The following publication Hedayati, S., Sadeghi-Firoozabadi, V., Bagheri, M., Heidari, M. and Sze, N.N., 2021. Evaluating differences in cognitive functions and personality traