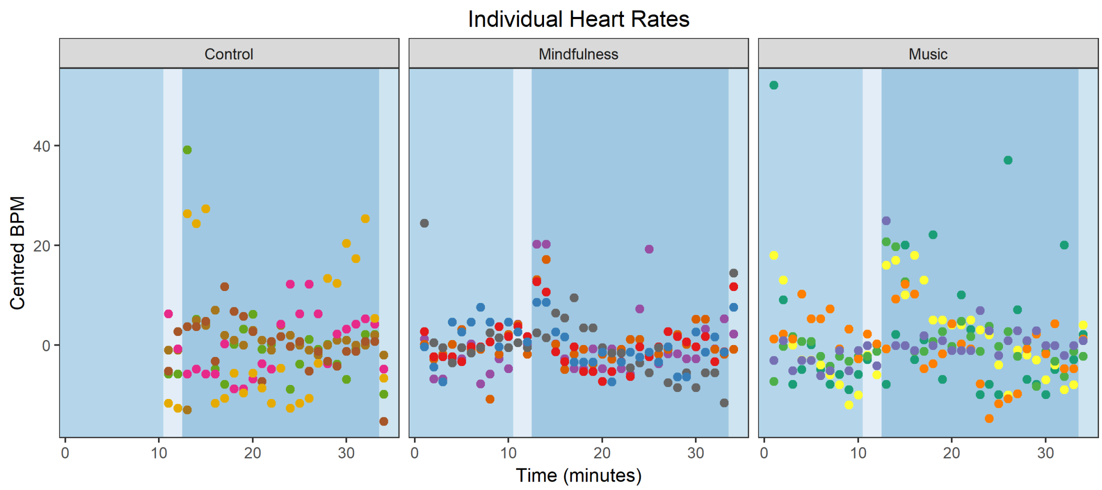
Average Heart Rate While Completing SSSQ and Controlling

			Five-minute interval of active controlling			
Group/Individual	**Intervention**	**Pre questionnaire**	**First**	**Second**	**Third**	**Last**
Control	**NA**	**74.38**	**81.72**	**75.80**	**77.44**	**81.64**
Control 1	NA	90.33	81.40	79.20	94.00	89.60
Control 2	NA	65.33	77.00	71.60	68.20	68.40
Control 3	NA	58.00	79.80	60.40	60.00	84.80
Control 4	NA	77.00	80.00	79.80	79.60	80.20
Control 5	NA	86.67	90.40	88.00	85.40	85.20
Mindfulness	**71.64**	**72.15**	**76.72**	**69.24**	**71.00**	**70.60**
Mindfulness 1	75.50	76.33	81.60	74.80	76.40	78.40
Mindfulness 2	70.70	67.67	73.60	69.20	64.20	61.20
Mindfulness 3	67.10	70.00	71.00	62.00	66.00	66.80
Mindfulness 4	84.00	84.00	86.00	78.60	80.60	81.40
Mindfulness 5	60.90	66.00	71.40	61.60	67.80	65.20
Music	**81.04**	**78.21**	**88.96**	**83.64**	**80.04**	**78.64**
Music 1	65.40	59.50	66.40	69.40	67.20	62.20
Music 2	73.90	75.00	82.20	76.60	79.40	77.20
Music 3	75.40	76.33	87.40	79.20	77.80	73.20
Music 4	109.00	106.67	111.00	105.40	94.80	104.80
Music 5	81.50	79.00	97.80	87.60	81.00	75.80
Overall average	**76.34**	**74.95**	**82.47**	**76.23**	**76.16**	**76.96**

The figure below illustrates individual ATCOs' average heart rate before and after the intervention. The start of their shift is indicated by the white bar at the ten-minute mark.

Figure 4.18

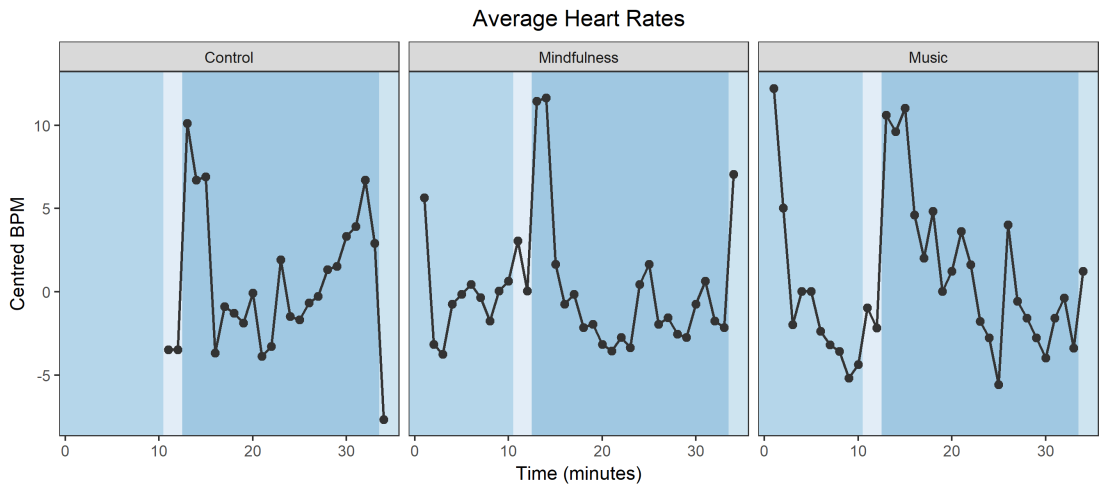
Individual Heart Rates from Start of Shift



The figure below illustrates the average heart rate of all the ATCOs before and after the intervention.

Figure 4.19

Average Heart Rate from Start of Shift



Average heart rate measured during completion of the SSSQ-Pre reflects the ATCOs' average normal heart rate during a seated activity, as the ATCOs were performing a minor physical activity and were therefore not totally at rest. Overall, it can be seen that, for all three groups, the average heart rate elevated as soon as the ATCOs commenced their shift. Although average heart rate decreased at times for some ATCOs during the task of controlling, it remained elevated overall, for the duration of the task of controlling. The ATCOs in the control group and the Music group showed significantly more scattered distributions during the control task in comparison to the ATCOs in the Mindfulness group.

When considering average heart rate within each group during the intervention phase, overall, the ATCOs in the Mindfulness group were relaxed, as the average heart rate decreased across the ten-minute intervention. This indicates that the mindfulness activity calmed the ATCOs. Although the average heart rate was seen to elevate as soon as they went on shift, it then decreased, remaining lowered during the first 20 minutes of controlling. The Music group's average heart rate was higher, and tended to be erratic over the first 20 minutes of controlling. It would therefore seem that music slightly elevated their average heart rate. The average heart rate in the control group tended to increase over the first 20 minutes of controlling.

4.7.4 SSSQ Individual Scale Items

A summary of the data from the SSSQ items is presented in the table below, together with a summary of the trends noted across individual scale items. Results for individual SSSQ items are presented in Appendix G.

Table 4.9

Summary of SSSQ Results

	Mindfulness		Music		Control		Overall	
Item	**Before**	**After**	**Before**	**After**	**Before**	**After**	**Before**	**After**
Dissatisfied	1.00	1.00	2.80	2.00	1.80	2.00	1.87	1.67
Alert	3.20	4.00	4.20	4.60	3.00	3.80	3.47	4.13
Depressed	1.40	1.40	1.00	1.00	1.00	1.00	1.13	1.13
Sad	1.20	1.20	1.40	1.00	1.20	1.00	1.27	1.07
Active	1.80	2.20	3.20	3.20	3.00	3.40	2.67	2.93
Impatient	1.20	1.80	2.40	1.40	2.80	1.60	2.13	1.60
Annoyed	1.20	1.60	2.80	2.40	1.80	1.80	1.93	1.93
Angry	1.00	1.00	2.40	1.20	1.40	1.20	1.60	1.13
Irritated	1.20	1.40	2.60	1.40	1.60	1.40	1.80	1.40
Grouchy	1.20	1.40	1.40	1.00	2.20	1.20	1.60	1.20
I am committed to attaining my performance goals.	3.60	4.60	4.60	5.00	4.20	4.40	4.13	4.67
I want to succeed on the task.	4.00	4.60	4.60	5.00	4.40	4.40	4.33	4.67
I am motivated to do the task.	3.60	4.20	3.80	5.00	4.40	3.80	3.93	4.33
I'm trying to figure myself out.	2.20	1.00	1.60	2.00	2.00	1.60	1.93	1.53
I'm reflecting about myself.	2.80	1.00	2.60	1.40	1.80	1.60	2.40	1.33
I'm daydreaming about myself.	2.40	1.00	1.80	1.60	1.80	1.60	2.00	1.40
I feel confident about my abilities.	4.00	4.50	4.40	4.00	4.60	4.60	4.33	4.36

I feel self–conscious.	1.60	1.00	2.20	1.40	1.60	1.80	1.80	1.40
I am worried about what other people think of me.	1.60	1.20	1.60	1.40	1.60	1.60	1.60	1.40
I feel concerned about the impression I am making.	1.40	1.60	2.20	1.80	2.00	2.00	1.87	1.80
I expect to perform proficiently on this task.	3.20	4.20	4.00	4.60	4.40	4.40	3.87	4.40
Generally, I feel in control of things.	3.00	4.40	4.20	4.80	4.40	4.60	3.87	4.60
I thought about how others have done on this task.	2.20	1.40	2.60	1.60	2.40	1.80	2.40	1.60
I thought about how I would feel if I were told how I performed.	2.00	1.20	2.40	1.40	1.60	1.40	2.00	1.33

In summary, 24 SSSQ scale items were considered across each group, to detect trends.

Six scale items demonstrated a consistent improvement across all three groups. Three positively phrased items showed a trend of heightening in ATCOs: *Feeling alert*; *I am committed to attaining my performance goals*; *Generally, I feel in control of things*; and three negative phrased items showed a trend of lowering in ATCOs: *I'm daydreaming about myself*; *I thought about how others have done on this task* (this trend was greater in the Music and Mindfulness groups); and *I thought about how I would feel if I were told how I performed* (this trend was greater in the Music and Mindfulness groups). For one item, *Feeling depressed*, no change was noted in the ATCOs across all three groups.

Both the Mindfulness and Music groups showed improvement with regard to the following items: *I want to succeed on the task*; *I am motivated to do the task*; and I expect to perform proficiently on this task.

Overall, the interventions had a positive effect on ATCOs' alertness and confidence, and lessened their self-consciousness and stress. The music intervention led to greater mental arousal, while the mindfulness intervention had a calming effect.

4.8 Chapter Summary

In conclusion, the results chapter presented the outcomes of all three phases of the research and the answers to the research questions.

The outcomes of Phase 1 confirmed the findings of the ATNS that the highest incidence of safety events occur within the first 30 minutes on shift, after a break, and towards the end of shift, i.e. during the high-risk shift-handover period.

The outcomes of Phase 2 were detailed with regard to the systemic, psychological, and physiological factors to which South African civil ATCOs attribute to their safe functioning, as well as factors that inhibit optimal performance. The results pertaining to RQ3: *What is the impact of mental task engagement, the state of flow, and mental workload on the occupational safety of South African civil ATCOs during the shift hand-over process?* cannot be generalised, as the sample was too small and flow could not be adequately measured.

The outcomes of Phase 3, the intervention, showed that both the music and mindfulness intervention positively impacted the ATCOs mental arousal, and can be used to enhance their mental alertness.

The next chapter provides a discussion of the results, together with recommendations for practice and future research. This is followed by an overview of the limitations of the present study and its contribution within the local South African and the broader international academic context.

CHAPTER 5: DISCUSSION

5.1 Introduction

This chapter provides a summary of the key findings of the current research, the conclusions drawn from the research data, and the significance of the research, together with recommendations for researchers and practitioners within the aviation industry. In the discussion, the significance of the findings is highlighted and interpreted by considering what is already known about, as well as new insights into, the research problem being investigated, namely human factors to which human error is attributable in safety incidents. The discussion includes both the Safety-I and Safety-II perspective. New insights that emerged from the research study are summarised, with particular emphasis on interventions that may optimise mental alertness and flow during shift handover, in order to facilitate the enhancement of the operational safety of civilian ATCOs.

The overall aim of the current research was to improve operational safety in air traffic control. The research formed part of a project to examine mental alertness carried out by ATNS. ATNS had identified a pattern of an increase in the number of safety events occurring within the first 30 minutes of ATCOs commencing shift, including returning from a break, as well as the last 30 minutes of shift, i.e. the high-risk shift-handover period. A gap in research was recognised, as identified by ATNS, providing the rationale for the researcher setting out to identify key human factors contributing to the identified pattern of increased safety events.

There is gap in the literature on this domain with regard to civil South African ATCOs, which led to the first South African Symposium on Human Factors and Aviation in January 2014, followed by the second African Symposium on Human Factors and Aviation Safety (ASHFAS) in September 2015, a third one in September 2017, and another in August 2019. Leading South African and international experts in the field of human factors and aviation safety attended and presented at the symposia, where research into South African ATCOs was encouraged. This provided the rationale for the present research.

Modern complex systems, such as air traffic control, place cognitive demands on the human operators (Wilson & Russell, 2003). If an operator is in a state of cognitive overload, the probability of making an error increases. As levels of automation become more sophisticated, a human operator's situation awareness may be negatively affected, due to complacency. Performance deteriorates, and the likelihood of error increases (Wilson & Russell, 2003).

Per Elo, Kääriäinen, Kanste, Pölkki, Utriainen, and Kyngäs (2014), the researcher considered the trustworthiness of the qualitative data by examining factors such as conformability (objectivity of the data, such as accuracy, relevance, and that meaning can be duplicated by an independent researcher), credibility (participants are described and identified accurately), transferability (the data can be extrapolated, i.e. generalised to other settings and/or groups), authenticity (a range of realities is established), and dependability (data are stable over time and under different conditions). Elo et al.'s (2014) checklist was referred to, in order to assess the trustworthiness of the qualitative data at the preparation, organisation, and the reporting stages of the research. For example, the researcher established thematic content analysis to be the best method to answer the research questions, the criteria of using volunteers only (excluding students), and a sample size of 11 to ensure data saturation. The trustworthiness of thematic content analysis requires the availability of appropriate and well-saturated data. Precise details of sampling methods and a description of participants were provided to enhance the trustworthiness, and the data are reported in an understandable manner.
This discussion evaluates the results obtained for each research question, in order to convey a deeper understanding of and insight into the human factors that contribute to human error leading to safety events. Recommendations with regard to how safety incidents could be minimised are made, with a theoretical understanding of the results woven into the discussion.

5.2 Phase 1

The assumption was made by ATNS, based on a preliminary analysis of incident reports, that the majority of safety incidents happen 30 minutes after ATCOs going on shift (including returning from a break) and the last 30 minutes of their shift. This preliminary analysis suggested that shift handover was a high-risk period of an ATCO's shift. The current research is similar to that of Pape, Wiegmann, and Shappell (2001), who examined air traffic control-related accidents and incidents over a 13-year period. The aim of Pape et al.'s (2001) research was to determine the operational conditions under which such events occur and the frequency with which different ATCOs are involved.

Phase 1 sought to verify ATNS's preliminary analysis by analysing more incident reports to establish whether shift handover was indeed a high-risk period. Safety incident reports were therefore analysed in Phase 1 to, firstly, verify whether this finding by ATNS was accurate.

Data were collected during Phase 1 by reviewing 123 safety incident reports. The analysis confirmed the findings of the preliminary study by the ATNS. Therefore, *RO1: Determine* *whether the pattern of incidents indeed conforms to the ATNS's hypothesis that the first or last 30 minutes of a shift and first 30 minutes after a break are high-risk periods*, was achieved.

In the second stage of Phase 1, the aim was identify whether any other factors are deserving of consideration in explaining the when, why, and who of safety incidents during the identified high-risk periods. The researcher first considered the data from Hollnagel et al.'s (2015) Safety-I perspective, whereby the most significant human factors trends contributing to the occurrence of safety incidents (i.e. a negative outcome) were identified after the safety incident had already taken place, in order to explain how and why the errors occurred. The researcher also reviewed the literature on human factors that could play a role in the safety operations of ATCOs.

The most critical human factors that were identified from the analysis of the safety incident reports as having an impact on operational safety of ATCOs from a Safety-I perspective were mental task engagement, mental workload, and situation awareness. Of significance is the theoretical overlap between the constructs. Reduced mental alertness was found to be the biggest contributor to safety events (see Figure 4.6). Psychology has shifted towards a consideration of positive cognitive constructs, which include mental task engagement and mental workload. These cognitive constructs are important components of situation awareness. ATCOs need to acquire and maintain good situation awareness to ensure operational safety. Reason (1990) considered the benefits of relying on cognitive science to improve the understanding of issues associated with situation awareness. Human error will occur when ATCOs fail to evaluate an operational situation correctly. Human factors trends identified in the research impact in some way on the situation awareness of ATCOs.

Although flow was not identified in the safety incident reports, it was recognised from the literature as possibly an important construct contributing to safety, through mental alertness. Cognitive factors were identified from the analysis of the safety incident reports as contributing to safety events. Poor decision-making, perception, and planning contributed the most to the occurrence of safety events (see Figure 4.4). Additional cognitive factors emerged from the analysis of the safety incident report, e.g., poor attention, diminished concentration, information overload, poor short-term memory, and faulty judgment and thought processes (see Table 4.1).

Eurocontrol (2010) notes the importance of human performance in safety, and confirmed Reason's (1990) emphasis on the cognitive aspect of an ATCO's work. The current research found that cognitive psychological factors play a significant role during the high-risk shift-handover period, in line with the findings of Eurocontrol (2010) and Reason (1990). These activities involve higher-level cognitive human factors, such as visual scanning, maintaining situation awareness via sustained attention, good decision-making, maintaining a mental picture, effective communication, and managing mental workload.

Additional psychological factors were identified from the safety incident reports to play a role in the operational safety of ATCOs (Table 4..1 and Figure 4. 8), i.e. general stress, anxiety, depression, self-esteem, self-confidence, self-doubt, frustration, irritation, anger, and disappointment. General stress, increased anxiety, and the presence of features of depression made the largest contribution to safety incidents, followed by lowered self-esteem, an increase in self-doubt, and lowered self-confidence. High levels of frustration and irritation were the next-highest contributors to safety events, followed by anger and disappointment.

The physiological factors (see Figure 4.7) fatigue and nutrition were identified as having a significant impact on operational safety. Furthermore, ATCOs experience fatigue when their shifts are too long, the breaks are insufficient, and when they do not take the mandatory leave. Nealley and Gawron (2015) define fatigue as a condition that is characterised by an increase in levels of discomfort, with a lessened capacity for work. The capacity to respond to a stimulation is lowered, and there is a general feeling of tiredness and weariness. The findings of the current research support the literature on fatigue as an important safety aspect that could lead to impairment of judgment, causing safety to be compromised in air traffic control (ICAO, 1993). The present researcher supports the recommendation of the ICAO (1993) that adequate rest- and meal breaks be provided (ICAO, 1993). The time at which breaks are scheduled, as well as the length of the break, has been found to play a role in safety events. Scientific research by the FAA (2013) found that ATCO scheduling practices impact controller performance and aviation safety.

Controllers generally work rotating schedules, during which the start and stop times vary between day, evening, and night. Reviews by the NTSB, the FAA's Civil Aerospace Medical Institute (CAMI), NASA, and the FAA's Fatigue Risk Management Work Group have shown that individuals working erratic schedules often experience fatigue, which can negatively impact performance and safety (FAA, 2013). In response to a number of incidents of sleeping or unresponsive controllers in 2011, the FAA took action to mitigate the impact of fatigue on controller performance by revising its controller scheduling policies. Recommended revisions included increasing the minimum rest periods between shifts, establishing a fatigue risk management system, and increasing the number of controllers assigned to midnight shifts. In addition, "recuperative breaks" on overnight shifts were introduced to lessen the risk of fatigue.

Factors identified by Nealley and Gawron (2015) to cause fatigue in ATCOs correspond to the findings of the current research, and include: shift work, task complexity and workload, age, family responsibilities, and sleep disorders. Nealley and Gawron (2015) consider the amount of sleep obtained by ATCOs to be linked the ability to be mentally sharp. Physical health and exercise are additional physiological factors that impact on the occurrence of safety events, where a lack of exercise was found to be the smallest contributor to the occurrence of safety incidents.

ATCOs are required to be consistently aware and mentally present. The analysis of the safety incident reports was performed in accordance with a Safety-I view, whereby it is essentially an analysis of what went wrong. This type of analysis is limited by not taking into account reasons why human performance goes right. An important goal in safety management is for things to go right despite uncertainties and unpredictability. Therefore, a Safety-II view was incorporated into the present study. The findings related to the Safety-I approach informed the consideration of the Safety-II approach, in other words, understanding what went wrong provided direction with regard to what factors are necessary to ensure things go right. Results from Phase 1 concur with the human factors trends found in the literature, whereby human factors contribute to safety events. Many of the human factors issues can easily be addressed by targeted interventions. However, in a complex work situation such as that of air traffic control, it is necessary to also understand how an ATCO copes with the complexity of multiple things going wrong at the same time. It is not always possible to control all things that may go wrong, indicating the need for a facilitative environment to deal with things going wrong and enhance the chances of things going right while doing so.

Additional factors were reported on in the current research, from the perspective of ATCOs, and included human factors such as flow. With regard to international studies, there appears to be a lack of recent reviews of safety events in air traffic control. A comprehensive review of accidents and incidents in air traffic control from a human factors perspective was conducted in 2001 by Pape, Wiegmann, and Shappell. Pape et al. (2001) reviewed NTSB records from January 1985 to December 1997. Their results indicated that accidents and incidents take place infrequently, and are attributable to skill-based errors, the most common being attention failures and memory lapses.

The results of the current study support those of Pape et al. (2001); however, the present study provides more extensive data on additional human factors that were found to play a role the occurrence of safety incidents, from both a Safety-I and a Safety-II perspective (e.g., mental alertness, situation awareness, and mental task engagement). In addition, the current research considered systemic and physiological factors. As with the ATNS's preliminary study, Pape et al.'s (2001) review was done from a Safety-I perspective. Pape et al. (2001) found that, when accidents and incidents occur, they are likely to involve local ATCOs interacting with two aircraft, in the air, during daylight hours. The reporting systems at that time were unsophisticated, as they were not designed around any theoretical framework of human error. As a result, the identification of error causes and the development of interventions were difficult, which prompted the development of an error-based framework to facilitate information gathering during accident- and incident investigations. It is interesting to note that, already at that early stage, there was an awareness of the need to develop interventions to assist in the reduction of safety incidents. The current research focused on more types of safety incidents, not just those occurring in the air, e.g., runway incursions. The current study confirms the finding that most safety incidents take place during the day; however, the study yielded more specific information, i.e. that incidents take place during or shortly after the high-risk shift-handover period.

This created a deeper understanding of ATCOs' contributing behaviour and actions, from a psychological and physiological perspective. Mental workload, mental task engagement, mental alertness, and situation awareness were identified as critical human factors from the safety reports. This answered *RQ1: What human factors can be identified from the safety incident reports as significantly impacting the operational safety of South African civil ATCOs?*

An extensive literature review informed the current research from a positive psychology paradigm with regard to identifying positive aspects of ATCO behaviour. Flow was identified from the literature as a positive mind state with the potential to improve operational safety. In the current research, flow was regarded as an exploratory variable. It was not located in the safety incident reports, as these were based on the Safety-I perspective, which identifies negative factors. When an ATCO is fully engaged in the task of controlling, he/she is in a state of flow, and the likelihood of operational safety is enhanced. Flow is difficult to establish if the emphasis is on what goes wrong. This led the researcher to consider measuring flow more directly, in order to determine if it had an impact on ATCOs' operational safety. Based on the literature review, the state of flow was added to the research as a variable. This contributed to achievement of *RO2: Investigate the theoretical basis for this occurrence beyond simply attributing any error to cognitive limitations*.

5.3 Phase 2

In order to gain deeper insight into the influence of mental workload, mental task engagement and flow, data were collected in Phase 2 by (a) conducting interviews with ATCOs and (b) administering measures of *workload*, *mental task engagement*, and *flow*. The data emerging from Phase 2 gave insight into these human factors (from Hollnagel et al.'s (2015) Safety-II perspective) that have a positive outcome on performance. These factors are discussed in detail in Section 5.5, together with recommendations for practice. This stage of the research also contributed to achievement of RO2.

Gaining an understanding of ATCOs' behaviour and actions that lead to a positive outcome informed the testing of an intervention (Phase 3 of the study) that may facilitate safety performance during the high-risk shift-handover period.

The theoretical concepts of mental task engagement, flow, and mental workload were the most critical human factors identified from the analysis of the safety incident reports, the review of the literature, and the interviews with the ATCOs. These constructs relate to and theoretically overlap with mental alertness, and are psychological phenomena that theoretically underpin higher-order psychological processes in active working situations. The discussion considers the results obtained with regard to similarities and differences when compared to other research, and demonstrate how these results link to the theoretical constructs of mental task engagement, flow, and workload.

A total of 11 ATCOs volunteered to participate in this phase of the current research study. The sample size of 11 was determined to be adequate, as data saturation was reached, evidenced by the collection of additional data not producing any new themes. In addition, in reviewing the literature on psychophysiological measures of mental arousal, it was evident that sample sizes of research conducted on ATCOs consisted of an equal number or fewer than the number of participants in the current research.

Wilson and Russell (2003) investigated mental workload during a simulated air traffic control task using psychophysiological measures. The study comprised seven working ATCOs, as opposed to previous research that relied on laboratory tasks that did not require skilled ATCOs, who have to undergo rigorous selection and training. Rodrigues et al. (2018) investigated the impact of stress on psychophysiological domains, with a particular emphasis on cognitive performance. The sample size comprised 11 ATCOs, while David, Caloo, Mollard, Cabon, and Farbos (2000, p. 12) utilised a sample of eight ATCOs, which they considered to continue “the Eurocontrol Experimental Centre policy of preliminary small-scale investigations”. David et al.’s (2000) study considered real-time simulations of air traffic control (as opposed to real-life scenarios) to evaluate the use of psychophysiological measures on performing ATCOs. They considered their research to be a feasibility study that should be repeated with larger numbers of participants, and, as such, regarded their results as tentative, although indicative.

Loft et al. (2007) note that there is a worldwide increase in air traffic volumes, and call on air traffic management to consider ATCOs’ mental workload more carefully.

Due to the number of factors identified, the factors are discussed in a separate section, together with recommendations for practice. The above discussion, read together with Section 5.5, answers *RQ2: To which systemic, psychological, and physiological factors do South African civil ATCOs attribute to their safe functioning at work?* and *RQ3: What is the impact of mental task engagement, the state of flow, and mental workload on the occupational safety of South African civil ATCOs during the shift hand-over process?*

5.4 Phase 3

The research concluded with Phase 3, which was intended to be exploratory, whereby two interventions were tested in order to help resolve the mental alertness issues as initially identified by ATNS and confirmed by the detailed analysis of incident reports in Phase 1. Phase 3 explored whether an intervention could facilitate optimal mental task engagement, mental workload, and flow, in order to positively impact ATCOs’ operational safety. Phase 3 evaluated two interventions, i.e. music and mindfulness, which were administered to the ATCOs during the high-risk shift-handover period. Music and mindfulness were selected as interventions after reviewing literature that highlighted a positive effect on mental alertness and mental arousal as a result of listening to self-selected music, as well as literature on a relationship between mindfulness and the ability to enter into a state of flow. Mental alertness was measured according to heart rate. With regard to assessing heart rate, trends within a group and in individual ATCOs were considered (see Table 4.8 and Figures 4.18 and 4.19). It is important to emphasise that heart rate, and not performance, was measured in Phase 3.

Heart rate is considered a more objective measure of mental workload. Studies have shown that, as more mental processing capacity is used, heart rate increases to mobilise additional mental capacity (David, Mollard, Cabon, & Farbos, 2000; Rodrigues et al., 2018; Wilson & Russell, 2003). Increases in heart rate have been correlated with subjective experiences of higher mental workload (Kirwan et al., 1998). The current research addressed this aspect in Phase 3 (see Table 4.8 and Figures 4.18 and 4.19) by using heart rate as an indicator of mental arousal, interpreted as mental task engagement.

A study by Blood and Zatorre (2001) found that a strong stimulatory effect on heart rate can be achieved by listening to self-selected music, and Lesiuk (2009) posits that music may enhance ATCOs' mental alertness and mental arousal. Kee and Wang (2018) researched the relationship between mindfulness, flow, and mental ability, and found a positive correlation between mindfulness and flow, one that leads to increased concentration and attention.

In the present study, each intervention was independently evaluated from the perspective of establishing its contribution to the enhancement of the ATCOs' level of mental alertness, allowing the ATCO to be sufficiently mentally engaged in the task of controlling, and increasing flow, with the ultimate aim of enhancing safety in controlling.

Based on the likelihood that incidents are likely to occur when arousal levels are medium to low, increasing psychophysiological arousal was the desired effect. From a review of the literature, it was clear that physiological measures are being incorporated into human factors research (Wilson & Russell, 2003). In the present study, heart rate was selected as the indicator of psychological and physiological arousal, and was considered indicative of cognitive performance.

Mental arousal is an important concept within the realm of cognitive psychology, and, in the current research refers to the process of decluttering the mind of superfluous thoughts, allowing the mind to become available to pay attention in order to receive and process information through all the sensory channels, in order to perform the demanding task of controlling air traffic (Lindsley, 1988). The goal of the selected interventions was to increase the ATCOs' mental arousal during the high-risk shift-handover period such that they are alert and motivated, in order to minimise operational error and, ultimately, improve safety. Previous research in the aviation sector measured heart rate, heart rate variability, blood pressure, breathing rate, vasoconstriction of the blood vessels, and muscle tension in response to stressful situations (Charles & Nixon, 2019; David et al., 2000; Rodrigues et al., 2018; Wilson & Russell, 2003). In the current research, heart rate was measured (see Figures 4.18 and 4.19) during the intervention, at shift handover, and during the first 20 minutes on shift. In addition, the SSSQ was administered (see Table 4.9) to assess how mentally engaged the ATCOs were before, during, and after the handover period.

With regard to making sense of heart rate data, overall trends are focused on, due to comparisons between groups not being statistically analysable. The heart rate of all the participants across the three groups was ten beats per minute higher than their resting heart rate during the pre-shift intervention, indicating increased arousal. During the first few minutes on shift, arousal increased, evident in an elevated heart rate. Heart rate then dropped and elevated slightly in a few participants, remaining consistently lowered until the heart rate monitor was removed.

In order to maintain mental alertness, the body has to work harder, engaging more resources in the form of alertness, arousal, and situation awareness to continue performing a task (Lindsley, 1988). Increased arousal is desirable in promoting operational safety. The current research differs from that of Rodrigues et al. (2018), in which linear heart rate variability was measured, as opposed to heart rate. In Rodrigues et al.'s (2018) study, a decrease in heart rate variability was used as an indicator of increased psychological and physiological arousal, and was measured using ECG measures; the ATCOs wore a medical-grade wearable ECG device known as a Vital Jacket. Rodrigues et al. (2018) highlight how their study (as was the case in in the current research) differs from other studies that focussed on measuring arousal using a questionnaire. Both Rodrigues et al.'s (2018) study and the current research obtained psychological and physiological measurements before and after the controlling task. However, the current study was conducted in a real-life scenario, while Rodrigues et al.'s (2018) study was conducted in a simulated environment.

As soon as the heart rate monitor was placed on the ATCO's wrist, heart rate was seen to increase. This could be explained by participants being immediately stressed knowing that their heart rate was being recorded. The heart rate was seen to start off high in all three groups. Heart rate then tended to decrease and stabilise during both the Mindfulness and Music tasks, when the ATCOs had perhaps also become accustomed to wearing the heart rate monitor. Heart rate showed that the mindfulness task kept ATCOs mentally aware and alert leading up to going on shift.

5.4.1 Mindfulness group

The finding supports the postulation in literature that mindfulness leads to improved mental performance (Lippincott, 2018). Norris, Creem, Hendler, and Kober (2018) found that mindfulness improves attention. According to Davis and Hayes (2012), mindfulness has been used to refer to a psychological state of metacognitive awareness by disengaging from perseverative cognitive activities, resulting in enhanced attentional capacities through gains in working memory. In the current research, the Mindfulness group's heart rate initially elevated and then lowered, remaining consistently lowered during the first 20 minutes of controlling. The mindfulness intervention therefore seems to have had a calming effect. This finding contradicts those of Norris, Creem, Hendler, and Kober (2018), and Davis and Hayes (2012) who found that mindfulness improves attention.

The Mindfulness group therefore showed lowered arousal following the mindfulness intervention, with ATCOs possibly being in a less alert state. Using heart rate as a measure of stress, the Mindfulness group was more stressed during the SSSQ-Pre questionnaires than during the controlling task. Thus, mindfulness was found to be useful as a technique to reduce stress, but not appropriate to enhance flow, mental task engagement, and situation awareness in ATCOs. While mindfulness exercises may help ATCOs to relax before going on shift, it could be argued that they should not be relaxed during this critical period; rather, they need increased mental alertness with high levels of situation awareness in order to facilitate flow and mental task engagement to ultimately ensure operational safety.

This finding contradicts that of Kee and Wang's (2008) research, in which they concluded that individuals with the propensity to be more mindful have a higher likelihood of experiencing flow and achieving peak performance. Cresswell (2017) also found that a mindfulness state leads to developing and deepening the capacity to pay attention to moment-to-moment experiences. The mindfulness intervention as applied in the current study did not facilitate optimal attention. Mindfulness facilitated moment-to-moment experiences, when what might have been needed was mental engagement that facilitated forward planning and active engagement with a dynamic system.

Mindfulness exercises used to enhance mental task engagement in the workplace (Zheng, Gunasekara, & Blaich, 2018) was not replicated in the current research. This may be due to a different sample being used in Zheng et al.'s (2018) research, together different measurement instruments. For example, in Zheng et al.'s (2018) study, conducted in a tertiary education institution, work engagement was measured with the short version of the Utrecht Work Engagement Scale, psychological flourishing was measured with the nine-item Flourishing Scale, and mindfulness was measured using ten items of the Cognitive and Affective Mindfulness Scale-R. Meland, Ishimatsu, Pensgaard, Wagstaff, Fonne, Garde, and Harris

(2015) sought to determine if mindfulness training has an impact on attention and stress, as measured by salivary cortisol. Meland et al. (2015) found that the physiological stress response is alleviated by mindfulness training. The finding of the current study that mindfulness is a psychological intervention that reduces arousal does not support the findings of the studies by Ditto, Eclache, and Goldman (2006) and Tang, Holzer, and Posner (2015). These researchers' findings differ from the current research in concluding that their participants were able to remain alert and situationally aware, while simultaneously being calm. It is possible that mindfulness training being a preferred mindfulness task yields more favourable results.

5.4.2 Music group

When considering heart rate in the music intervention, the desired impact of the music intervention was to elevate and optimise arousal with the goal of facilitating an increase in the ATCOs' ability to mentally engage with their task. Goldstein (2019) found that music activates, sustains, and improves attention. A study at the University of California investigated how listening to music affects cognitive function in general, and spatial-temporal reasoning in particular. The researchers hypothesised that listening to music helps to organise the firing of neurons in the part of the brain responsible for higher functions; therefore, they regarded listening to music as an exercise that 'warms up' selected brain cells, allowing them to process information more efficiently (Harvard Health, 2011). Researchers at Johns Hopkins University reported that listening to music is 'exercise' for the brain. Listening to music keeps the brain engaged, with particular reference to mental alertness and memory.

In the present study, heart rates measured higher in the music intervention than in the mindfulness intervention. One might therefore deduce that music may be useful in increasing mental alertness in ATCOs. Music very slightly elevated the heart rate in three of the five ATCOs in the Music group. The outcome of the research is not in accordance with what was predicted beforehand; it was hypothesised was that both the mindfulness and the music tasks would promote and enhance mental alertness. Instead, music as an intervention was found to have the potential to lead to the desired effect of increased mental arousal and alertness.

This finding supports previous research such as that by Blood and Zatorre (2001) and Lingham and Theorell (2009). Blood and Zatorre (2001) found that listening to self-selected music can produce stimulative effects such as an increased heart rate, while Lingham and Theorell (2009) discovered a general trend of stimulative music increasing heart rate, which is indicative of increased activity in the sympathetic nervous system, and, therefore, increased arousal.

On the other hand, the findings of the current research study are contradictory to those of Allen and Blascovich (1994), who found that physiological arousal decreased when listening to self-selected music. These results may be due to the participants being able to select music that had a calming effect, whereas the participants in the current research were instructed to select music that had a stimulative effect.

In the present study, the control group's heart rate increased as they went on shift. Two ATCOs' heart rate then decreased and remained lowered. Towards the end of the first 20 minutes on shift, their heart rate increased, indicating mental arousal. The trend seen in the control group is relatively similar to that noted in the Mindfulness group, i.e. not the desired increase in mental alertness. However, this phase of the study was limited by the small sample making it difficult to draw definitive conclusions. Randomisation to control and experimental conditions were carried out, but it may not have been sufficient to control for all the random and systemic effects.

5.5 Mental Task Engagement

The current research identified flow from the one-on-one interviews with the ATCOs as a human factor that has the potential to contribute to operational safety. An ATCO who is able to achieve a state of flow is more likely to be mentally engaged in the task of controlling, to have higher levels of mental alertness and/or arousal, and to be more situationally aware (see Table 4.9). This finding is in accordance with research by Lindsley (1988), which found that ATCOs who are fully focused and absorbed in their work have higher levels of mental alertness and situation awareness, and are more engaged in the task at hand, leading to improved operational safety and reduced safety incidents.

Lindsley (1988) refers to the overlap between flow and mental alertness. Data obtained in the current research indicated that ATCOs who enjoyed their work were more likely to enter into a state of flow (see Tables 4.4 to 4.7). A flow-producing activity requires an initial investment of attention before it becomes enjoyable. More attention is paid to what is happening, leading to noticing and investing more (Csikszentmihalyi, 1997). Concentration then follows, whereby outside stimuli are excluded, allowing deeper concentration on the task (Nakamura & Csikszentmihalyi, 2002). ATCOs being in flow leads to a total immersion in the task (see Table 4.5), resulting in high mental arousal and, therefore, situation awareness.

From the data collected using the WOLF Scale (see Table 4.4), the most meaningful data were gathered using the subscales Work Enjoyment (see Table 4.6) and, to a lesser extent, Intrinsic

Work Motivation (see Table 4.7). However, the most useful quality of flow considered in the current research was absorption (see Table 4.5). Unfortunately, the data obtained using the Absorption subscale were not useful. It may be that the ATCOs who were interviewed considered themselves highly mentally engaged in their work, rather than absorbed. The data gathered using the WOLF Scale were, however, useful in examining flow when considered in combination with indications of ATCOs being in flow from the interviews (see Appendix F). This was evident in references to 'blocking out' what is happening around the ATCO, the ATCO working 'on autopilot', and their experience of being 'in the zone'.

The researcher was hesitant to draw conclusions with regard to flow based on the numeric (quantitative) data. Qualitative data and trends were more useful, indicating that situation awareness, comprising workload, flow, and mental task engagement, when heightened and maintained, may lead to enhanced operational safety of ATCOs. Flow is not an easy concept to define and could not be measured using the WOLF Scale, as internal reliability could not be obtained. Consequently, the focus moved to how mentally engaged the ATCOs were during controlling (see Table 4.9 and Appendix L and M). The researcher went on to investigate how mentally engaged the ATCOs were with the immediate task of controlling, and mental task engagement was therefore measured (see see Table 4.9 and Appendix L and M). Mental task engagement is linked to mental alertness and/or arousal. ATCOs are required to fully concentrate on and be deeply engrossed in their work. They have to be absorbed and, therefore, immersed, which is often linked to the task being a fulfilling experience (Kirwan et al., 1998). Mental task engagement is an aspect of flow.

Mental task engagement was assessed by measuring self-reported stress state of ATCOs before and after tasks performance, using the SSSQ. The SSSQ measures motivation, affect, and cognition, in order to assess subjective state reactions to task manipulations. The overall scale data for *Mental task engagement* were not reliable, and individual items were therefore given more attention, i.e. the consideration of trends occurring in the 24 individual SSSQ scale items (see Appendix G). Each of these items was considered across all three of the intervention groups, in order to gain insight into whether, overall, responses to an individual scale item consistently indicated improvement, deterioration, or no change.

There was an improvement in feeling alert, level of commitment, and feeling more in control across all three groups. Kahn (1990) recognised mental task engagement to involve commitment, with commitment being in the form of cognitive, affective, and physical engagement. Engaged workers are more satisfied with their jobs and feel more committed to the organisation and their occupation (Demerouti, Bakker, Janssen, & Schaufeli, 2001). According to Demerouti (2001), mental task engagement is facilitated by the presence of (job) control. Mentally engaged workers, according to Rapayana (2008), are more likely to work more overtime and to perform better. Results of a study by Pop et al. (2012) showed that engaging the ATCO may alleviate the vigilance decrement, leading to higher levels of alertness and attention. The current research found that, across all three groups, the ATCOs' tendency to daydream about themselves lowered, they spent less time thinking about how others have done, and about "how I would feel if I were told how I performed". No change was noted for one scale item — *Feeling depressed* — across all three groups. Overall, mental task engagement across all three groups tended towards being elevated, although, once again, this result should be cautiously interpreted, due to the small sample size, and rather be considered exploratory. No research in which the individual scale items if the SSSQ were examined could be located.

Seven of the 24 SSSQ scale items demonstrated a trend of consistency across the three groups. The other scale items yielded useful information. In both the Music and Mindfulness groups, the following trend were noted: ATCOs wanting to succeed on the task; an improvement in ATCOs being motivated to perform the task; reflecting less about themselves, feeling less self-conscious; a lowered tendency to worry about what people thought of them; and an increase in their expectation to perform proficiently, indicating an increase in confidence.

In closing, as noted earlier, the results of this phase should be cautiously interpreted, and may not be generalisable to the larger population of ATCOs, due to the small sample size. However, the trends determined may be useful. The researcher recognised the benefit of ATCOs participating in an intervention prior to commencing shift. It may be that doing something is preferable to doing nothing just prior to commencing a shift. The music task, in particular, was found to promote mental arousal. The researcher gained insight into the potential for interventions to contribute to the promotion of operational safety in ATCOs, based on underlying theoretical principles of increasing attention and mental alertness. The results from the current study can be considered preliminary, and additional interventions need to be tested.

5.6 Details of Risks and Factors Identified, and Recommendations for Practice

The human factors identified from reviewing the safety incident reports were categorised into systemic, psychological, and physiological. Systemic factors cannot readily be applied in direct relationships; rather they should be understood in the context of a larger system of influences. This section starts with an overview of the risks identified from the incident reports, to inform management and practitioners regarding areas that require attention in planning and prioritising remedial actions. The recommendations are also based on the themes that emerged from the interviews with the ATCOs.

5.6.1 Risks

5.6.1.1 High-risk periods

The highest number of safety events was found to occur during the high-risk shift handover period, i.e. the first 30 minutes since the start of the shift, following a break, and the last 30 minutes of a shift (Figures 4.18 and 4.19). This finding confirmed the preliminary findings of the ATNS, and supports that of a study by Della Rocco, Cruz, and Clemens (1999), who found that 25% of all operational errors occurred in the first 15 minutes after position relief and briefing in air route traffic control centres and terminal radar control facilities.

In addition, shift handovers taking place early in the morning and at midday were found to be high-risk periods (Figure 4.2). This supports the similar findings in the literature, e.g., Parke and Hobbs (2010) and Parke and Kanki (2008), who concluded that shift handovers are high risk in many safety-critical environments, including medicine, air traffic control, and mission control for space shuttle and space station operations.

It is therefore advised that concerted vigilance be applied during these periods, and that sufficient support is available to assist ATCOs in ensuring a safe handover.

5.6.1.2 Types of risk

With regard to type of safety event, loss of separation occurred at the highest rate (see Figure 4.13), followed by runway incursions. The highest incidences of safety events were recorded at O R Tambo Airport, followed by Lanseria Airport and then Cape Town Airport (see Figure 4.10). However, it needs to be borne in mind that O R Tambo Airport is the busiest unit, responsible for the most complex traffic and the highest traffic load. This indicates the need to gather data with which to determine proportion of incidents according to volume of traffic, not just number of incidents per airport. Nevertheless, it is advised that these areas are examined to determine causes and provide additional support.

5.6.1.3 High-risk sectors

The present research identified a link between the occurrence of safety events and sector. The highest number of safety incidents occur in Approach, followed by Aerodrome (see Figure 4.11). Approach is considered a complex sector, with aircraft changing altitude, increasing the potential for loss of separation. It is therefore recommended that these sectors be manned by experienced ATCOs, and that they are given support during high-traffic periods.

5.6.1.4 High traffic volume/Workload

With regard to systemic factors related to safety incidents, the results indicated that the highest number of safety events (29) occurred during 2011, followed by 26 in 2010, and 25 in both 2009 and 2012. The number of scheduled flights increased over this time, with a sharp increase in 2010, due to South Africa hosting of the Soccer World Cup (see Figure 4.1). It is therefore clear that extended periods of high air traffic require additional focus in preventing safety incidents. Previous studies, e.g., that of Moon, Yoo, and Choi (2011), also found that a higher traffic load leads to a greater potential for safety incidents. Moon et al. (2011) found that navigable airspaces are becoming more crowded with increasing air traffic, and the number of accidents caused by human errors is increasing.

Brooker (2003) posits that the highest mental workload levels arise from short-term peaks in traffic, when task load is at its highest. Hopkin (1998) notes that a low workload leads to boredom in ATCOs, which may result in increased rates of errors. From the interviews with ATCOs in the present study, boredom was confirmed as a factor, as it was consistently raised as playing a role during periods of low workload (see Tables 4.3 and 4.4 and Figure 4.17). ATCOs commented that, during quiet traffic periods, remaining focused on a radar screen was challenging, and they felt they needed additional stimulation to remain focused on the task of directing traffic. The impact of workload on the operational safety of ATCOs could not be determined in the current research, as statistical significance in the data collected could not be determined, due to the small sample size. The results are therefore generalisable to the population of ATCOs (see Figure 4.3 and 4.5).

5.6.1.5 Low traffic volume

Low-traffic periods are considered high-risk periods (Eurocontrol, 2007), a view that is supported by the current research (Figure 4.3 and 4.5). Vigilance is reduced, leading to a failure to identify critical events. A low workload impacts negatively on arousal. Low workload as a high-risk factor in the occurrence of safety events is supported by the current research (Figure 4.3 and 4.5). Dekker (cited in Eurocontrol, 2007, p. 6) notes that ATCO need the ability to handle ebbs and flows in workload, and that "mental workload matters". Dekker (cited in Eurocontrol, 2007) explains that mental workload is subjectively interpreted, whereby the same situation may be experienced differently by different operators.

The findings of the current research differ from those of Moon et al. (2011), whereby a lower occurrence of safety events was noted during the high-risk shift handover period when there was greater complexity in the traffic situations and higher traffic loads (see Figure 4.3 and 4.5). The results of the current study show that, in traffic situations of greater complexity, ATCOs' stress levels increase (Figure 4.8), which is associated with an increase in the production of adrenaline, leading to increased attention and arousal. In the current study, it was found that the number of incidents was high during shift handover when traffic load was low and weather conditions were not adverse (see Figures 4.3 and 4.9). In both these instances, a higher number of safety events occurred due to ATCOs' stress levels being lowered, which may have led to a decrease in attention. It is during these periods that interventions could be implemented to assist ATCOs to be more mentally alert and to enhance their situation awareness.

From the above, it is clear that additional vigilance is required during both these periods. This should be impressed upon ATCOs, and management should be available to provide rapid support.

The next section discusses factors identified as having an influence on ATCOs' safety performance, from both a Safety-I and Safety-II perspective. The factors that were found to affect ATCOs' performance were divided into systemic, physiological, and psychological.

The next two sections discuss the systemic, psychological, and physiological factors identified from the interviews with the ATCOs. A vast number of factors were identified, and it was therefore decided to concentrate on factors that are amenable to corrective action in this discussion, which includes recommendations. The discussion therefore excludes factors such as adverse weather conditions.

The factors that would improve ATCOs' safety performance (a Safety-II view) are the following.

5.6.1.6 Support

ATCOs require ongoing support and supervision while on duty, especially when extraordinary situations or emergencies occur. Support could be in the form of supervisor shifts, collegial support, assistants, managerial support, supportive documentation, and, in the case of trauma, critical incident stress management, including a debriefer.

It is also recommended that ATNS continue to remove ATCOs from position immediately following a safety event, to undergo critical incident stress management debriefing. ATNS should assist the ATCOs to not feel that reporting a safety incident will lead to punitive consequences, to ensure that ATCOs report safety incidents immediately and transparently.

5.6.1.7 Environment

Environment was found to play a critical role in employee performance, and a number of complaints were raised in this regard, which may play a direct role in impairing ATCOs safety performance.

It is advised that ATCOs are consulted, and that issues such as insufficient lighting, unclear sight lines, limited console space, poorly positioned consoles, and faulty or substandard equipment (binoculars, pens, printers, radios, air conditioning) be addressed as a matter of urgency. Certain upgrades may also be required, such as the required information being available on one screen, instead of six. ATCOs' flow may also be disrupted by excessive noise levels. It is recommended that visitors be limited, and that ATCOs be made aware when noise levels are unacceptably high.

5.6.1.8 Rostering

Fatigue is widely recognised as a factor underlying poor performance (Nealey &Gawron, 2015). To combat fatigue, it is advised that sufficient staff be assigned to shifts, and that breaks are scheduled according to task demands, giving an ATCO a rest from a period of controlling a high volume of traffic. However, in ensuring sufficient staff, care should be taken not to extend ATCOs shifts, as this may have an adverse effect on their performance in subsequent shifts. In addition, the mandatory leave of ATCOs should be enforced. Rostering should also take into account the hours required on duty to ensure that ATCOs remain proficient.

ATCOs should be made aware of the dangers of fatigue, and be encouraged to get enough sleep. In support of this, it is further advised that reast areas be upgraded, and consideration be given to providing easy access to healthy hydration and nutritious meals or snacks.

5.6.1.9 Management

It is suggested that management engage with ATCOs to address issues that were reported to disrupt their functioning. It would seem that more communication is required, in both directions.

The factors that emerged from the interview data were inadequate supervision and support from management and efficiency being placed ahead of safety, which may be issues that require escalation to higher levels. It is further proposed that improving the relationship between management and ATCOs would greatly enhance ATCOs' flow and honesty in reporting accurately on safety incidents, and to open lines of communication regarding assistance and prevention.

This concludes the discussion of the outcomes of the present research. The next section provides and overview of the study's contribution to theory.

5.7 Contribution to Theory

The current research has several implications in terms of contributing to existing theory and knowledge, with particular emphasis on gaining insight into the human error component of human factors that contribute to enhanced situation awareness, mental task engagement, and flow in ATCOs, with the ultimate goal of promoting optimal mental alertness by minimising safety events during the high-risk shift handover period. On a theoretical level, the current research attempted to gain a deeper understanding of the theoretical overlap between mental task engagement, mental workload, and flow, as well as the interplay between these concepts. Demonstrating the links between the state of flow and mental task engagement was another theoretical contribution. In order to achieve the theoretical objectives of the research as outlined above, the focus of the literature review was on human factors, particularly on why things go right (Safety-II).

Flow was identified in the current research as being an independent theoretical construct, but related to mental task engagement and situation awareness. However, while theoretically distinct, it was not possible to conclusively determine the impact of flow on ATCOs' performance. It may be that flow is difficult to establish in this context. Safety-II emerged as critical to the understanding of the occurrence of safety events, reinforcing the need to shift from a Safety-I to a Safety-II perspective when considering human error.

Insight from the current research revealed the usefulness of an intervention in the promotion of operational safety in ATCOs, whereby mental alertness and attention is enhanced, especially during the high-risk shift-handover process. After the initial arousal of taking up a shift wears off, mental alertness and arousal need to be maintained. The music intervention showed the greatest promise in this regard.

In shifting to a Safety-II perspective, the importance of the ATCOs' cognitive activities and processes requires more emphasis. This is a further contribution to existing theory and knowledge with regard to safety in air traffic control.

The next section provides a discussion of the limitations of the present study and recommendations for future research.

5.8 Limitations and Recommendations for Future Research

Several limitations to the current research were identified. Drawing definitive conclusions was difficult, due to small sample sizes. This a common problem in research on mental arousal in aviation. Furthermore, the ATCOs were reluctant to participate, despite anonymity being guaranteed. ATCOs who participated may therefore have answered what they believed was the 'correct' answer, to cast themselves in a more favourable light. While useful insights were gained, the sample of participants may not have been representative of the population in their views.

The study was limited to ATCOs in the South African context. Future studies could include ATCOs in other countries. Participation in the study was also limited to ATCOs. Future studies could incorporate their managers.

The researcher was not permitted into the ATNS area after a certain time, due to security clearance issues, which may have impacted the results, as the traffic situation differs over the course of the day and night.

The incident reports analysed were limited to the years 2008 to 2012. It is possible that trends in human factors have changed with regard to their impact on safety.

The measurement of flow may have been limited due to the scales selected in the current research. Utilisation of alternative measures may have yielded more definitive results.

Heart rate was chosen as a measure of mental alertness. Future research could employ additional or alternative measures of alertness, such as heart rate variability, respiratory rate, skin conductance, eye movements, and EEG studies.

The intervention study may have been limited by the finite list of music from which the ATCOs could make a selection. The music may not have been experienced as uplifting by everyone in the sample. Ideally, participants in future studies should be able to listen to music from their own collections.

Some participants were reluctant to engage in the mindfulness task, as they considered colouring-in a task for children, which may have influenced the results. Future researchers could consider other mindfulness tasks. In addition, ten minutes may not have been sufficient time for the ATCOs to complete the intervention tasks. The ATCOs in the Music group did not listen to their entire music selection, and those in the Mindfulness group did not complete the colouring-in task. In future research, longer periods should be allocated to such interventions.

ATCOs at Wonderboom Airport were interviewed in the restroom, which may have been distracting, as other ATCOs came in out at for the duration of the interview. ATCOs at Lanseria Airport were interviewed in offices that overlooked the runway; therefore, noise may have distracted the participants. In future studies, researchers should attempt to secure privacy for interviews.

The present study was shortitudinal, which is a limiting factor in testing the efficacy of interventions. Future studies could measure the longitudinal effects of interventions administered intermittently.

5.9 Conclusion

Safety in air traffic control will continue to feature in international headlines. Developments in technology in the Fourth Industrial Revolution are also bound to impact this domain. There is growing empirical knowledge regarding the relationship between safety events and human factors, particularly in the field of air traffic control. The attempts that have been made have been from a Safety-I perspective: why things go wrong. The current research was conducted from a Safety-II perspective: whereby safety events are considered from the perspective of why things go right.

There is a gap in the knowledge and research on South African civilian ATCOs. The current research contributes to the growing body of knowledge on human factors in this domain. The ATNS emphasises safety ahead of service, and ATCOs are encouraged to put safety ahead of efficiency. The culture is changing at ATNS, as seen by studies on safety culture, whereby ATCOs are more likely to report safety incidents. The fear of being suspended that existed previously is now a lesser factor. This bodes well for the gathering of knowledge with which to prevent safety incidents.

The current research confirmed the pattern of increased safety events occurring during the high-risk shift-handover period as a result of a reduced state of mental alertness, as proposed by ATNS. This indicates the periods at which short-term remedial actions to address the factors identifies in this study should be applied as a priority. Studying the effects of remedial efforts on the number of safety incidents may yield useful information.

Dekker (2019) recommends being ‘risk competent’, rather than risk averse, and accepting and taking responsibility for the fact that not everything will always go as planned. The current research makes a contribution to safety in air traffic control by highlighting the importance of mental alertness and mental arousal during the high-risk shift-handover period. The current research is original in identifying flow as a Safety-II factor that could play a role in operational safety during the high-risk shift-handover period. It is hoped that the outcomes of this study will assist both ATCOs and their managers to understand and promote flow, thereby enhancing safety in air traffic control.

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APPENDICES

Appendix A

HERA-JANUS Report Format

HERA ANALYSIS							
DESCRIPTION OF ERROR							
1.							
How detected:							
How recovered:							
Causal		**Contributory**		**Compounding**		**Non-contributory**	
HERA CLASSIFICATIONS							
Error type:							
Error detail:							
Error mechanism:							
Information processing:							
Task Taxonomy:							
Information/ Equipment							
Contextual condition:							
Reporter's assumptions:							
Analyst's assumptions:							
NOTES							
Source: EUROCONTROL, HERA-JANUS. 2003. HRS/HSP-002-REP-03							

Appendix B

Consent Forms and Participant Information Sheet

Invitation to be interviewed

Hi,

Psychology

School of Human & Community Development

University of the Witwatersrand

Private Bag 3, WITS, 2050

Tel: (011) 717 4500 Fax: (011) 717 4559

My name is Beverly Slater and I am conducting research for the purposes of obtaining a PhD degree in Psychology at the University of the Witwatersrand. The research will focus on task engagement and flow in the operational safety of South African civil air traffic controllers. I would like to invite you to participate in this study.

Participation in this research will involve an interview with the researcher, in which you will be asked a series of questions. It is estimated that this should take 60-90 minutes to complete. With your permission, this interaction will be recorded, in order to ensure accuracy. Electronic transcripts will be kept in a safe place. The transcripts will be kept in a password-protected computer folder. These transcripts will only be accessible to the researcher and her supervisor. This interview will be scheduled at a time that is convenient for you, and will take place at your place of work, in a private location.

Participation in this research is completely voluntary, and you will in no way be advantaged or disadvantaged for choosing to take part or not. There are no benefits to taking part in the study, and participation is not foreseen to be harmful in any way.

Your responses will be kept confidential, pseudonyms will be used, and no information that could identify you will be included in the research report. The transcripts will be safely stored and only accessed and processed by my supervisor and me. Feedback will be given to the organisation in the form of a summary, and can be supplied to participants at their request. Participants may withdraw from the study at any time.

If you have any questions about the study, please contact me on bevs@netactive.co.za.

Thank you for considering participating in this research.

Yours sincerely,

Beverly Slater (Researcher)

Prof. Andrew Thatcher (Supervisor)

Consent form for interview

Psychology

School of Human & Community Development

University of the Witwatersrand

Private Bag 3, WITS, 2050

Tel: (011) 717 4500 Fax: (011) 717 4559

I ____ consent to being interviewed by Beverly Slater for her study on Task Engagement and Flow in the Operational Safety of South African Civil Air Traffic Controllers.

I understand that:

- Participating in this interview is voluntary.
- I may chose not to answer questions I would prefer not to.
- I may withdraw from the study at any time.
- No information that may identify me will be included in the research report, and my responses will remain confidential. Thus, I will only be identifiable by the researcher, and no other personnel.
- Direct quotations from the recording may be used as long as my identity is kept confidential.
- The transcripts will be kept in a password-protected folder.

Signed: __________________________

Date: ____________________________

Permission to be audio-recorded

Psychology

School of Human & Community Development

University of the Witwatersrand

Private Bag 3, WITS, 2050

Tel: (011) 717 4500 Fax: (011) 717 4559

I ____ consent to my interview with Beverly Slater for her study on Task Engagement and Flow in the Operational Safety of South African Civil Air Traffic Controllers.

I understand that:

- The transcripts will not be seen or heard by any person besides the researcher and her supervisor, and will only be processed by the researcher.
- This will be assured as electronic transcripts will be kept in a safe place, which will only be accessible to the mentioned parties.
- The transcripts will be kept in a password-protected folder.
- All recordings will be destroyed after they have been transcribed.
- No identifying information will be used in the transcripts or the research report.
- I give permission for the researcher to use direct quotations from the recording, provided my identity is kept confidential.

Signed: ____________________

Date: ________________________

Appendix C

Phase 2: Excerpts from Interview Transcripts

Interviewer: What do you think about as you're approaching the end of your shift?

Interviewee: Basically, what I said in the paragraph above but just that I now have to get ready to hand over a clean slate and then explain all that happened on my shift to my colleague so that they have a bigger picture to work with.

Interviewer: What factors contribute to your levels of fatigue at work?

Interviewee: The fact that I manage the station adds to my fatigue. I do find having to answer emails, et cetera, tiring and frustrating.

Interviewer: Anything else?

Interviewee: No.

Interviewer: What would assist you to be less fatigued on duty?

Interviewee: From an ATC point of view, is being able to make use of the restroom. Maybe watching TV and just relaxing. Not worrying about anything.

Interviewer: Can you identify any factors that interfere with your work flow?

Interviewee: From an operational point of view, no?

Interviewer: But adding in the managerial side does affect it slightly.

Interviewer: How?

Interviewee: As I said, a break to me is to sit in the office and answer emails and not relax in front of the TV.

Interviewer: What is the most common error you find yourself making while on duty?

Interviewee: Ultimately, you should not make any errors. I can't think of anything. The idea is to strive not to make any errors.

Interviewer: Okay. But are there any that you make, is there one that tends to get you every time?

Interviewee: Not really, no.

Interviewer: What are the most difficult conditions you have had to control under.

Interviewee: Controlling traffic when we have an emergency situation is difficult in that you have to look after the emergency traffic. You have to concentrate on assisting the emergency traffic as well as looking after the other traffic on frequency. This is difficult and stressful.

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Interviewer: What would enhance or improve the quality of your work?

Interviewee: Equipment status.

Interviewer: Meaning?

Interviewee: Meaning that the equipment we need to work with is always working. As I mentioned before, weather does effect your shift, so having no thunderstorms or strong winds for example would enhance making my shift easier.

Interviewer: What impacts negatively on the quality of your work?

Interviewee: I would say referring back to the previous paragraph, equipment. If you rely 100% on the serviceability of the equipment. And add in the infrastructure of the airport Example, the runway conditions and taxiway conditions.

Interviewer: What is the biggest distraction during operational duty?

Interviewee: Noise in the tower and visitors.

Interviewer: Visitors.

Interviewee: Yes. Visitors that are allowed and not visiting for the right reasons.

Interviewer: What would the right reasons be?

Interviewee: Being interested in aviation, example scholars or young pilots learning to fly. I don't mind them as they ask pertinent questions. People that are there just for an outing is a disturbance.

Interviewer: And noise, in what sense?

Interviewee: Noise in the sense of too many people in the cab and the location of the tower to the apron as aircraft that taxi past and are noisy.

Interviewer: What would assist you to be more alert on duty?

Interviewee: What I find, if the traffic movements are more constant, I am a lot more alert than when it is quiet as you tend to not be so alert during these times. In other words, constant movement outside would assist me to make me more alert.

Interviewer: What would assist you to pay more attention on duty?

Interviewee: The same as the previous paragraph. What's the question?

Interviewer: What would assist you to pay more attention on duty?

Interviewee: As I mentioned before, if there is constant movement outside, it does assist. And when the radio is busy.

Interviewer: What information or signals prompt you to act to prevent a difficult situation turning into one where safety margins are compromise?

Interviewee: Bad radios, bad radio work, i.e. pilots not speaking fluently or not using standard phrases would prompt me to provide and concentrate more on that person to avoid an incident.

Interviewer: How do you decide that a difficult situation is different to a normal situation?

Interviewee: A difficult situation would require more attention and more effort. Just the last part of that question?

Interviewer: How do you decide that a difficult situation is different to a normal situation?

Interviewee: I said a difficult what?

Interviewer: You said a difficult situation would require more attention.

Interviewee: And more effort than a situation which is not difficult. This last situation comes naturally for me therefore it is not a difficult situation. I don't find those situations difficult.

Interviewer: How do you plan or foresee what will happen next when dealing with a tricky traffic situation?

Interviewee: How do you plan?

Interviewer: Or foresee what will happen next when dealing with a tricky traffic situation?

Interviewee: To answer the question, we never know that a tricky situation is lying ahead of us. When it does occur, we are trained and have procedures in place to take on the situation. During training, we plan and simulate tricky situations and therefore we are prepared for it.

Interviewer: How do you foresee what will happen next when you are attending to traffic?

Interviewee: How do you see?

Interviewer: Foresee what will happen next when you are attending to traffic? So, that would be general traffic.

Interviewee: If the pilots are complying with the rules and regulations and ATC clearances and instructions, allows for a shift to be completed without incidents. In other words, if we all work

Appendix D

Interview Schedule

BIOGRAPHICAL INFORMATION

Name:

Gender:

Age:

Marital status:

Children (& age):

Sector worked:

Shift:

Sign-on to sector:

Time of last break:

Duration of break:

Period validated:

Time of last meal/snack and description:

Medication:

Medical conditions:

GENERAL

1. What motivated you to become an ATCO?
2. Most traumatic (emotionally challenging) event/history of traumatic event (NOT ATCO-RELATED, i.e. in personal life and not on duty):
3. Best experience on duty as an ATCO in the last 12 months (was there something that happened beforehand?)
4. Worst experience on duty as an ATCO in the last 12 months (was there something that happened beforehand?)
5. What, if any, anxiety do you have about being an ATCO (worst fear)?
6. What personal stress are you currently experiencing?

7. What stress are you experiencing at work?
8. Have you ever had a safety incident?
9. Describe the atmosphere at work?
10. What support/supervision is provided on duty/during shift? If so, describe.
11. At work, do you have support/supervision when do you access support mechanisms such as supervision, and which support resources do you access?
12. If you have children? How do you manage the situation?

SHIFT HANDOVER AND FLOW

1. How far do you travel to get to work, how do you travel to work, and how does this affect performance once taking position?
2. What do you think about on your way to work?
3. When is it that you consider yourself to have arrived at work?
4. When is it that you consider yourself to have left work?
5. What do you think about on the way home from work?
6. When you start your shift, either at the beginning of the shift or when you return from taking a break, what activities (mental and physical) do you do to prepare?
7. What do you think about as you settle into your shift?
8. Are starting a shift on arrival and starting a shift after a break the same?
9. What do you think about while you are in the midst of your shift?
10. At the end of a shift or when you are about to take a break, what activities (mental and physical) do you do to prepare?
11. What do you think about as you are approaching the end of your shift?
12. What factors contribute to your levels of fatigue at work?
13. What would assist you to be less fatigued on duty?
14. Can you identify any factors that interfere with your work flow?

SITUATIONAL AWARENESS/MENTAL ALERTNESS

1. What is the most common error you find yourself making while on duty?
2. What are the most difficult conditions you have had to control under?

3. What would enhance/improve the quality of your work?
4. What impacts negatively on the quality of your work?
5. What is the biggest distraction during operational duty?
6. What would assist you to be more alert on duty; that is, to maintain alertness?
7. What would assist you to pay more attention on duty; that is, to focus your alertness, in times of high and low traffic load?
8. What information or signals prompt you to act to prevent a difficult situation turning into one where safety margins are compromised?
9. How do you decide that a difficult situation is different to a normal situation? In other words, what are your cues?
10. How do you plan and/or foresee what will happen next when dealing with a tricky traffic situation? Please break this mental task down.
11. How do you foresee what will happen next when you are attending to traffic?
12. What causes you to become more attentive to a situation that you think may become difficult?
13. What information or signals prompt you to act to prevent a difficult situation turning into one where safety margins are compromised?

Appendix E

Work-Related Flow Inventory (WOLF)

THE WORK-RELATED FLOW INVENTORY (WOLF)

BAKKER (2008)

The following statements refer to the way in which you experienced your work during the last two weeks.

Please indicate how often you experienced each of the statements.

1 = Never, 2 = Almost never, 3 = Sometimes, 4 = Regularly, 5 = Often, 6 = Very often, 7 = Always

Absorption

1. When I am working, I think about nothing else

1	2	3	4	5	6	7

2. I get carried away by my work

1	2	3	4	5	6	7

3. When I am working, I forget everything else around me

1	2	3	4	5	6	7

4. I am totally immersed in my work

1	2	3	4	5	6	7

Work Enjoyment

1. My work gives me a good feeling

1	2	3	4	5	6	7

2. I do my work with a lot of enjoyment

1	2	3	4	5	6	7

3. I feel happy during my work

1	2	3	4	5	6	7

4. I feel cheerful when I am working

1	2	3	4	5	6	7

Intrinsic Work Motivation

1. I would still do this work, even if I received less pay

1	2	3	4	5	6	7

2. I find that I also want to work in my free time

1	2	3	4	5	6	7

3. I work because I enjoy it

1	2	3	4	5	6	7

4. When I am working on something, I am doing it for myself

1	2	3	4	5	6	7

5. I get my motivation from the work itself, and not from the reward for it

1	2	3	4	5	6	7

Appendix F

Phase 2: Qualitative themes: Systemic, Psychological, and Physiological factors

Qualitative analysis of interviews

Systemic factors

Factors that can enhance or improve the quality of work	
Staff	Need more staff
Weather	"Having no thunderstorms or strong winds would make shifts easier" [ATCO3]
Equipment	• "...equipment status, i.e. all the equipment that is required is always working… [ATCO3] • "…more user-friendly equipment… We've got a lot of screens in front of us which constantly require scanning and monitoring… That, coupled with having to look out of the window, don't make for an ideal situation… If we were able to capture more information on 1 screen instead of 6 screens … it would make for a better working environment." • "…proper binoculars … they are in the process of acquiring new ones … better pens … they're cheap, they break … actual strip boards that's made for strips … we use FPS and the new boards they sent us were made for the smaller strips … you make it work. It's not really made for us." [ATCO11] • Radar system: "…so that there is no room for interpretation, e.g., visual approach is being done differently from ATCO to ATCO." [ATCO9] • "…especially when you are relying on the serviceability of the equipment." [ATCO3]
Support	"Efficiency of your support, your back up, your administrator, things like computer technician, overtime claims, basic human resource factors that were efficient and not something you had to put much effort into making sure happened … you can actually be more focused on the operational job you're meant to do." [ATCO10]
	"…management to trust ATCOs more."
	"You get the feeling that they are so worried about something else going wrong that they put in too many procedures to prevent it makes your work harder to keep the traffic flow where it should be … but stay within their lines." [ATCO6]
Restroom	"…better relaxation facilities." [ATCO3]
	"Cape Town has a ping-pong table working computers … reading material is up to date, magazines, the kitchen is better equipped." [ATCO8]
Factors anticipated to impact negatively on the quality of work	
Management	"…tending to micromanage. It's like being in school, managers are the principal and teachers and ATCOs are the children. This doesn't work very well with adults." [ATCO1]
	"…unnecessary pressure from management … double standards … lack of information regarding operational issues … communication." [ATCO8]
	"If you file an incident, you know you are not in the wrong. There's always that fear of management will investigate … if you file an incident … you know it's definitely the pilot's mistake… No matter how much you prepared to prove it is a pilot's mistake, there's always that fear of management will investigate to see if it really was a pilot mistake and not an ATCO mistake." [ATCO11]
	"…management's bad attitude towards you, which occurs a lot less now, but used to be a major thing … e.g., manager saying to us we should be happy because we're paid so well for people who have such low levels of education … it is the attitude of management towards us … if management looks a bit more carefully, they can see most of the ATCOs actually have higher education … BSc genetics, physiology, psychology…" [ATCO10]
	"…bad attitude, so you can't get hold of them to change an instruction." [ATCO10]
Pilot–ATCO	"a pilot questioning your judgement, somebody not listening or complying with bad attitude" [ATCO10]
	"…come up to the TWR and scream and shout at you." [ATCO10]
	"…if the pilots are complying with the rules and regulations and ATC clearances and instructions, i.e. if we all work together … one pilot questioning your judgement or authority, not listening or complying

	with a basic instruction … pilots sometimes don't listen, not giving full read backs, you have to call them two or three times." [ATCO3]
Break\Roster	"A couple of days in a row … when you come back, the first 20 minutes you are a bit rusty." [ATCO4]
	"We don't have the numbers to fill the positions. It places extra strain on everyone and sometimes you end up working without an assistant for the day.".[ATCO11]
	"You work shifts; you don't have the same Monday to Friday, weekends off structure … so you don't pay attention to what day of the week it is … or what day of the month it is … you focus more on your roster so that your weekend off is any two days off in a row that you get … so you actually lose touch with your normal 08:00 to 17:00 Monday-to-Friday friends … because they might be able to go out Friday nights and you are working … early morning at 06:00"[ATCO10]
Noise	"people on a break … still in the radar hall. Talking behind you … it's a bit loud … can go through while you are speaking." [ATCO4]
Frustration	"…services that aren't doing their work." [ATCO5]
Systems	"…systems that are not set up properly … and management blinded that it should have been or should or could be better…" [ATCO5]
Skill and experience	"You work with a lot more experienced people that you should work to their level … you keep trying to be what they are and end up impacting negatively on yourself … you should just do what you can … [I] put in one hundred and ten percent and provide the best possible service to anybody that calls on my frequency" [ATCO6]
Other	"…not doing work and not following instructions." [ATCO2]
General	
Passion for aviation, enjoy what they do, work is fun	"Every day is fun … it is all joy." [ATCO5] "Every day I come to work and I enjoy every day to the fullest." [ATCO11] "We come and do our jobs with our colleagues mostly … every day is different … it's challenging, it's fun … it's nice to be doing what we do … it's like our job is like a hobby … nice to work with … in general, it's good … everyone is providing and doing what we love doing." [ATCO 4] "It is a lot of fun when you come to work." [ATCO9]
Career choice	"I initially wanted to fly as a career. After applying in the air force and I didn't get selected, I asked what else I can do, and they recommended I become an ATCO." [ATCO3]
	"I didn't know what it was about initially. I just saw an advert in the newspaper and it caught my attention. That's when I started researching what ATC is all about. I didn't know much about aviation when a family friend was doing his private pilot's licence, and that's when I found out about the various aspects, and then applied for ATC. I had studied a BSc but couldn't find a job for a year after, then a friend who is a recruitment agent put my name down for ATC." [ATCO2]
Positive team dynamics	ATCOs tend to get along with everyone, and consider their team dynamic, vibrant, diverse; mostly young teams
Support and supervision	
	Needed when extraordinary situations and emergencies occur
Supervisor shift	In process of being formalised
	Means of obtaining support
	"We get rostered for supervisor shifts to support and help when there may be an emergency." [ATCO4]
Collegial support	"At no point are you sitting by yourself … there is always an extra pair of eyes … you always have your colleagues around you if you unsure … have an agreement amongst staff to listen out and look out for each other to avoid any incidents." [ATCO1]
	"…get the support with what you supposed to do, as it is your duties." [ATCO2]
	"Whoever is available or is not busy can help." [ATCO1]
No support	A minority of ATCOs do not experience any support or supervision while on duty
ATCO assistant	"…the ATCO assistant as a source of support." [ATCO2]
Managerial support	"Our team … has a section manager to turn to, to resolve issues … management down the corridor, always someone there." [ATCO6]
	"…only a phone call away." [ATCO8]
Documentation	"…aeronautical documentation that you can access when you need it." [ATCO9]

	CISM debriefer	CISM debriefer is available to anyone who experiences any form of trauma
Age/Experience		
		"Some people do not understand entirely what they are doing … there are some people in our TWR who have very little experience … that have validated on very basic requirements. When you validate, you are supposed to grow and expand your knowledge. When some people plateau and take a dip … you see it every now and then when you are working next to somebody and occasionally they lose the plot … forget where aircrafts are, mix up call signs … inexperience … a lot of these people come from airports where there is very little traffic." [ATCO7]
Safety vs efficiency		
		ATCOs juggle safety versus efficiency and are instructed to put safety first
		A commonly noted theme was the emphasis of the ATCOs on service ahead of safety
		"You can't only be safe, you have to be efficient as well. It's about the balance between the two … that is the biggest challenge." This is an example of what an ATCO considers to be service. [ATCO5]
		ATCOs are always accountable
Distance travelled to work and/or time taken to travel to work		
		Increased anxiety and stress levels
		Travelling shorter distances with heavy traffic may be as mentally taxing as travelling further with lighter traffic
		"If late, then everything becomes rushed and anxiety and stress levels rise; thus, there is an attempt to try and arrive early to allow a calm transition from one colleague to another." [ATCO1]
		"…does not feel any more or less tired as a result of travelling to work; rather, does feel drained driving home from work." [ATCO11]

Psychological Factors

Personality type		
	Controller personality type	ATCOs seem to have a common need to be in control
		"I consider myself one of those ATCOs that's always in control … and is able to keep up with the traffic, no matter how busy it gets." [ATCO7]
		High expectations of self
Attention		
	None	No particular factor was predominant for all ATCOs with regard to increasing attention on duty
		"I pay enough attention … you don't really have a choice …you have to look at what you're doing." [ATCO5]
	Other	"…pays attention to every detail." [ATCO5]
		"…block out what is happening around you." [ATCO9]
		"Sometimes you're having a bit of a lazy day … you're not absolutely fully focused on … .safety is always there … but perhaps going out of your way to be more efficient … I could have done this better … or I could have saved a fair amount of fuel." [ATCO5]
	Posters	"There is a lot of things we already do for that, posters in the tower with sentences that are meant to keep you focused … but I don't know if they really work and I wouldn't know what else to add to help." [ATCO10]
	Complexity of the work situation	"…constantly be switched on … you have to be focused … whether you have one aircraft or 10 or 15 on your radar screen." [ATCO1]
		"…more attentive to a situation that you think is difficult … or may become difficult." [ATCO3]
	Challenging scenarios	"…if something out of the norm happens … medical emergency, aircraft emergency, approaching thunderstorms … big traffic flow inbound … more attentive to a situation that you think is difficult." [ATCO8]
		collapsing sectors = more traffic = more airspace occupied and more potential conflict situations

		FAWB: "…complexity is a lot higher … due to the student training environment … new pilots all of the time… if you can't calculate that risk, then it's high chance you can make a mistake … we can't have ATCOs making too many mistakes in the environment. Current ATCO pass rate is one in four people." [ATCO10]
	Pilot's voice	"…tone of the pilot's voice when they read back to you … don't think I can say what tone or what it is, but when I hear a pilot saying something, that will make me decide to watch him because he is unsure of himself or he's lying or … and that's my personal opinion, but I think it's yet again experience and instinct." [ATCO10]
		"I can hear it in a pilot's voice … if a pilot says thank you a lot of times … and started asking questions. That's not normal. You should pay more attention to him. So abnormal behaviours normally sign … an abnormal situation in the cockpit … so if a pilot calls you somewhere he is not supposed to call in, especially once he is airborne and he is calling in. There is no reason for him to talk to you then; you give him priority … nine out of ten times, there's something wrong on the aircraft and he needs to come back and land. You can hear the urgency in the voice and it's not normal for him to call you then … it's an abnormal behaviour." [ATCO11]
	Type of aircraft	"…you decide a lot on what aircraft he is flying." [ATCO10]
	Sense of responsibility	"…having to be responsible and stay focused on what is happening around you." [ATCO1]
	Experience	"past experience tells you … you need to be attentive and act accordingly." [ATCO4]
	Self talk and mental preparedness	"get on with it … if you feel a bit lazy or not keen on working … tell yourself ... focus … sometimes I will jump straight in there with some other stuff in my mind … you have to tell yourself … do your work … getting the right mental state." [ATCO5]
	Expect the unexpected	"…subtle and/or big, therefore staying vigilant … being realistic and expecting the unexpected … following the cues." [ATCO5] "The warning ... that we get, the aircraft goes red … on the screen … and there's an alarm sound." [ATCO9]
	Noise	"…stop the noise and distractions around you…" [ATCO6] "…supervisor to answer outside calls from pilots or surveys". In this way, the ATCO can focus their attention on the task of controlling without having to take phone calls while on duty. "…from your radar screen …we have audio cues on the ground radar, but the system is not functioning 100% ... so a lot of the time, these audio cues are cancelled or dismissed without even thinking about it." [ATCO7]
		"less people in the radar hall … if they don't need to be there … even managers … need to ask or check the roster or check something." [ATCO4]
		Construction at the airport
		"…noise levels around you … people getting carried away with conversations … the people who are going on a break or coming back from a break … managers behind you chat … the chairs are quite old in the centre … when you sit down you end up going way back … you don't want to…" [ATCO6]
		"Noise levels do occasionally get to a point where it becomes distracting." [ATCO7]
		"A colleague engages you in conversation when you're busy and will talk to you about personal things." [ATCO4]
		"Visitors that are allowed and not visiting for the right reasons. The right reason would be an interest in aviation, scholars and young pilots learning to fly, people that are just there for an outing is a disturbance" [ATCO3]
	Environment	"Just focus on what you are doing, concentrate … not dwell on distractions such as air conditioning" [ATCO8]
	Scheduling of shifts	"…shorter working intervals and a shorter break … an hour break is just long enough for you to completely settle down and calm down … half an hour is just enough to give you that little break and do whatever you need to do. After half an hour, come back and work, you're not totally switched off and have to re-start the process again. After half an hour, you're fine to go again. You're still kind of with the picture." [ATCO11]
Perception		
		Real world perception "to see things, because as a radar ATCO … the picture is always a bit delayed, so when you control, you think of the actual scene." [ATCO5]
Flow		
	Relationships	"…if there is a person that you don't work well within a team at a different airport."
	Equipment	Air conditioner not working

			"…a mouse stops working or the radar." [ATCO4]
			"…equipment malfunction…" [ATCO8]
			"…can be something so small as a headset wire getting stuck in the chair." [ATCO11]
			"…unserviceabilities, broken equipment. Printer has been broken for four weeks; you can't print anything … like the weather report so that you can easily access it. Now you go to the computer, look at it, which is far away from your work station, to make decisions based on the weather … it can't be printed out and brought to you, so you have to go to the computer, which is far away from your position, in order to get information you need to do your job… It's one of the many little small things; headsets that stopped working while you trying to control, therefore change headsets, pens that don't work, cheap pens … aircons that fail in the summer…" [ATCO10]
			"…equipment in general, radios, antennas, like today's routine maintenance on the VOR … so it has to happen, so yes, runways is another one where it does slow down your work flow." [ATCO10]
	Operational factors		"…procedures that are not well written …work procedure design where you need to make another plan to be more efficient and you can save half the time … procedures should be designed to make things flow safe and efficient … often you have to fight against those improper procedures to hopefully make things safer and efficient. That gets frustrating … and you need to work harder to get going." [ATCO5]
	Dual role		[During a break] "I have to sit in the office and attend to admin duties … not relax in front of the TV." [ATCO3]
	Short staff		"…which means you have to cope with multiple positions." [ATCO10]
	Tower layout		"There is nothing I can change, I just work around it. We have pillars of invisibility; you're working the runway and it runs over here. If you have to look to your right, your final approach path, we have had quite a few incursions. If you look up and you don't see anything because it's behind a pillar. So you need to get up and move around. I am quite tall; when I get up, I start losing my traffic, because the view goes behind, it's not shortened. So it's just the tower layout. If I could rebuild the tower, I would take the London Southend's tower they have and drop it over here. I think it's a brilliant tower. It's about the same size. It has a really high roof, glass is perfectly slanted, nicely tinted, and there's no obstructions. You can look around. Nowhere there's a blind spot." [ATCO11]
	Situation awareness		
			"…in the background amongst other people and sometimes myself, when I have to point and I want to get it across, if somebody is having a conversation and something I can add to it,, but I'm busy controlling. I finish controlling and I hope they are still there when I'm done. They try and train us to be situationally aware. For me, that means if you are aware of your surroundings, what is happening around you as well as with you, so you pick up all the other stuff as well, not just work stuff."[ATCO9]
Workload			
			ATCOs may perform other duties that impact their workload
			"…not being placed in positions where you have to work combined sectors or be overloaded with traffic." [ATCO1]
Stress and anxiety			
	Confidence		"…when on training … the instructor deemed that my work was not good enough. I subsequently failed my progress check … knock on your confidence … and then you have to come back and you have to do the progress check again … you are a bit apprehensive and fearful, especially since you know that might be your last shift." [ATCO9]
			"There are days where nothing works … on days that happens, you normally, it's near the end of the shift, but the rest of the day was fine … or it picks up and improves after that … in the middle of the shift, if it is very busy and you made a bad decision and it snowballs from there, and then you have to recover … .and if you recover well, it ends up being a good day, and if you recover badly, you're left with a little bit of a down." [ATCO10]
	Personal		
		Moving house, selling and/or purchasing a home	"…getting the bond, being sure if you can afford the new bond … I think that stresses everybody out. There is lots to do – painting, waterproofing, quite a few things." [ATCO1]
		Stress with a landlord	"He turned off my electricity, he turned off my water before that. Overall, he just makes life harder and harder to rent from him. It's obvious he doesn't want us there, so we're trying." [ATCO10]
		Financial stress	"…getting broke from time to time … I was stressed as my kids were completing their final years of study and the study loans hadn't come through yet." [ATCO2]
		Family member's health	"…my father is disabled." [ATCO4]

	Personal health problems	One ATCO had not been permitted to work for 19 weeks due to health issues
	Pet's health	"My dog wasn't eating the last two weeks." [ATCO9]
	Argument with spouse/friend/family	"…the occasional tiff with my wife." [ATCO4]
	Not enough time with the children	"…juggling the attention and needs of the children … not enough time with my kids." [ATCO5]
	Anticipatory anxiety	One ATCO anticipated a holiday to China to be stressful, and had anxiety around getting shot at in the aircraft on the way.
	None	"…no personal stress…"
Work		
	Administration	ATCOs may perform other duties, having to balance administrative and controlling duties
		Lack of administrative back-up
		"…wear two caps. As a manager, it is stressful keeping staff happy, completing paperwork in time…" [ATCO3]
		"…acting pool manager. Extra admin keeps me quite busy … stressful, because … constantly on the go. Probably self-imposed." [ATCO5]
		"There is a lot of small things we have to do on top of ATC, which is paperwork-based … we're expected to do more and more of that type of work, which means you end up doing tons of paperwork that's not in your job description, so that someone else's job becomes easier." [ATCO10]
	Management	"…having to watch over your back."[ATCO4]
		"We are under a microscope at the moment. It's a bit daunting when you know somebody is watching over your every move and every step. They've got tapes, they just pull all the tapes back and then they review the tapes include radars, picture, what we say, what we say to our neighbours, phone calls, everything."[ATCO9]
		"Management and colleagues don't share the same beliefs and understandings of this job, occasionally putting efficiency ahead of safety … not being efficient at all." [ATCO7]
		"Currently, there is a bit of uncertainty, because the manager of the centre is on suspension and one of the other pool managers is also on suspension, so some people are rattled. Managerial developments in the centre, which is quite concerning – there's ructions between some pools due to this whole managerial thing. There is currently an investigation into two senior people working at Joburg centre … senior members of the pool (radar) interpreting rules to suit their situation … some of our senior managers have been suspended." [ATCO1]
	Traffic levels	"Busy periods can be stressful, as you need to divide your time or give everyone attention." [ATCO4]
		"…you've got to talk more, a lot more clearances, a lot more conflicts … as ATCOs, that's when we thrive … do our best … a lot of people will freeze and not be able to do it." [ATCO4]
	Instructor role	"It is my first student as a designated examiner, and knowing he is not up to standard and you fail him, it's going to have repercussions in his personal life, but if you pass him and he is not ready, you have friends flying, and is it really safe?" [ATCO11]
	No stress	
Mental alertness/awareness		
Increasing		
	Mindset	A clear head is necessary, and ATCOs have to engage their brains above any sophisticated tools with which they are provided.
		Maintaining vigilance even when it is not busy is a challenge.
		Have to be involved from start to end, at the handover both at the start and the end of shift.
	Adrenaline	"I suppose your adrenalin goes up, and, when it wears down, then you feel tired." [ATCO10]
		"When you are younger, you drive to work in fear of what is coming. You are scared, are you going to be able to handle this shift, you are very alert? Then, and much more at a later stage … you always have to be vigilant … you can never be too over confident … you have to always be careful … there was quite a transition for me … when I could drive into work and tell myself … now I need to concentrate … that is something I really miss … pure adrenaline, where you could feel it when at work … more recently I don't really … surge of adrenaline … probably like sniffing cocaine … I miss the adrenaline rush" [ATCO5]

Minimal	It was found that the majority of ATCOs did not do much preparation. "I don't think there is much one can do; when your shifts starts to the end of your shift, you've got to be involved. I go to work and I start working, when I take over, I start working, I don't prepare." [ATCO4]
Mental preparedness	ATCOs have to constantly be aware and mentally present.
Mental and physical activities	Routines and rituals that an ATCO may carry out in preparation for the start of a shift centred around the consideration of mental and/or physical activities that needed to be performed.
	"I start working …when I take over … when I plug in the headsets … I focus, now I am here to work, but I don't do anything to prepare." [ATCO10]
	"Cleanse your mind of anything worrying you, that is, put aside and focus on the position you taking over … be mentally prepared for the shift and focus just on the ATCO work." [ATCO3]
	"…being totally calm, relaxed and clearing my mind of anything and everything … by trying not to think about anything at all." [ATCO7]
	"You are already in a certain mindset when you walk into work … when we drive in and see the runway in use, and the weather … it's going to be good/bad depending on what can I expect for the day." [ATCO9]
	"…find your headset … decide with the other who is working where … stand behind that position to get a mental picture of what is going on … make sure water bottle is filled, bladder empty." [ATCO8]
	"…make sure before the shift I am well rested." [ATCO9]
	"…unwind my headset and start to take over … put the headset on before plugging it in … find a pen … takeover or open watch…" [ATCO10]
	"…going for a walk…" [ATCO10]
	"maybe a computer game or computer ... gets your mind ticking." [during a break] [ATCO4]
Factors that impact negatively on mental alertness	
Personal stress	"If I should have any personal issues during that day, I try and switch off and forget about it. I don't want to occupy my brain with other stuff other than work while I am working." [ATCO11]
Noise/Distraction	Visitors (people in the tower)
	"…people in the tower, that is, people that are not doing anything. There can be a lot of people in the tower, people visiting for incorrect reasons [just for an outing]. There was a consensus that visitors should be limited to those interested in aviation, such as young scholars and young pilots learning to fly." [ATCO3]
	Noise is a factor that causes distraction.
	"Because our job relies on listening to what people say, noise in the tower is your biggest distraction." [ATCO3]
	"Too many people in the cab or location of the tower to the apron as aircraft that taxi past are noisy." [ATCO3]
	"…people talking too loudly in the centre…" [ATCO8]
	"…background noise of just general chatter from people that's off position. That's my biggest distraction." [ATCO11]
	[Conversations] "Trying not to get involved with other people's conversations … or, if they are not busy, they may be chatting to each other and you have to try and block them out." [ATCO1]
	"…the conversations we have with each other." [ATCO3]
	"People talking … colleagues, friends … come and sit next to you and chat … maybe they're on a break. But they understand not to talk when it's busy." [ATCO9]
	"…environment where you're close, there is a station close to us where the assistants sit and sometimes they will converge and make a noise." [ATCO5]
	"…loud voices in the tower, any loud noises." [ATCO10]
	[People] "loitering around and watching you." [ATCO5]
	"…a night shift … wants to wipe your whole desk and console … you have to move away from the desk." [ATCO4] "…cleaner vacuums…" [ATCO4]
	"…window cleaners cleaning the windows, they are terrible. But they have to do it." [ATCO10]

		Management	"…micromanagement, the managers are like the principal and the teachers and we are the children – that doesn't work well with adults." [ATCO1]
		Environment	Temperature/adequate climate control. ATCOs emphasise the importance of being comfortable in their environment – the ambient temperature is not too hot or cold.
			[Ambient temperature] "If there is a big fluctuation … you don't want to be working busy spells while you are shivering with cold or sweating." [ATCO8]
		Traffic levels	"…constant movements outside does assist, as well as when the radio is busy … more traffic." [ATCO3]
			"…if the traffic movements are constant, I am a lot more alert than when it is quiet … i.e. constant movements outside … being busy … if you are not busy, then you lose attention … you need to find something to do … operationally related." [ATCO3]
			"…more traffic … the traffic volumes ebb and flow, increase and decrease … if it was constantly busy, I would be alert when the traffic volumes start dying down, you become less alert, more distracted." [ATCO9]
			"…know how much of the outside to tune out … and how much … to concentrate … it is based on how busy or how quiet it may be." [ATCO6]
			"While it is busy, your mind is fully focused on that … when there is a lull in traffic, I look to see what everybody is doing or who else is working in the area … usually you find lots of people are talking about stuff. When on position, you don't really have much time to think about other stuff … think about the traffic." [ATCO9]
			"If it is busy, you're still concentrating on traffic …you don't stop with that thought process, you feel literally the buzzer moment. If it's not busy, then I start planning out the rest of my day … what am I going to do after work…" [ATCO10]
		Rostering	"I am quite happy with the shift work and the way it works for me." [ATCO6]
			Shifts that are too long; breaks that are too short or not sufficient
		Clearing your mind (mindfulness)	"If there is nothing bothering you, then you are not thinking about it all of the time; therefore, you are not distracted by thoughts." [ATCO2]
			"…leaving personal stuff at home … sometimes it is difficult." [ATCO11]
		Support	"I am responsible for getting the necessary help, for example, if it's too busy or you can't handle something, then say something." [ATCO1]
			Taking on more than you can handle
		Restroom	Rested before a shift
			"I am pretty alert already… I think people need to rest … coming to work fully rested." [ATCO11]
		Instructor role	"Having a student requires a lot of mental alertness as an OJTI … you are constantly trying to think about what the student's next move is going to be and what impact it will have on safety and efficiency … trying to make sure that the student is emotionally well, by not getting upset with a student making a mistake or doing things slowly … not shouting or screaming at them … reassuring them that if something goes wrong or they make a mistake that I am here to fix and prevent disaster, and prompting the student to think the way that you want them to think in terms of moving the traffic" [ATCO7]
		Anticipation of shift	When an ATCO anticipates that a particular shift may be more challenging
		Audio cues	"…from your radar screen …we have audio cues on the ground radar, but the system is not functioning 100% ... so a lot of the time, these audio cues are cancelled or dismissed without even thinking about it." [ATCO8]
Cognition			
	Thought processes/patterns		To gain insight into the psychological impact of the ATCO's thought processes on operational safety
	On way to work		
		Mental preparedness	[ATCOs who think about work may subconsciously becoming mentally prepared for the shift. "The fact that I may get suspended … that would be my subconscious thought … my conscious thought would be not to get those two aircraft closer than what is allowed … suspended means that I won't be allowed to work for a period of time … I have to undergo an investigation … stigma that I've had an incident." [ATCO9]
			"If there is a challenging shift coming up, something out of the ordinary … reflect on it to get mental preparedness … familiarise myself with what is required." [ATCO5]
		Safety	"…starting the shift in the right frame of mind and hope that nothing goes wrong." [ATCO3]

	Weather	"…subconsciously look at the weather … you know whether it's going to be good for aviation or not …. see the aircraft in the sky … so you know what the runway's going to be … you can see what direction the aircraft are moving." [ATCO11]
	Non work-related	"…have radios on and listen to the news or to music, which would distract them from any kinds of thoughts." [ATCO8]
Handover		Vary greatly and link to mental preparedness
	Teamwork	Received and ensure the whole picture is understood, as well as double check what is required.
		"…get ready to handover … a clean slate and explain all that happened on shift to colleagues so they have a bigger picture to work with." [ATCO3]
		"…who is going to be on relief, what special considerations I'll brief them on … are they going to be on time?" [ATCO5]
		"…have I done everything that I was meant to … have I resolved all the conflict points? …is this traffic situation manageable for whoever is taking over?" [ATC07]
		"Where is my relief?" [ATCO9]
	Weather	Wind and/or any change in weather in terms of whether it will contribute to a more stressful shift
		"The first thing I do is look at the weather station … wind, runway. Where is the sun? Where is the traffic? …in that order." [ATCO10]
	Safety	"…check equipment and tools are in working order … or … try and build a mental picture of what might happen in the next ten minutes." [ATCO8]
		"…check whether there is any immediate situation that needs attention." [ATCO8]
		"I'm looking at … what they always tell us is that you're most likely to have an incident within the first 15 minutes of taking position … that's normally when you're most likely to have something go wrong. So try and be extra vigilant. Pay closer attention to everything that's said. Just ensuring I turn my mental alertness to the higher level required … by paying extra attention to everything that is said and just focusing on the job at hand and forgetting about what's for dinner tonight or when the next holiday is going to be." [ATCO11]
		"…how much sleep have I had." [ATCO9]
		"If you are on top of your game, you can do 10 things at once." [ATCO5]
		"Try not to dwell on something other than work … things that are happening in the company … like the politics … or a news article I have read…" [ATCO8]
		"I am pretty focused on position." [ATCO8]
		"Go home and rest." [ATCO9]
		"Have I done a good enough job to ensure safety and efficiency was not compromised?" [ATCO1]
		"You are likely to have an incident if you are not concentrating." [ATCO8]
	Team	"sum up the environment in terms of the team, the other sector's teams, personality traits of those ATCOs and adjust to working with them. Adjust to the environment rather than the environment adjust and the team adjust to me … if I know there is a weak link in the system then I would rather adjust to that than putting the link under pressure to adjust to my expectation". [ATCO5]
	Operations	Any operational requirements that are standard
	Teaching role	[Consider whether the student] "is prepared for whatever situations come his or her way." [ATCO7]
	No thoughts	Focus on the task at hand
		"…just do my job the way I was taught … very focused on the job at hand." [ATCO3]
	Activities	"If it's morning, what time I'm going to gym, rush to the shop after that and home. If it's an afternoon, think of what you going to eat, what time you need to be in bed if you working morning shift." [ATCO11]
		"What am I going to do when I get home, e.g., cook, watch Soccer World Cup." [ATCO2]
		"If it is lunch or supper time, then whether I should get something." [ATCO9]
	Relief	"I'm happy to be going home." [ATCO6]
Mid-shift		The ATCOs tended to think about similar things in the middle of their shift to the settling-in period.
	Safety	"Am I providing a safe and efficient service to everybody concerned?" [ATCO7]
		"Tune out the rest of your world … think about the actual controlling you are doing … you are always planning three steps ahead." [ATCO6]

	Break	"If you're busy or tired, then you look at the time and think of break." [ATCO5] "I don't really watch the time, I don't really care when the next break is." [ATCO5]
	No thoughts	"…not thinking of anything, until you hear something and make a decision based on what you heard … and you immediately do something about it … wait again … it's almost a blank mind, but you're consistently scanning … what you can see, what you can hear … with your senses, to see if you can pick up something wrong." [ATCO10]
		"when it's quiet … your thought processes often become discussions you're having with your colleagues, which always seem to be aviation related … and normally joking." [ATCO10]
	Current traffic situation	"The traffic that I am working … if there is traffic … it is usually only traffic that I think about … if it is quiet, then it depends what the topic of conversation is." [ATCO9]
	Distraction	"…construction which is not regular … look out the window and see people." [ATCO2]
	Enjoy work	"If all is going well, I don't want it to end, as I'm enjoying myself as I am passionate." [ATCO3]
Home from work		Similar thought pattern on the way home from work as on the way to work
	Sleep and rest	"It's quite mentally draining when you are on shift…" [ATCO9]
	Self reflection	"…what could have been done better or something new that was learnt." [ATCO9]
		"…a way of constantly improving what I am doing." [ATCO11] "I run through exactly what happened in my head … and think of how I could have done things differently or how I could have done things better." [ATCO9]
	Non work-related	Especially if nothing eventful took place
		"…what is to eat." [ATCO11]
		"…what has been spoken about on the news or what song is being played on the radio." [ATCO9]
Shift handover		
Activities		The same preparation tended to extend to starting a shift on returning from a break, as well as preparing to take a break and/or end the shift.
		This refers to ending a shift before going on break or prior to ending shift for the day.
		Physical and mental activities at the end of a shift and/or as the ATCO was about to take a break were explored.
		The most common activities that the ATCOs tended to engage in, included shift handover.
		With regard to handover, more than half of the ATCOs interviewed participate in handover at the end of shift or just prior to going on a break.
		[Handover is given] "to the next person, recollect the whole picture, consolidate the whole picture as reflected in front of you to give the next person a true reflection of what's happening. Stand behind the person to see if I am satisfied with what they are doing or with the picture as I presented it." [ATCO2]
		"Tidy up the scenario, get rid of as much complexities as you can, so that it's an easy handover … the next guy walks into an easier scenario … and get all the crap out of the way." [ATCO5]
		"wait for relief to come, go over in your mind what you need to tell them … you don't want to forget important information about what is going to happen, what is being planned … then they would take over position … and I would stand behind for a few minutes just to check that I had not forgotten anything." [ATCO6]
		"making sure that you have resolved as much of the conflict points or streamlined the traffic such that in a way it is manageable for the next person taking over to do so with minimal effort." [ATCO7]
		"Ensure that all of the movements are in order." [ATCO3]
		"Ensure the mental picture can be accurately handed over for the colleague to start the shift in a relaxed and understanding frame of mind." [ATCO3]
		"Make sure that all the relevant details are passed on to the next ATCO … so when he takes over, he's got all the details to continue." [ATCO8]
		"You pass on all the relevant information for the next ATCO to continue doing the job in the same way." [ATCO8]
		"Just before I go on break, I start ensuring that if there is any aircraft overdue or close to the time that they had to be here … make sure they are here or I know where they are, so I can give a clean handover to the next ATCO." [ATCO11]
		One ATCO emphasised that nothing is done.

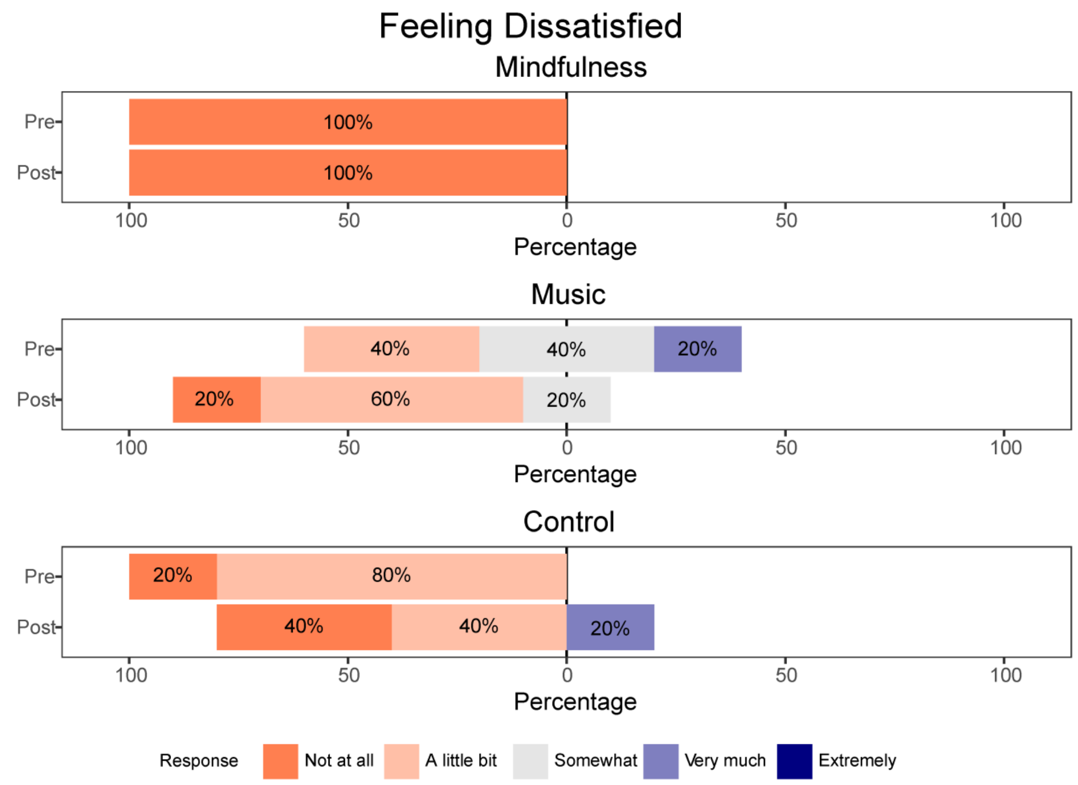
		"I don't have to prepare for a break, I just go on one … I don't prepare for a break or going home … it is something you do at the end of a shift." [ATCO8]
		Other ATCOs tend to constantly watch the clock.
		Others refer to standardising everything.
		"I start tidying up the work area around me, normally stand up and make sure that everything is neat for the person who is going to take over, or if I'm closing for the evening, then I just go through the whole tower … instead of just the work environment in front of me, the whole tower, making sure the chairs are in place, cups are put away, that you leave the work environment clean and neat … not always possible to have it perfect … turn off the lights … leave the runway lights on." [ATCO10]

Physiological Factors

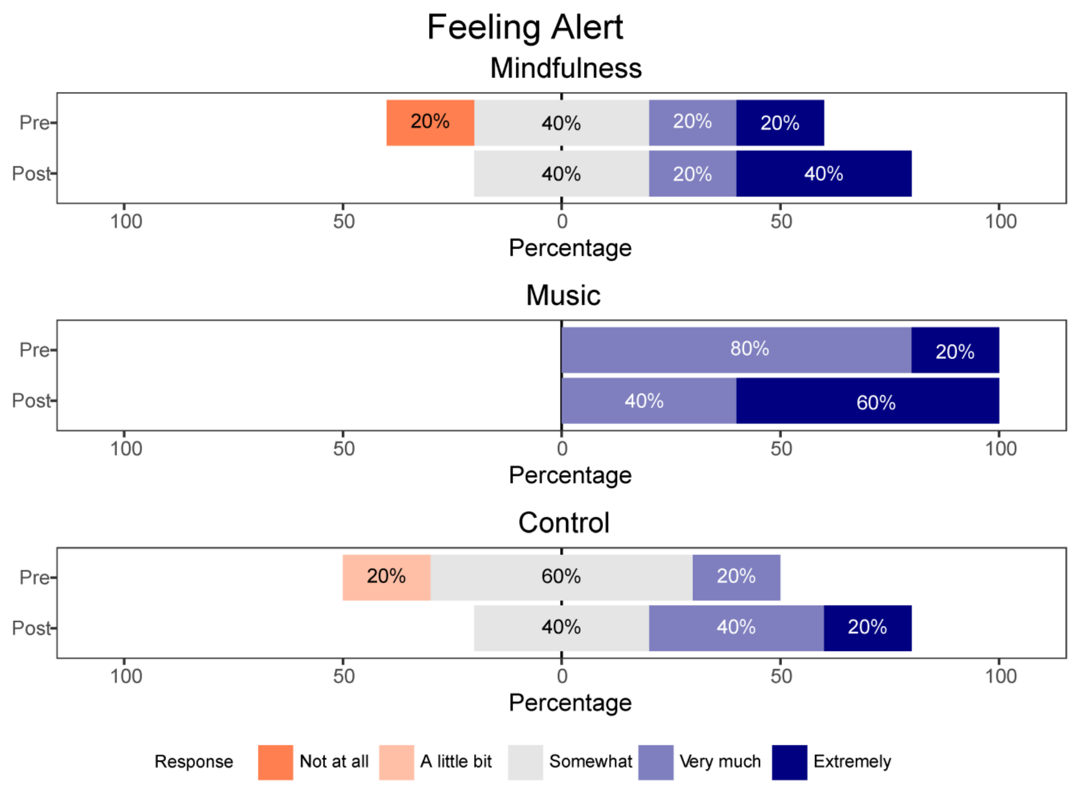
Nutrition/hydration		
	Inadequate nutrition and hydration	Poor hydration on shift due to inadequate intake of water and lack of adequate nutrition
		A reason given by many is that there may not be anywhere nearby to purchase food, such as a canteen.
		Tending to eat irregularly and inconsistently, for example, either eating prior to commencing shift and then nothing until completion of shift, or eating once during shift or not eating at all; the importance of food. "…regular, proper, healthy food." [ATCO6]
	Nutritional habits	"easier access … if you want to buy food from the canteen or fast food shop." [tea and coffee] "We already drink too much." [ATCO8]
	Hydration	Another trend identified as inadequate hydration; ATCOs do not drink water consistently while on shift. If they consume liquids on shift, it tends to be coffee or tea. In one instance, an ATCO did not take any fluids in from the time he got up in the morning until after the shift. Inadequate nutrition and hydration could impact negatively on ATCOs' performance.
Fatigue		
Medical conditions		
	General medical conditions	ATCOs preferred not to disclose medical conditions and medication.
		ATCOs seemed especially resistant to disclosing information relating to general medical conditions.
		This may be due to a fear of how this information may be interpreted or utilised.
		The majority of ATCOs interviewed denied the existence of any medical conditions, while a minority confirmed the presence of medical conditions, which include high cholesterol, acne, stomach ulcers, and the absence of a thyroid gland.
		It is possible that the ATCOs may have preferred not to disclose the presence of any medical conditions as they feared an impact on their fitness to work.
		ATCOs interviewed were not on any medication, while a small percentage were on vitamins, an antibiotic for acne, and another on Eltroxin.
		There appears to be an overall apprehensiveness and insecurity within the sample of ATCOs interviewed that their jobs could at risk should they not adhere to stringent rules and regulations.

Appendix G

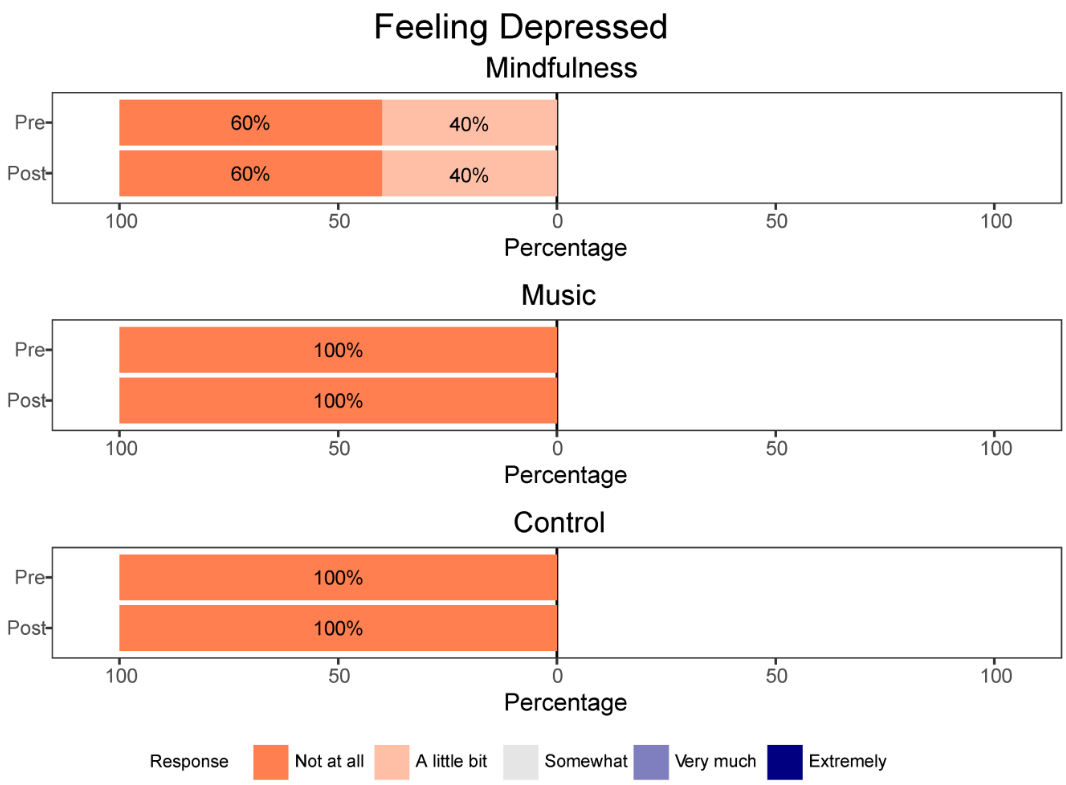
Results: SSSQ Individual Scale Items



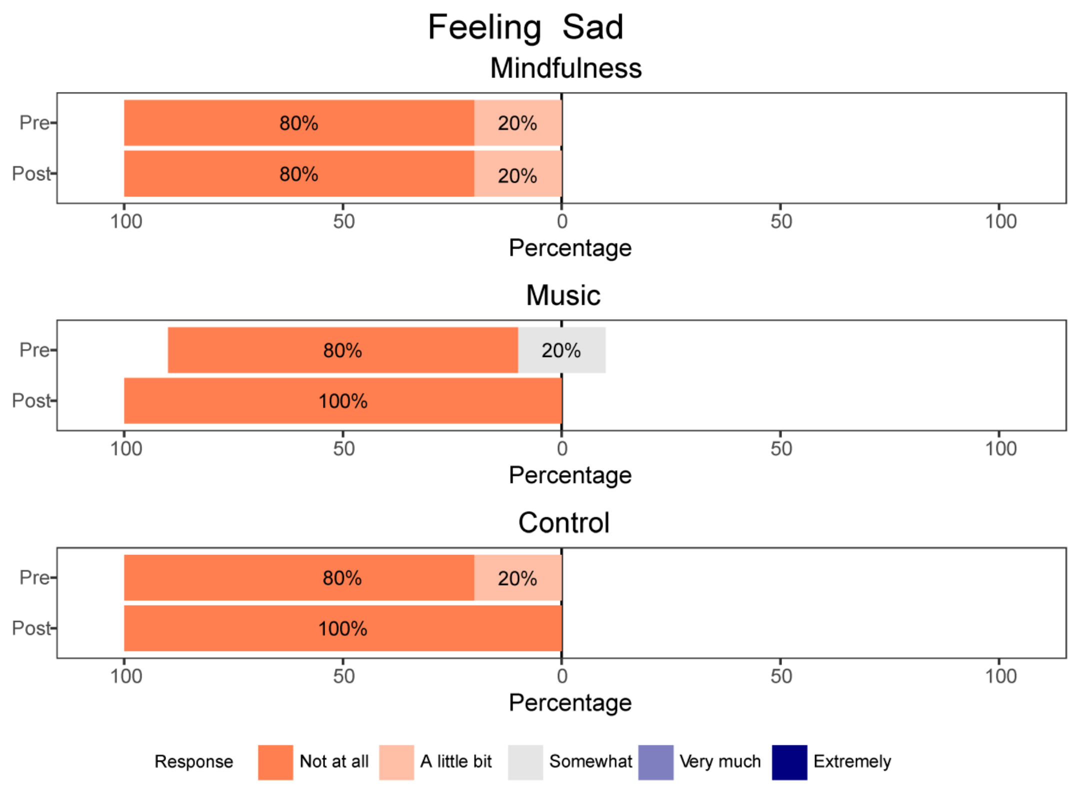
In the mindfulness group, no one was feeling dissatisfied before, and no one was feeling dissatisfied after. Therefore, there was no change in level of dissatisfaction. With the music intervention, ATCOs felt slightly dissatisfied before and less dissatisfied after; therefore, a slight improvement. The control group went from not dissatisfied to slightly dissatisfied; therefore, a slightly deterioration.



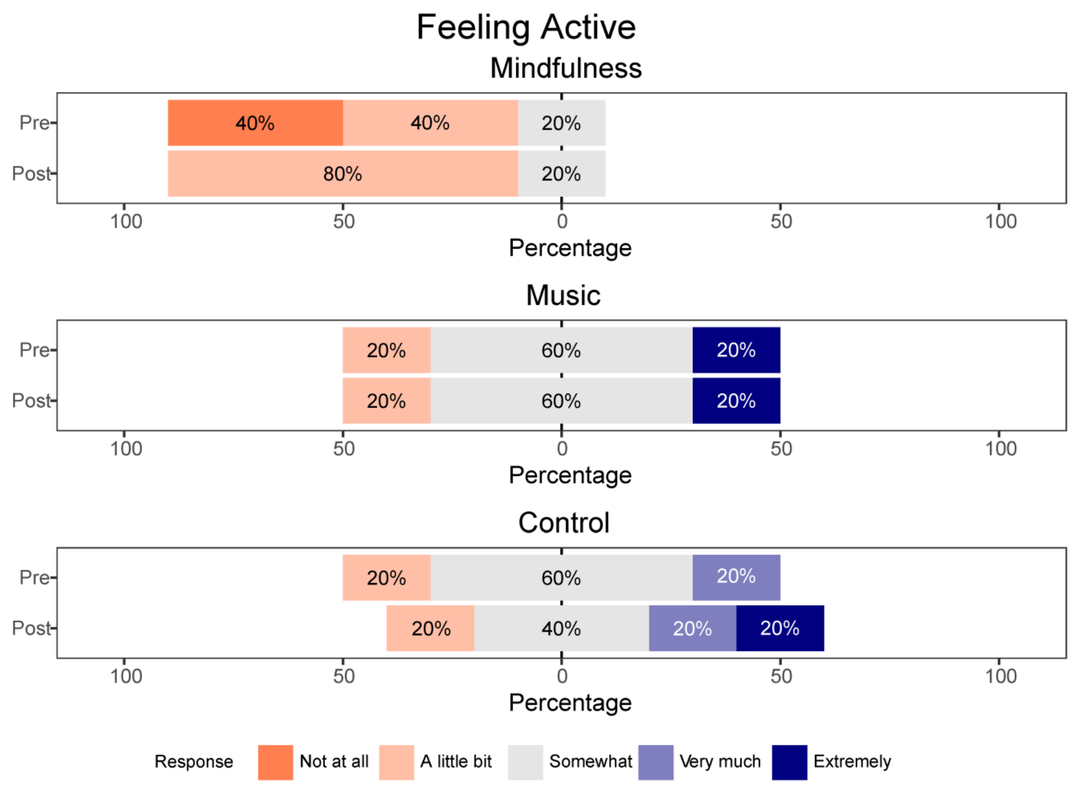
In the mindfulness group, ATCOs started off feeling somewhat alert and became a lot more alert; therefore, a considerable improvement. In the music intervention, ATCOs started off feeling very much alert, but achieved an even higher level of alertness; therefore, again an improvement. ATCOs in the control group started off feeling somewhat alert and became more alert. Therefore, all three groups demonstrated an improvement in alertness. The differences between the groups were, however, small.



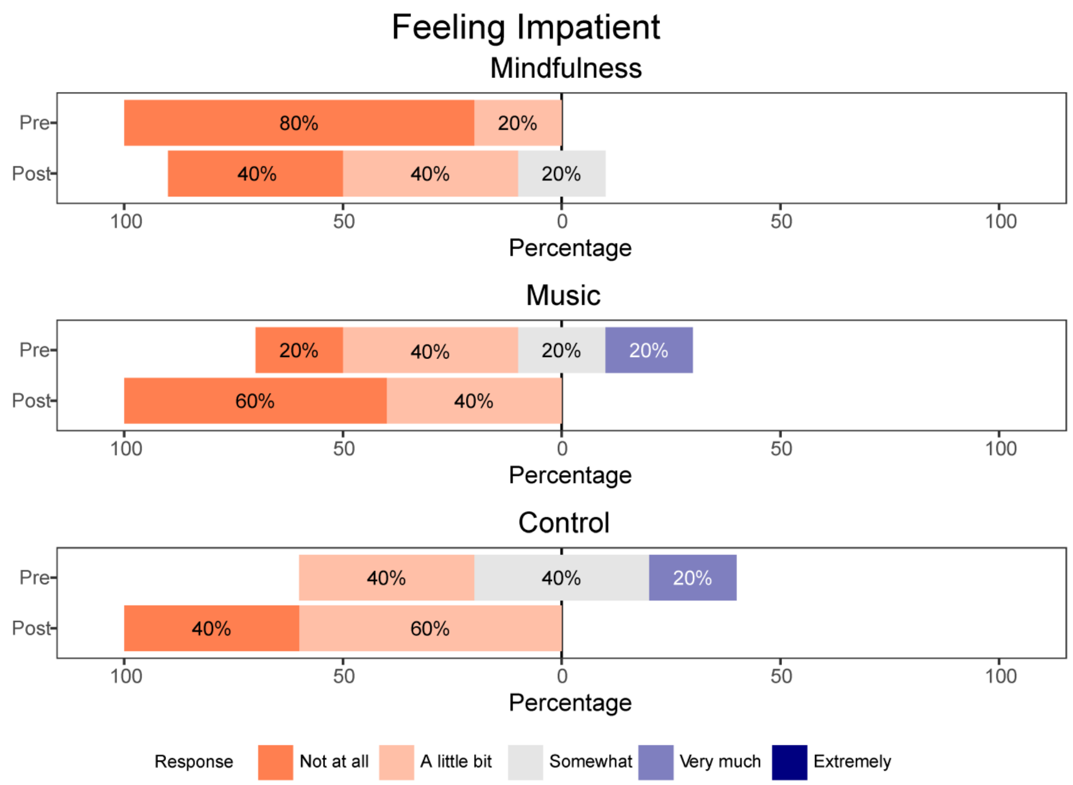
In the mindfulness, music and control group, no change can be noted in the ATCOs with regards to feeling depressed.



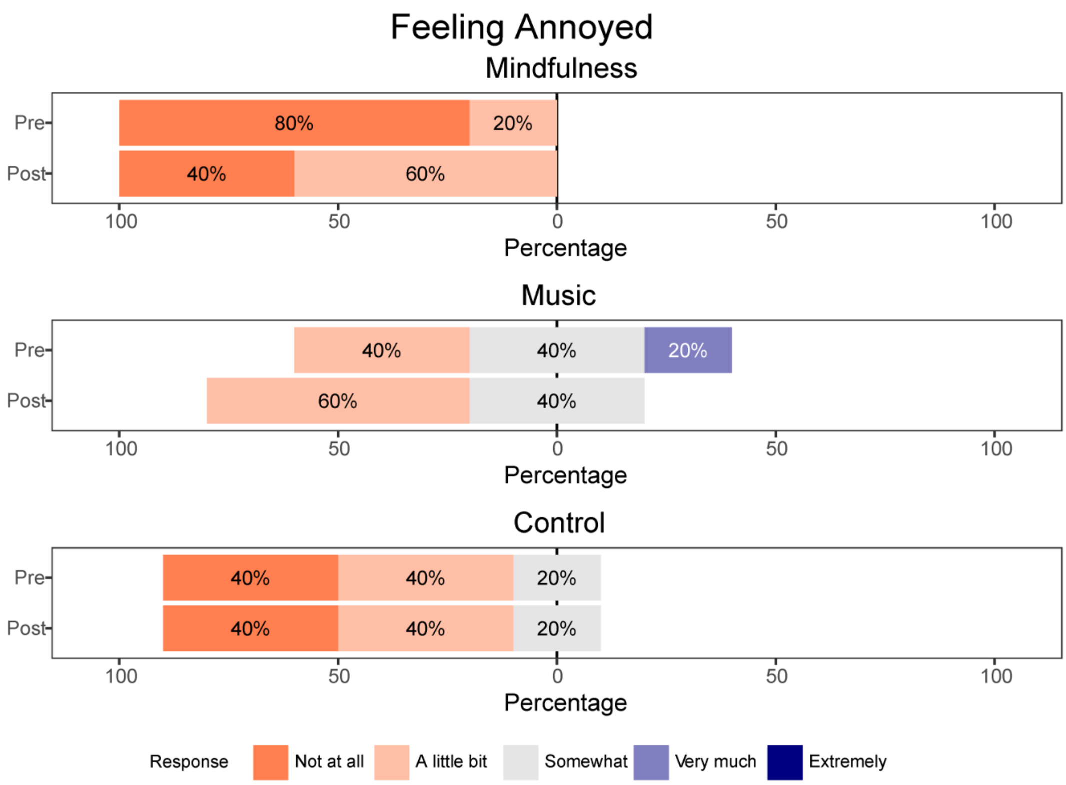
In the mindfulness group, no change in feeling sad could be noted in the ATCOs while in the music condition there is an improvement whereby the ATCOs felt slightly sad and changed to not feeling any sadness at all, while ATCOs in the control group became slightly less sad.



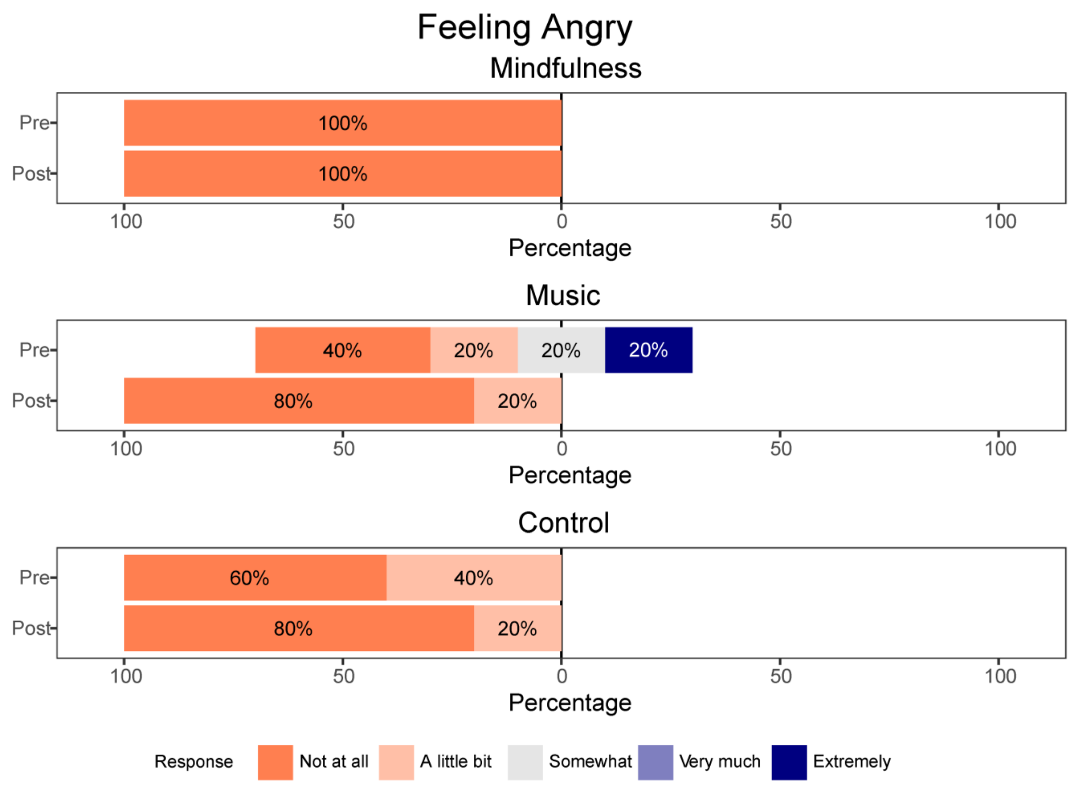
In the mindfulness group the ATCOs felt less active at the start and at the end they feel slightly more active (i.e. a slight improvement). In the music condition there was no change. In the control group there was a slight improvement in feeling active.



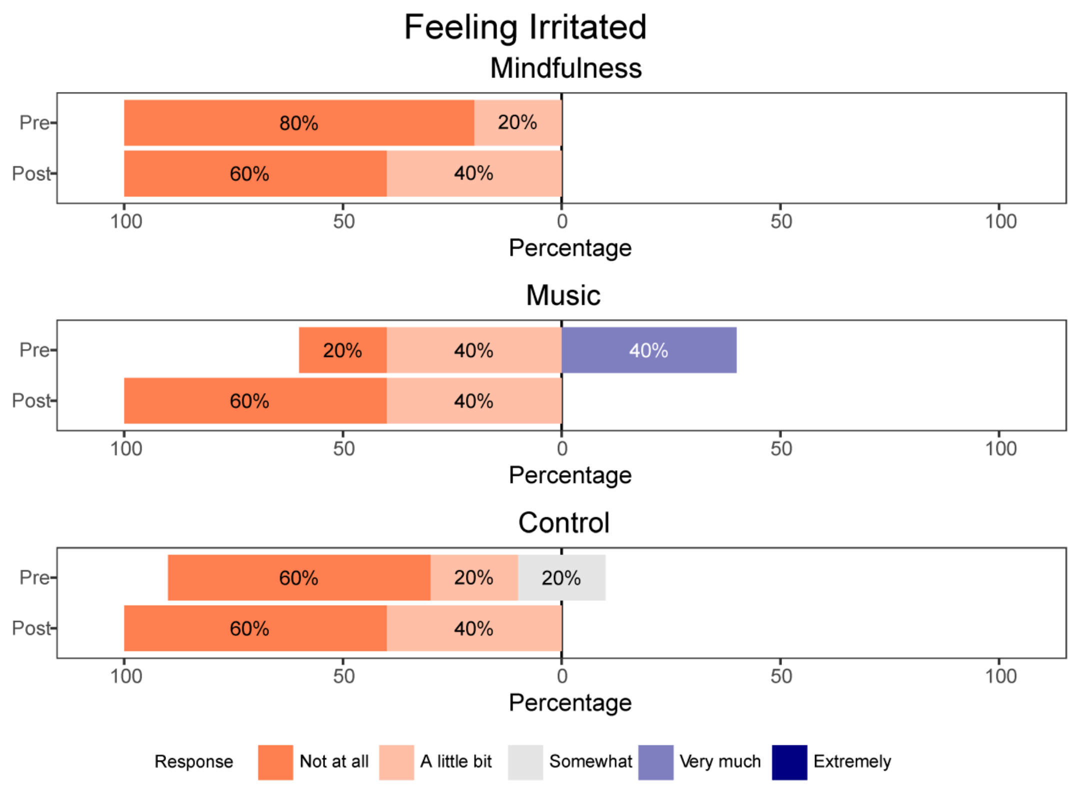
In the mindfulness group, ATCOs became more impatient while in the music condition and the control condition, the ATCOs become less impatient.



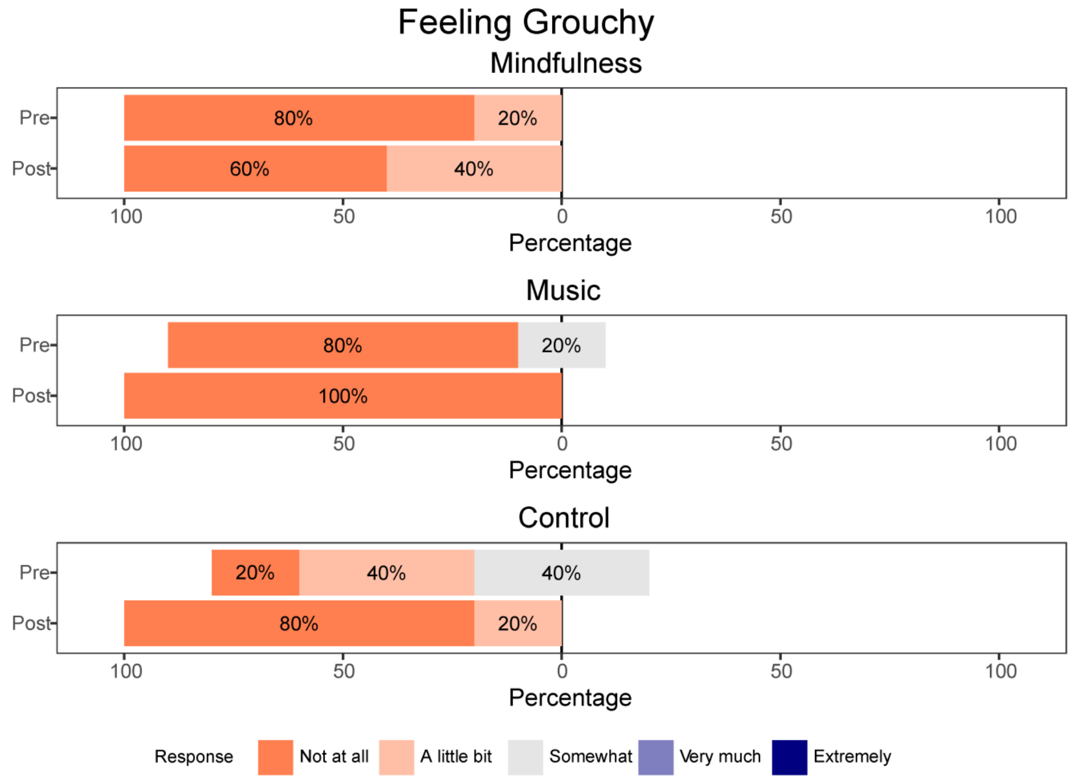
In the mindfulness group, there was an increase in levels of annoyance in the ATCOs while in the music condition, there was an improvement whereby the ATCOs became less annoyed. No change was noted in the ATCOs in the control group with regards to feeling annoyed.



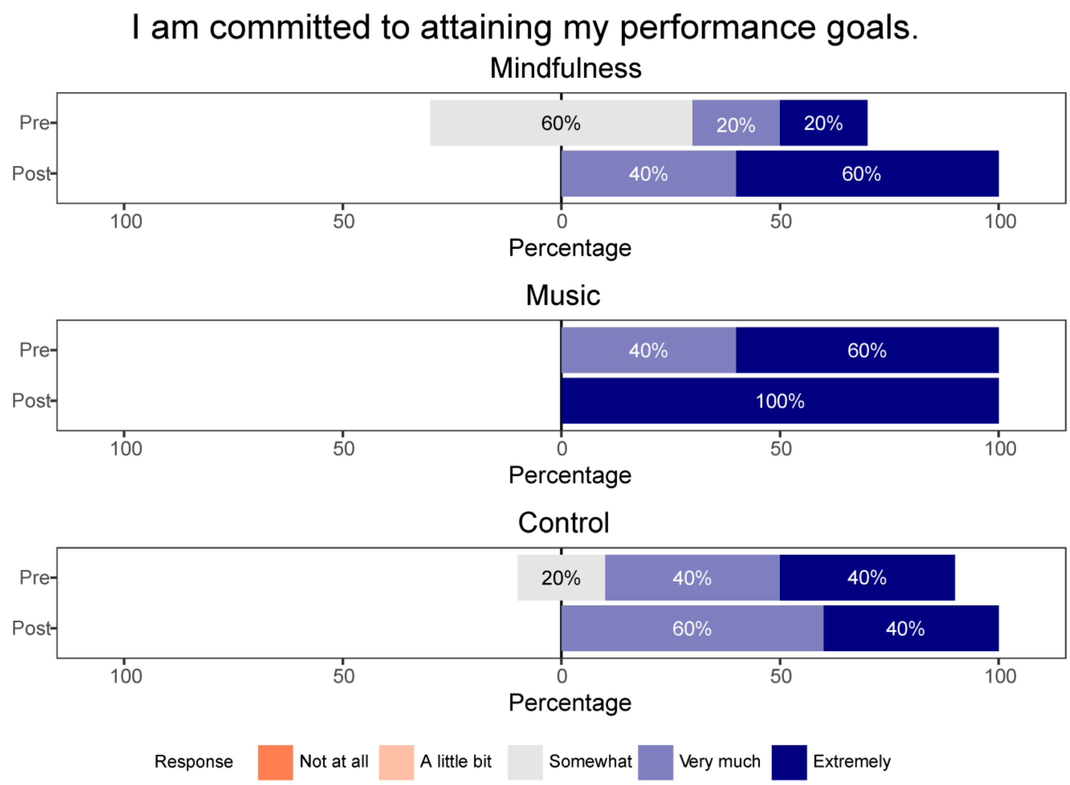
In the mindfulness group, there was no change in the ATCOs with regards to feeling angry while in the music and control condition, there was an improvement in levels of anger whereby the ATCOs become less angry.



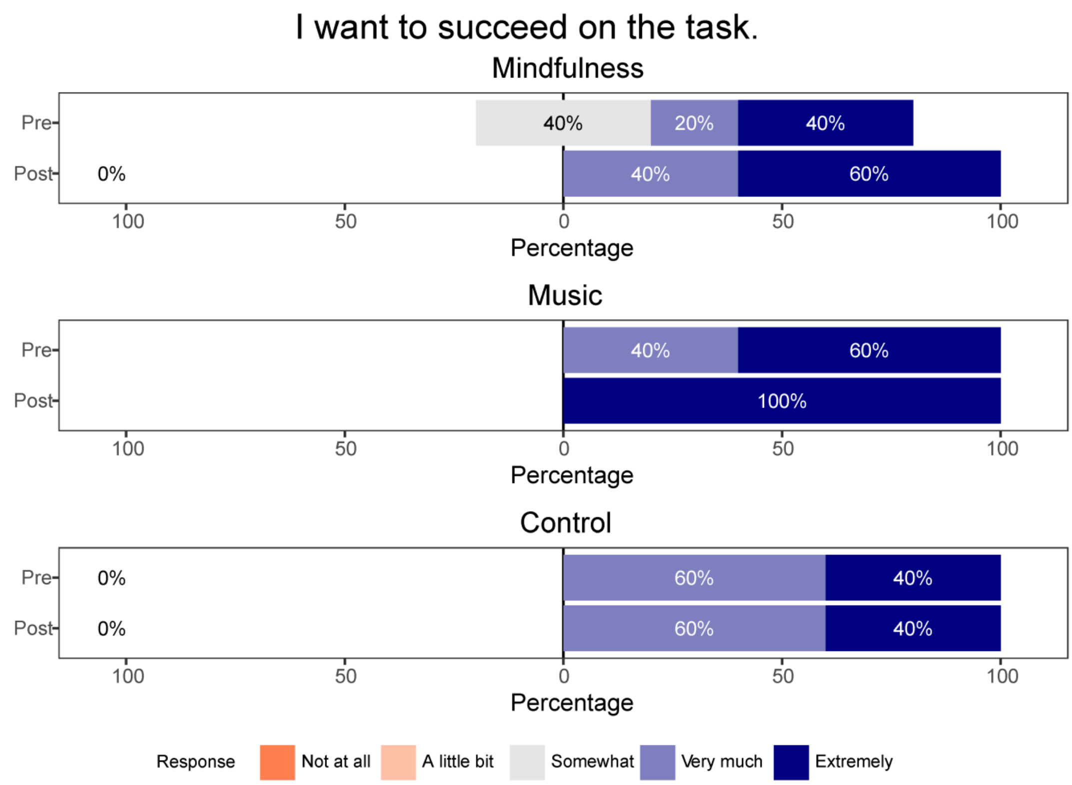
In the mindfulness group, there was a slight deterioration in irritability while in the music and control groups there was an improvement in feeling less irritated.



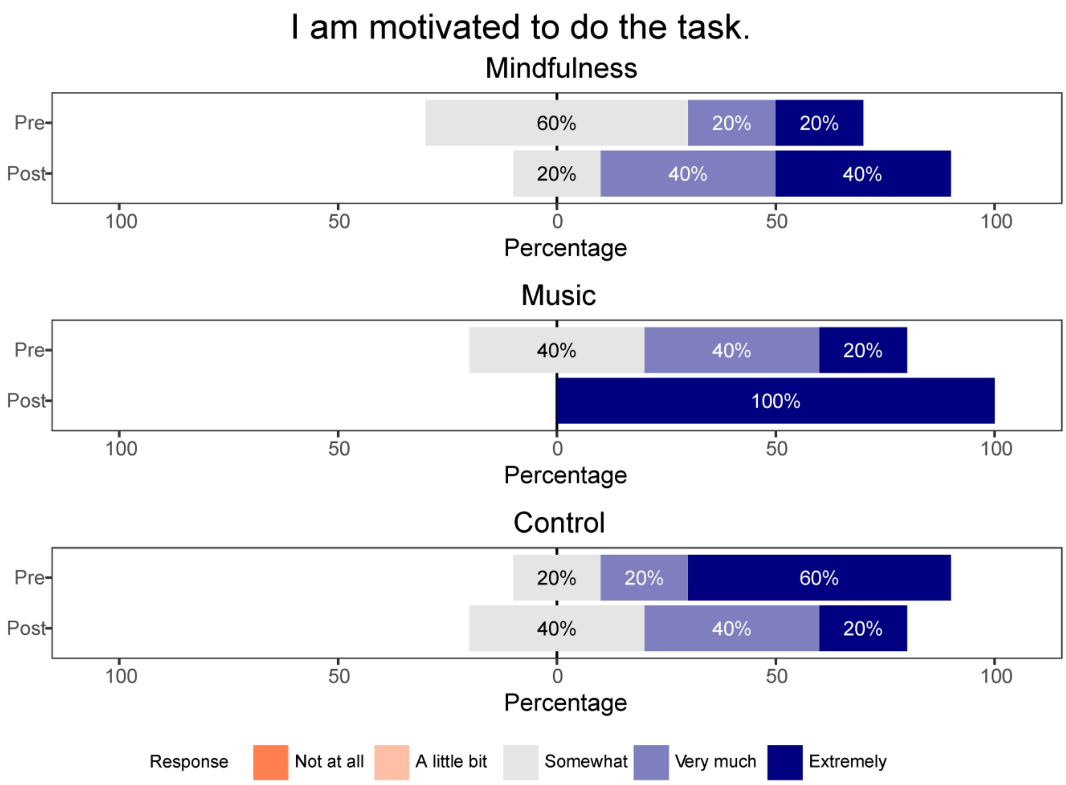
In the mindfulness group, ATCOs were observed to feel slightly worse (i.e. slightly more grouchy), while in the music and control conditions, an improvement can be noted in feeling less grouchy.



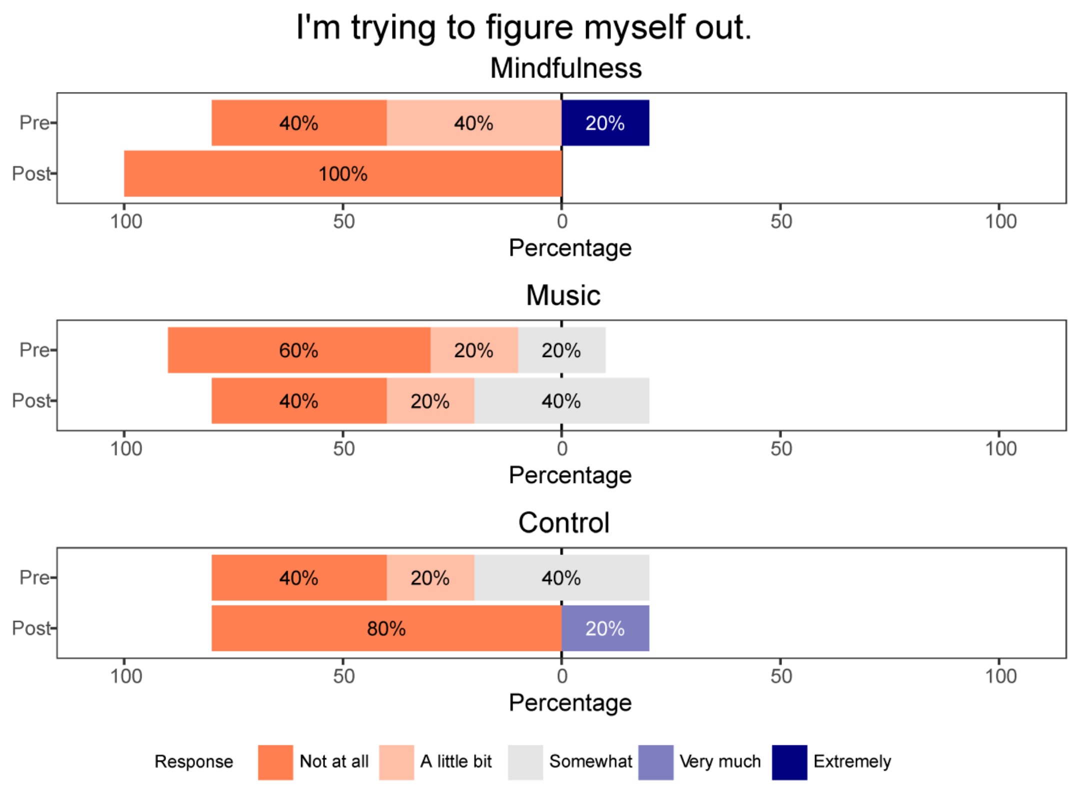
In the mindfulness, music and control groups, there was an improvement in levels of commitment (i.e. ATCOs became more committed to their performance goals).



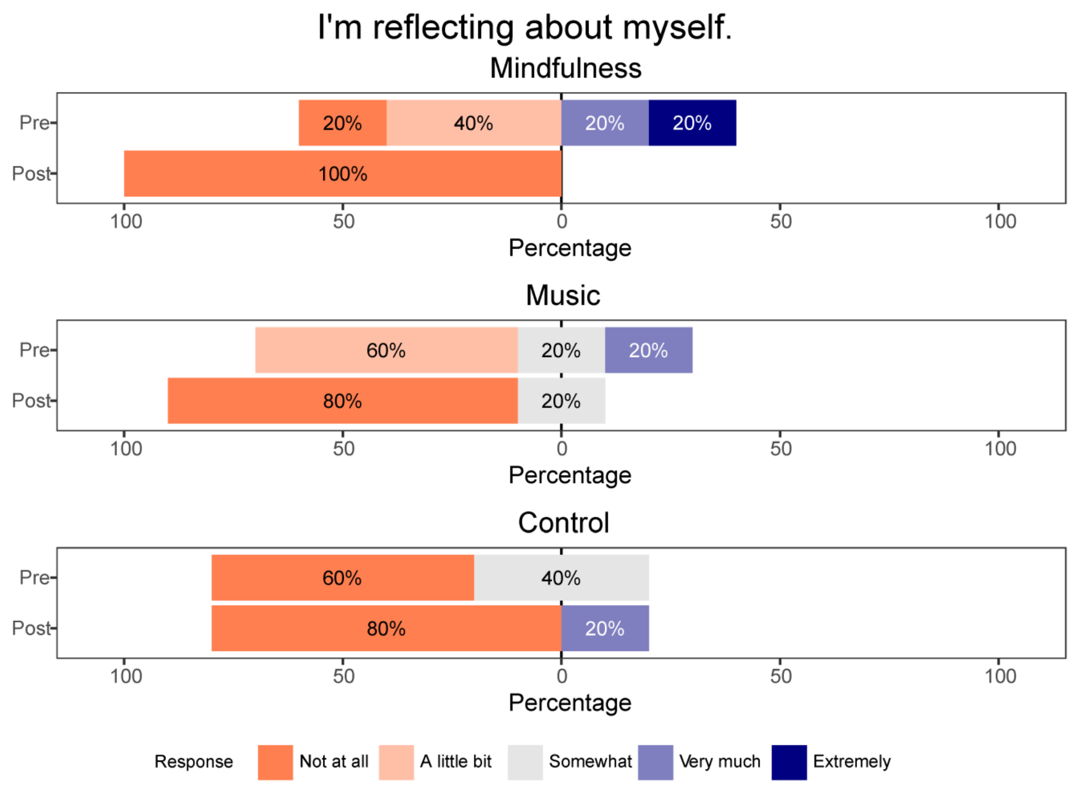
Motivation to succeed on a task improved in both the mindfulness and music group while no change was observed with regards to motivation to succeed on a task in the control group.



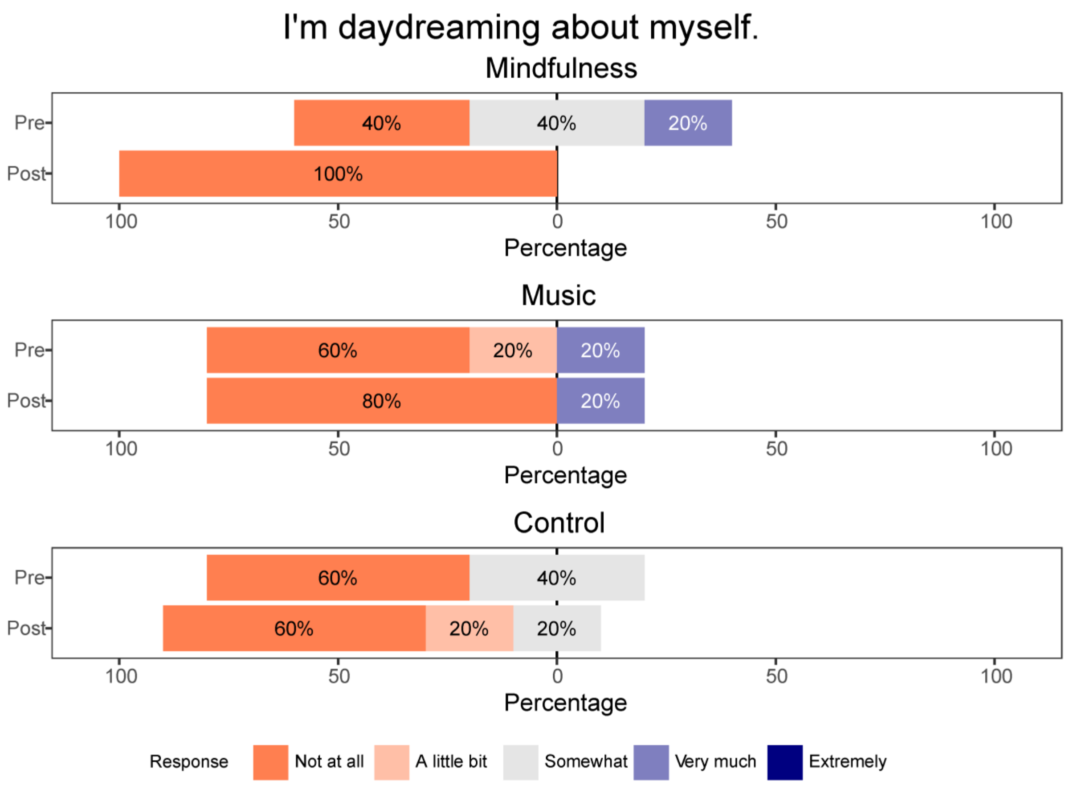
With regards to being motivated to perform the task, there was an improvement in motivation to perform the task in both the mindfulness and music groups while the motivation to do the task became lower in the control group.



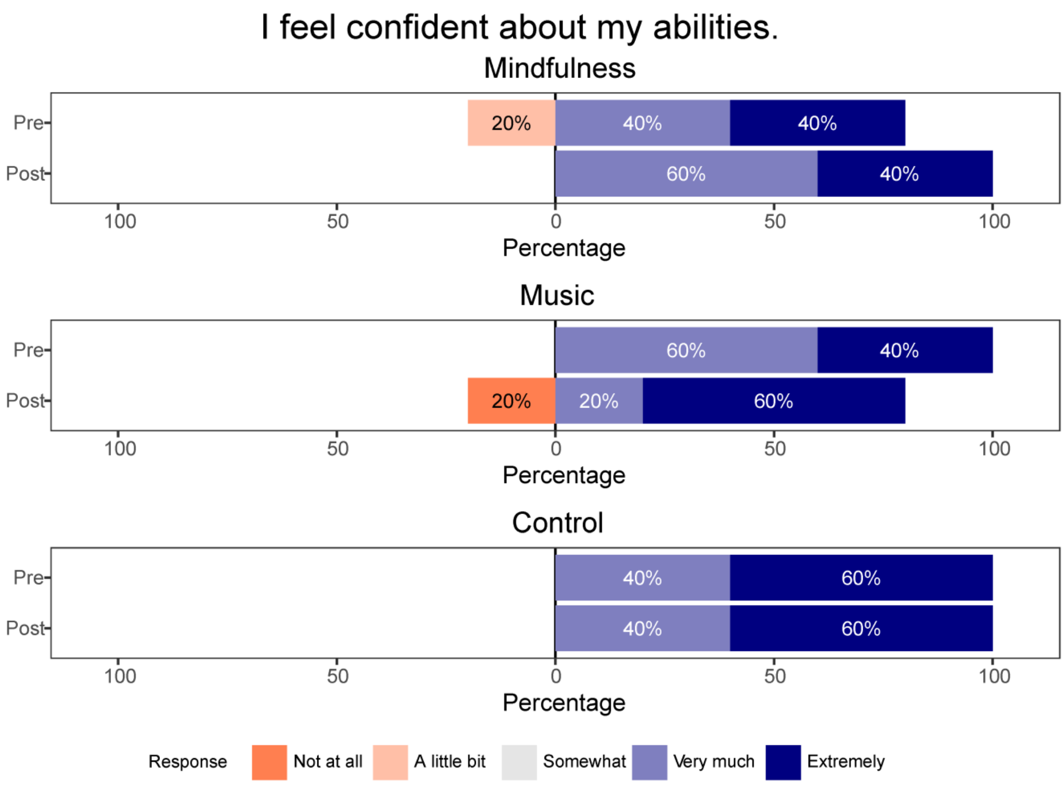
When considering ATCOs trying to figure themselves out, it can be observed that ATCOs attempts to figure themselves out becomes lower in the mindfulness group while their attempts to figure themselves out increased in both the music and control groups.



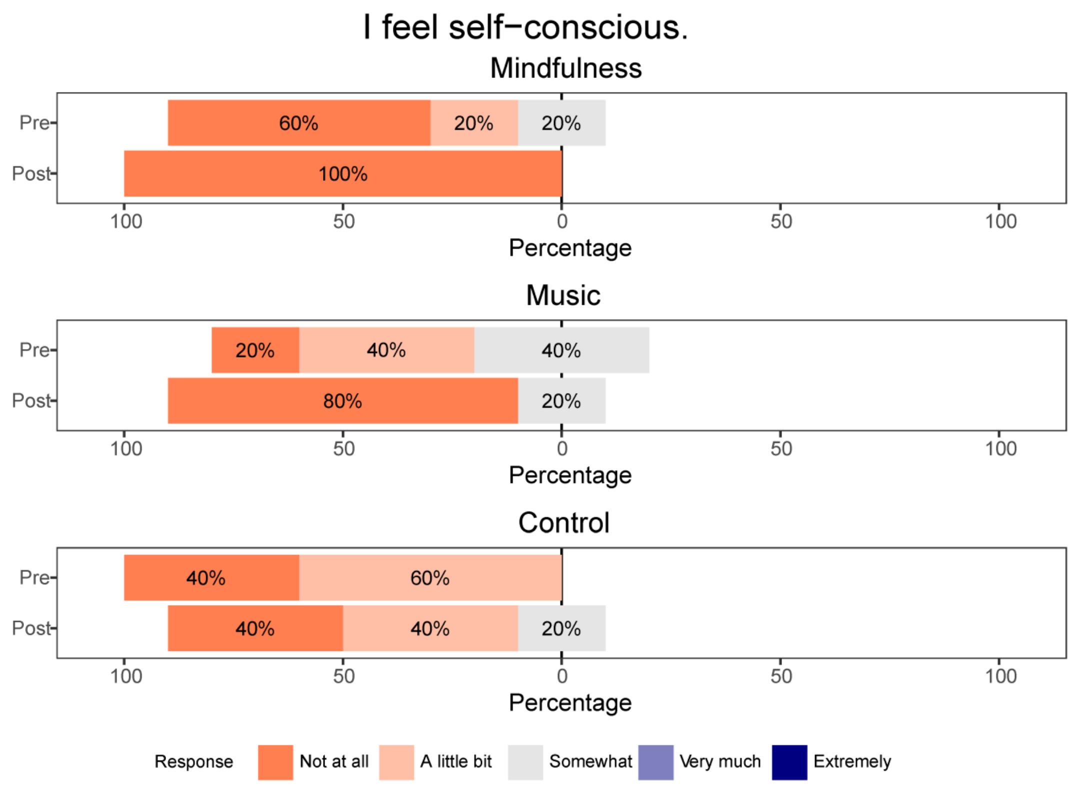
In the mindfulness and music group, the tendency of the ATCOs to reflect about themselves became lower, therefore mindfulness and music interventions did not help the ATCOs to reflect about themselves. In contrast the tendency for ATCOs to reflect about themselves while it did in the control condition.



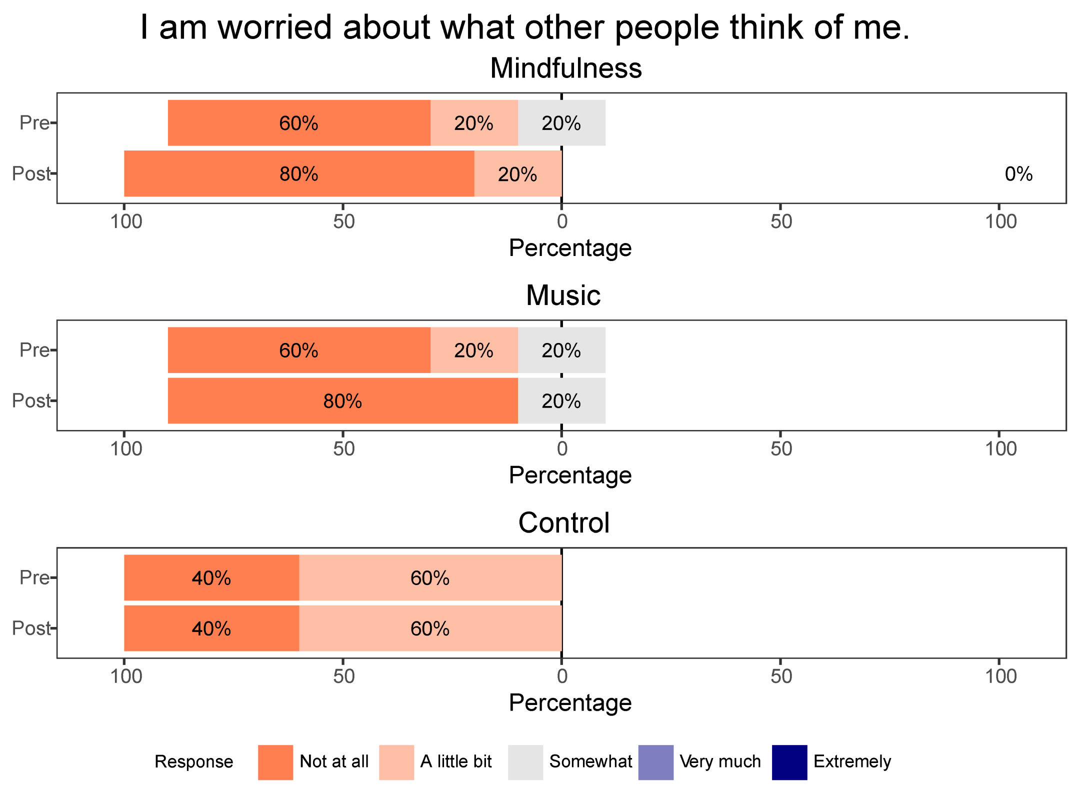
ATCOs tendency to daydream about themselves became lower in the mindfulness, music and control groups.



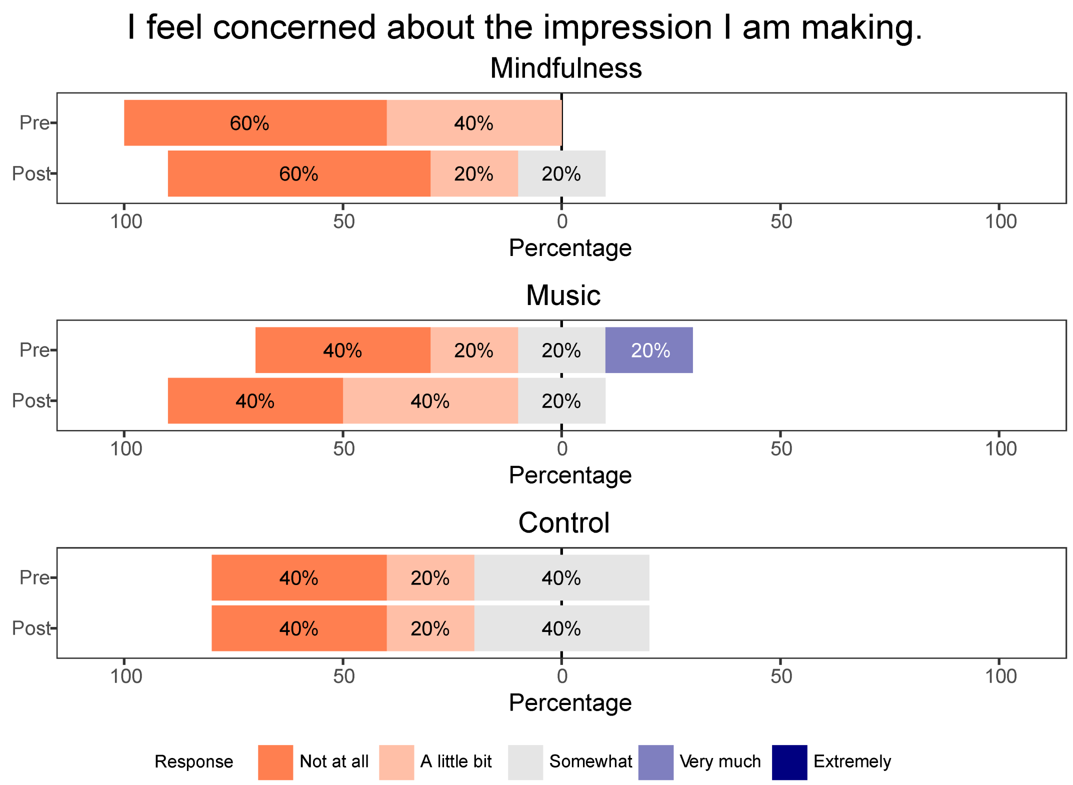
In the mindfulness group there was an improvement in the level of confidence in the ATCO's abilities, while in the music condition the ATCO's confidence deteriorated and there was no change in confidence about their abilities in the control group.



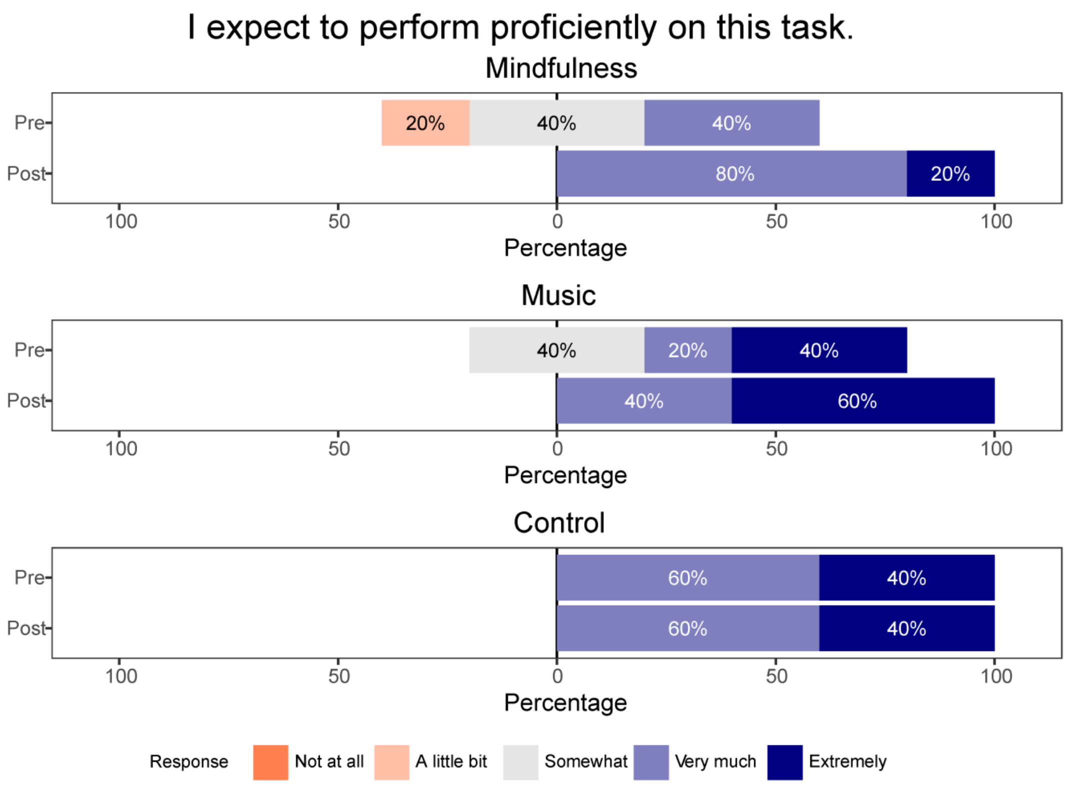
In both the mindfulness and music conditions the ATCOs felt less self-conscious, while in the control condition ATCOs felt more self-conscious.



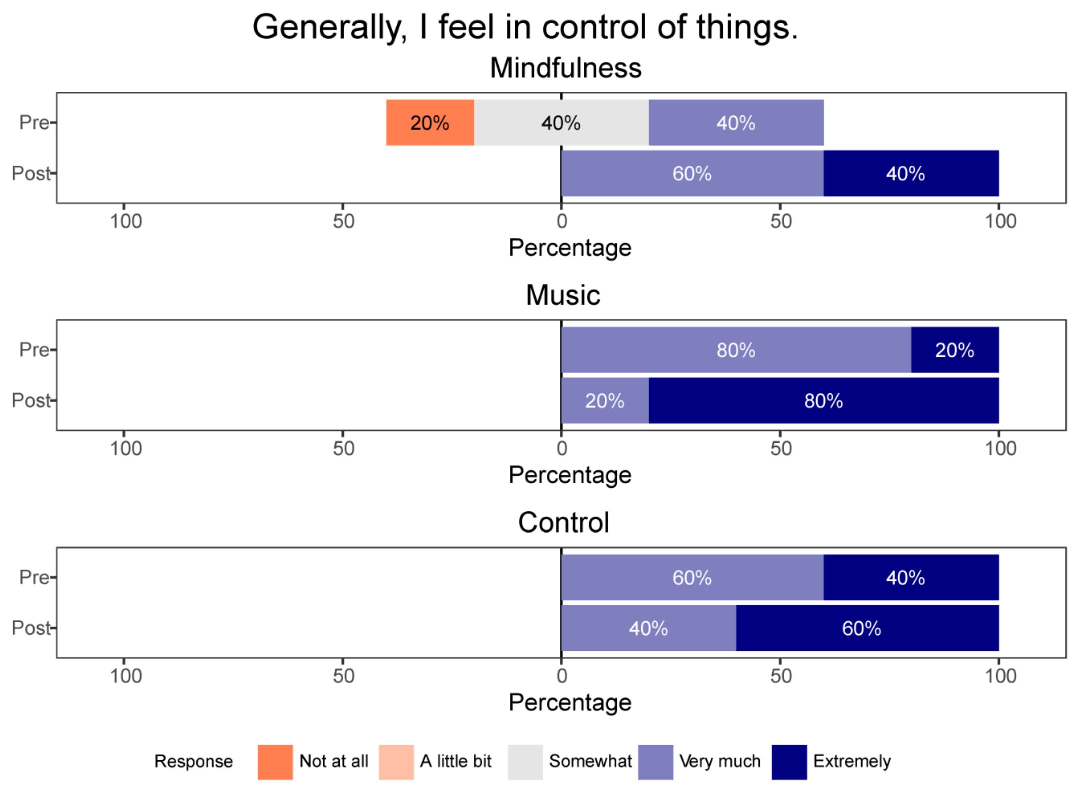
In the mindfulness and music conditions, ATCOs tendency to worry about what other people thought of them lowered (i.e. they worried less) while in the control group there was no change in the ATCOs tendency to worry about what other people thought about them.



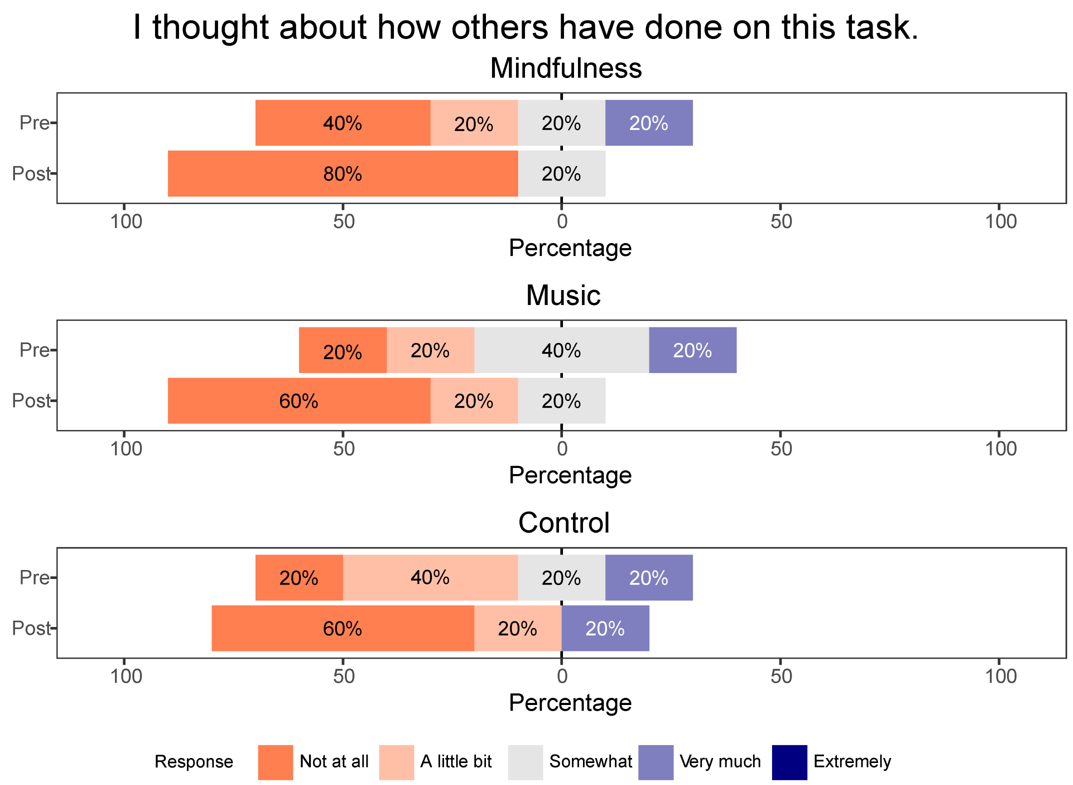
In the mindfulness condition, the ATCOs become more concerned about the impression that they were making, while in the music condition, the ATCOs became less concerned about the impression they were making. In the control condition there was no change in the ATCOs concern with regards to the impression they were making.



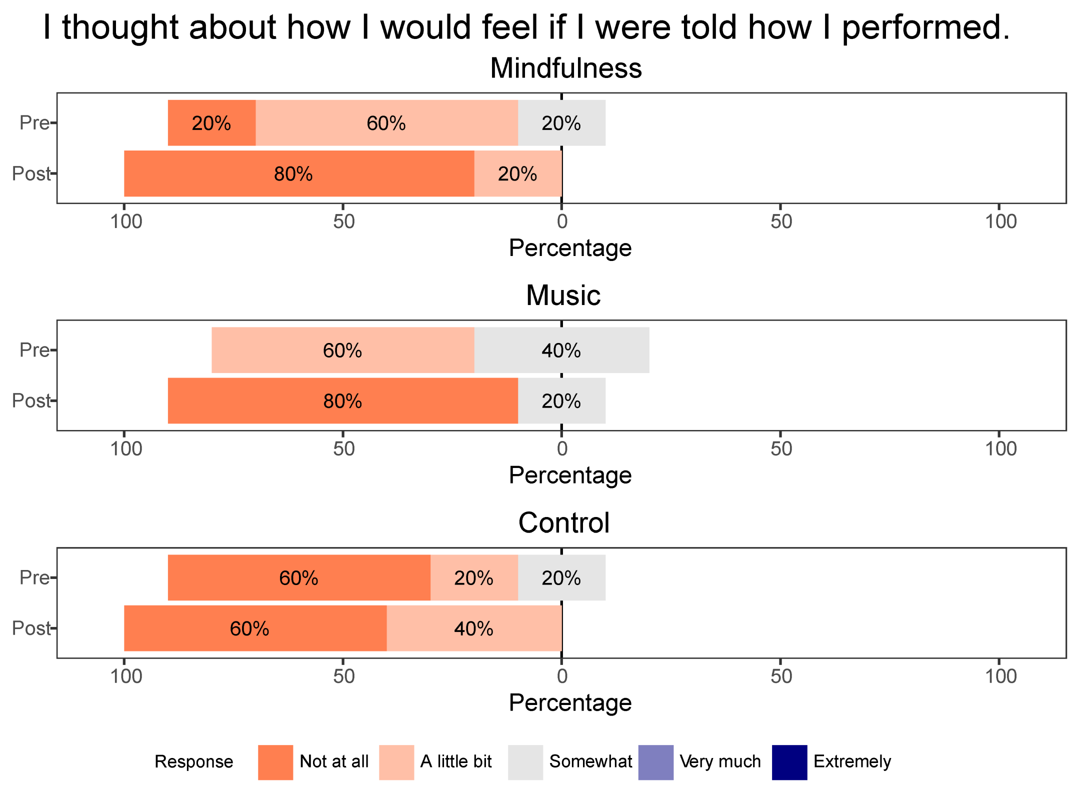
In the mindfulness and music conditions there was an improvement in the ATCOs expectation to perform proficiently on the task, which reflects an improvement in self-confidence and self-belief. In contrast, the ATCOs in the control condition did not shift with regards to their expectancy to perform proficiently on the task.



In all three groups, the ATCOs felt more in control of things, which highlighted an improvement.



ATCOs in both the mindfulness, music, and control groups thought less about how others have done on the task.



In all three conditions, ATCOs tended to think less about how they would feel if they were told how they performed.

Appendix H

Ethical Clearance Certificate

Research Office

HUMAN RESEARCH ETHICS COMMITTEE (NON-MEDICAL)
R14/49 Slater

CLEARANCE CERTIFICATE	**PROTOCOL NUMBER: H16/08/30**
PROJECT TITLE	Task engagement and flow in the operational safety of South African air traffic controllers
INVESTIGATOR(S)	Mrs B Slater
SCHOOL/DEPARTMENT	Human and Community Development/
DATE CONSIDERED	19 August 2016
DECISION OF THE COMMITTEE	Approved
EXPIRY DATE	18 September 2019

DATE 19 September 2016 **CHAIRPERSON** J Knight
(Professor J Knight)

cc: Supervisor : Professor A Thatcher

DECLARATION OF INVESTIGATOR(S)

To be completed in duplicate and **ONE COPY** returned to the Secretary at Room 10004, 10th Floor, Senate House, University.

I/We fully understand the conditions under which I am/we are authorized to carry out the abovementioned research and I/we guarantee to ensure compliance with these conditions. Should any departure to be contemplated from the research procedure as approved I/we undertake to resubmit the protocol to the Committee. **I agree to completion of a yearly progress report.**

B Slater
Signature

12 / 10 / 2016
Date

PLEASE QUOTE THE PROTOCOL NUMBER ON ALL ENQUIRIES

Appendix I

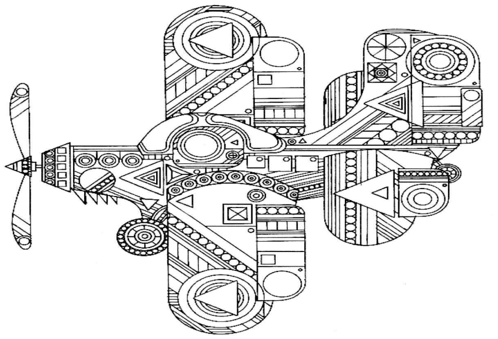
Music Playlist

1. Danger zone (Kenny Loggins)
2. Lose yourself (Eminem)
3. Beat it (Michael Jackson)
4. Good vibrations (The Beach Boys)
5. I wanna hold your hand (The Beatles)
6. Bohemian rhapsody (Queen)
7. I can't get no satisfaction (Rolling Stones)
8. We will rock you (Queen)
9. RESPECT (Aretha Franklin)
10. Rip tide (Vance Joy)
11. It's my life (Bon Jovi)
12. All summer long (Kid Rock)
13. Hold my hand (Jess Glynne)
14. Party in the USA (Miley Cyrus)
15. Ain't nobody (Felix Jaehn/Shaka Kahn)
16. Get outta my Way (Kylie Minogue)
17. Hungarian dances No. 5 in G minor (Brahms)
18. Gayaneh Sabre Dance (Aram Khachaturian)
19. Coming with you (Ne-Yo)
20. Staying alive (Bee Gees)
21. The Nutcracker, Opus 71: III March (Tchaikovsky)
22. Love never felt so good (Michael Jackson)
23. Get down on it (Kool and the Gang)
24. I'm an albatraoz (Aron Chupa)
25. Blank space (Taylor Swift)
26. Fire is low (Freshly Ground)
27. Rise again (Liquid Deep feat. Gregor Saltor)
28. Stomp (The Brothers Johnson)
29. Ai no corrida (Quincy Jones)
30. Goodbye (Feder)
31. I really like you (Carly Rae Jepsen)

32. Back in time (Pitbull)
33. Little L (Jamiroquai)
34. Summertime sadness (Lana Del Ray)
35. Ain’t nobody (Loves Me Better) (Felix Jaehn feat. Jasmine T)
36. King of pain (The Police)
37. On broadway (George Benson)
38. Fine China (Chris Brown)
39. Beautiful people (Chris Brown)
40. Rather B (Clean Bandit)
41. Get lucky (Daft Punk feat. Pharrell Williams)
42. One more time (Daft Punk)
43. Walking on a dream (Empire of the Sun)
44. Baby don’t lie (Gwen Stefani)
45. By the night (Kings of Leon)
46. Say it right (Nelly Furtado)

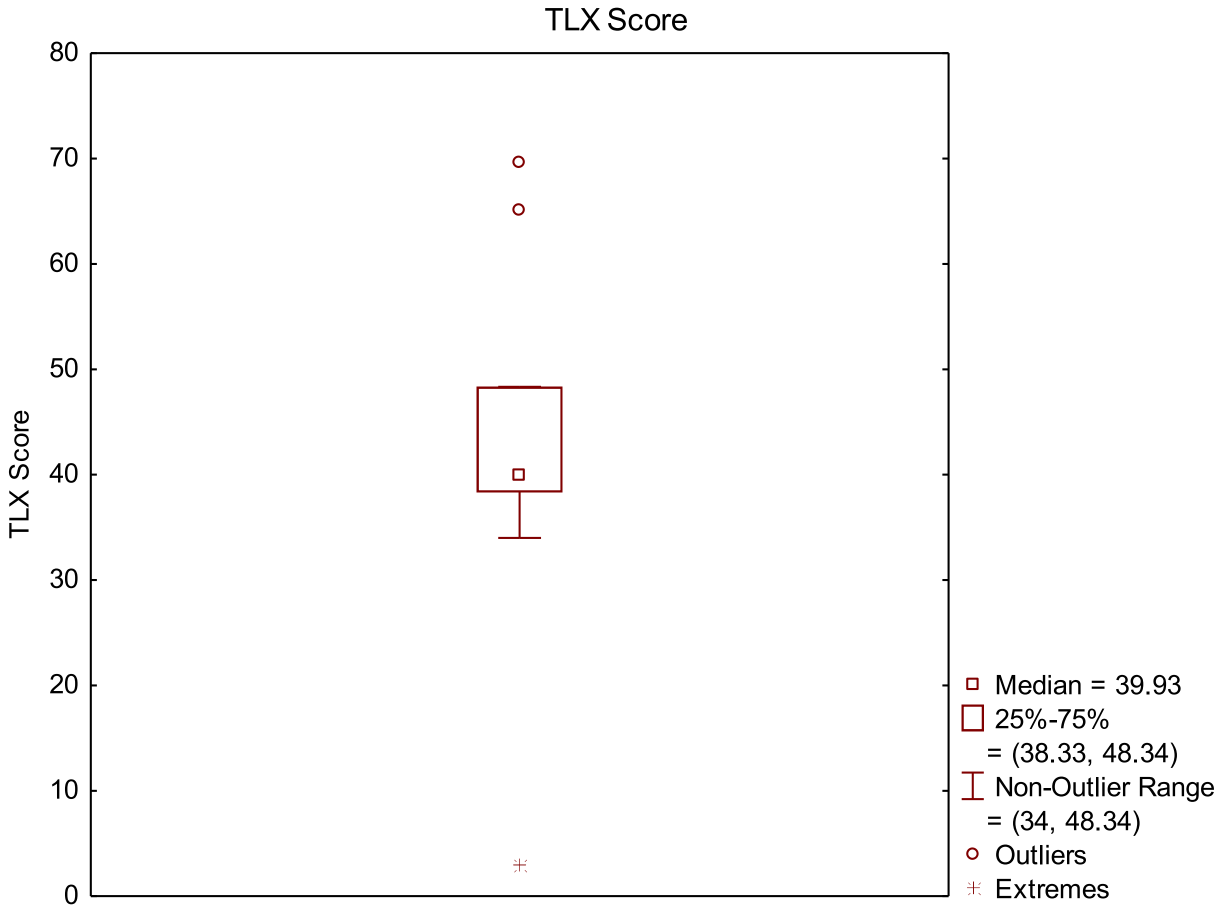
Appendix J

Mindfulness Colouring-in Picture

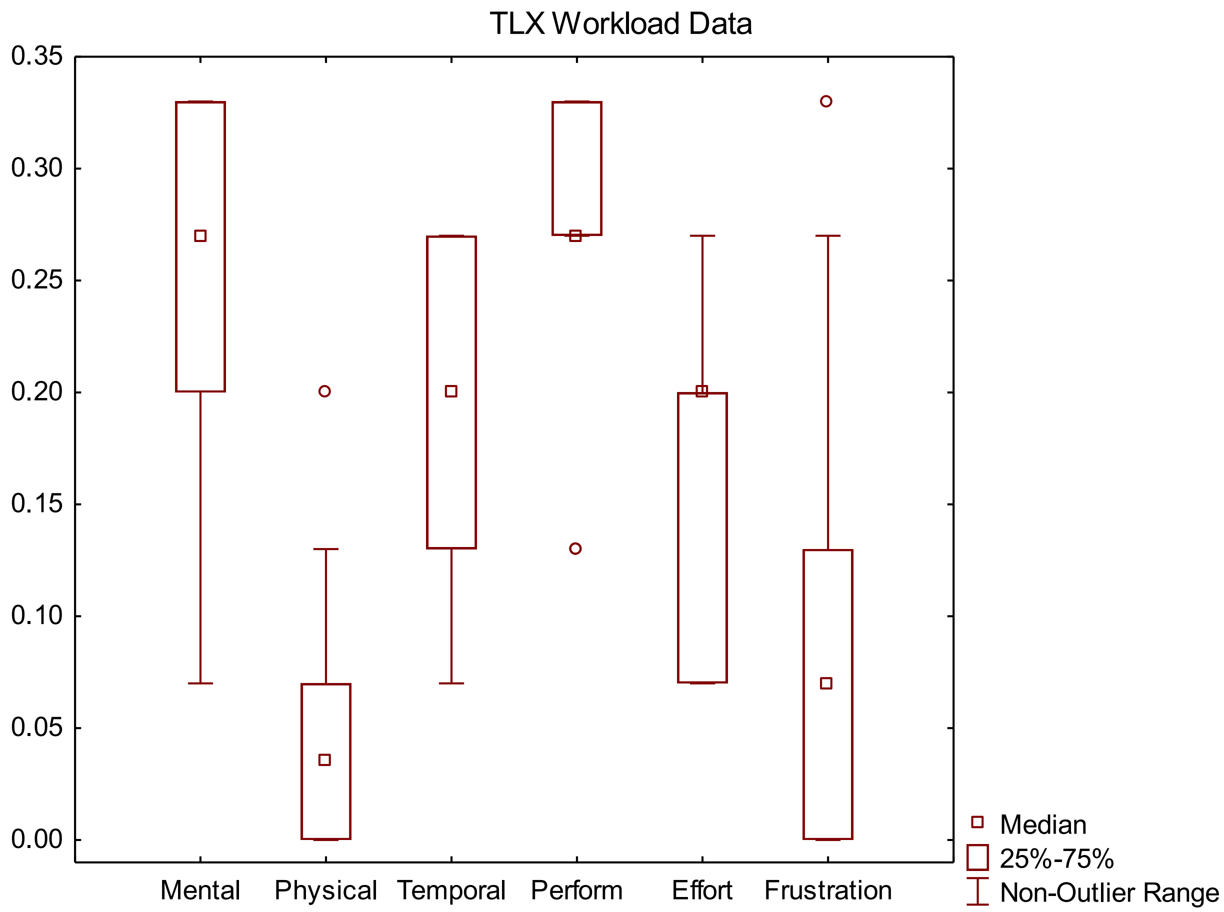


Appendix K

Box and Whisker Plots for NASA-TLX



Mean = 42.74; standard deviation = 17.31; variance = 299.70



Mental Demand: mean = 0.25; standard deviation = 0.09; variance = 0.008

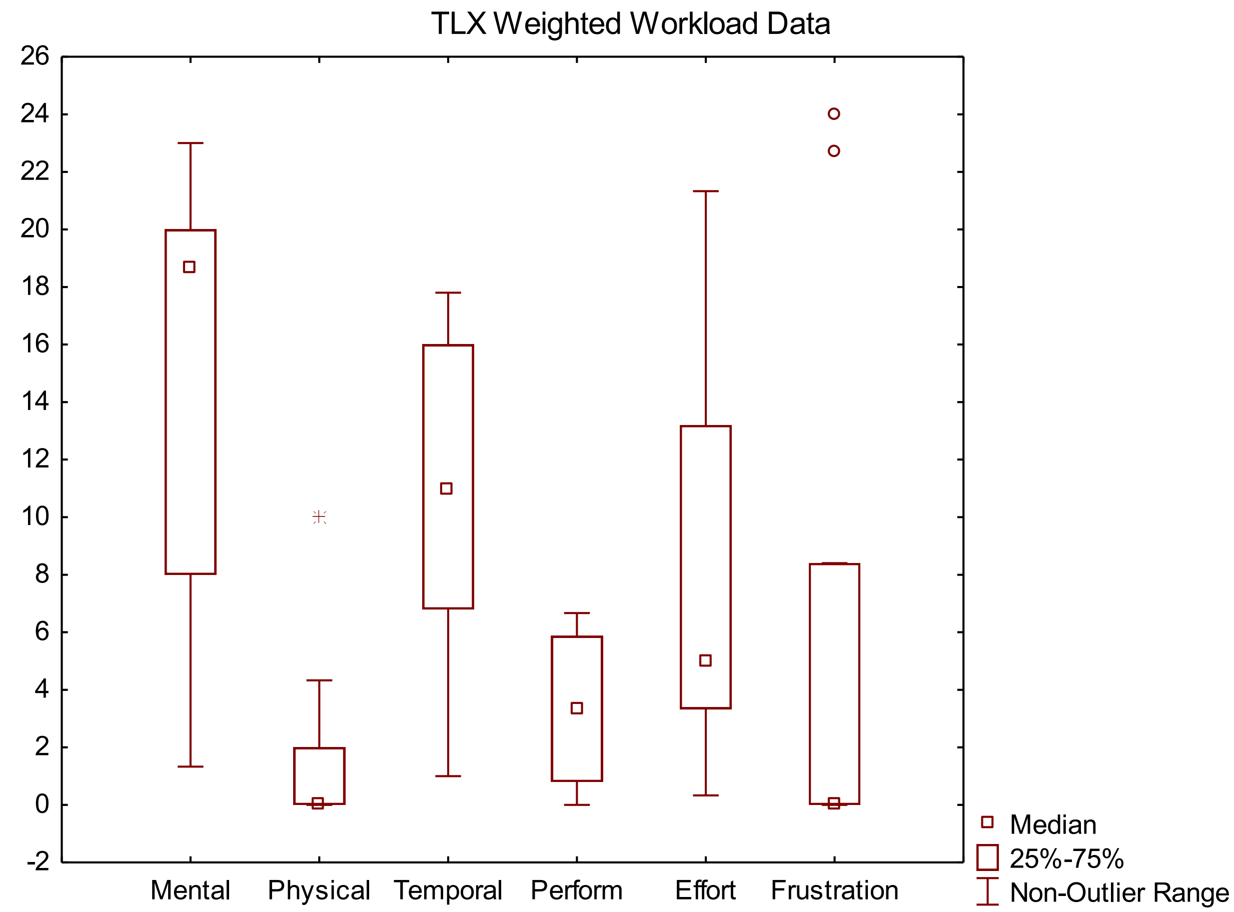
Physical Demand: mean = 0.05; standard deviation = 0.07; variance = 0.005

Temporal Demand: mean = 0.19; standard deviation = 0.06; variance = 0.004

Own Performance: mean = 0.26; standard deviation = 0.07; variance = 0.01

Effort: mean = 0.16; standard deviation = 0.08; variance = 0.01

Frustration: mean = 0.10; standard deviation = 0.12; variance = 0.02



Mental Demand: mean = 14.26; standard deviation = 7.92; variance = 62.80.

Physical Demand: mean = 1.72; standard deviation = 3.06; variance = 9.40

Temporal Demand: mean = 10.22; standard deviation = 5.48; variance = 30.04

Own Performance: mean = 3.14; standard deviation = 2.41; variance = 5.80

Effort: mean = 8.02; standard deviation = 6.44; variance = 41.45

Frustration: mean = 5.38; standard deviation = 9.25; variance = 85.57

Appendix L

SSSQ-Pre

SHORT STRESS STATE PRE-QUESTIONNAIRE

Please indicate how well each word describes how you feel *at the moment*

Not at all = 1   A little bit = 2   Somewhat = 3   Very much = 4   Extremely = 5

1.	Dissatisfied	1	2	3	4	5
2.	Alert	1	2	3	4	5
3.	Depressed	1	2	3	4	5
4.	Sad	1	2	3	4	5
5.	Active	1	2	3	4	5
6.	Impatient	1	2	3	4	5
7.	Annoyed	1	2	3	4	5
8.	Angry	1	2	3	4	5
9.	Irritated	1	2	3	4	5
10.	Grouchy	1	2	3	4	5

Please indicate how true each statement is of your thoughts *during the past fifteen minutes*

Not at all = 1   A little bit = 2   Somewhat = 3   Very much = 4   Extremely = 5

11.	I am committed to attaining my performance goals	1	2	3	4	5
12.	I want to succeed on the task	1	2	3	4	5
13.	I am motivated to do the task	1	2	3	4	5
14.	I'm trying to figure myself out	1	2	3	4	5
15.	I'm reflecting about myself	1	2	3	4	5
16.	I'm daydreaming about myself	1	2	3	4	5
17.	I feel confident about my abilities	1	2	3	4	5
18.	I feel self-conscious	1	2	3	4	5
19.	I am worried about what other people think of me	1	2	3	4	5
20.	I feel concerned about the impression I am making	1	2	3	4	5
21.	I expect to perform proficiently on this task	1	2	3	4	5
22.	Generally, I feel in control of things	1	2	3	4	5
23.	I thought about how others have done on this task	1	2	3	4	5
24.	I thought about how I would feel if I were told how I performed	1	2	3	4	5

Appendix M

SSSQ-Post

SHORT STRESS STATE POST-QUESTIONNAIRE

Please indicate how well each word describes how you felt *during the task*

Not at all = 1   A little bit = 2   Somewhat = 3   Very Much = 4   Extremely = 5

1.	Dissatisfied	1	2	3	4	5
2.	Alert	1	2	3	4	5
3.	Depressed	1	2	3	4	5
4.	Sad	1	2	3	4	5
5.	Active	1	2	3	4	5
6.	Impatient	1	2	3	4	5
7.	Annoyed	1	2	3	4	5
8.	Angry	1	2	3	4	5
9.	Irritated	1	2	3	4	5
10.	Grouchy	1	2	3	4	5

Please indicate how true each statement was of your thoughts *while performing the task*

Not at all = 1   A little bit = 2   Somewhat = 3   Very much = 4   Extremely = 5

11.	I was committed to attaining my performance goals	1	2	3	4	5
12.	I wanted to succeed on the task	1	2	3	4	5
13.	I was motivated to do the task	1	2	3	4	5
14.	I tried to figure myself out	1	2	3	4	5
15.	I reflected about myself	1	2	3	4	5
16.	I daydreamed about myself	1	2	3	4	5
17.	I felt confident about my abilities	1	2	3	4	5
18.	I felt self-conscious	1	2	3	4	5
19.	I was worried about what other people think of me	1	2	3	4	5
20.	I felt concerned about the impression I am making	1	2	3	4	5
21.	I performed proficiently on this task	1	2	3	4	5
22.	Generally, I felt in control of things	1	2	3	4	5
23.	I thought about how others have done on this task	1	2	3	4	5
24.	I thought about how I would feel if I were told how I performed	1	2	3	4	5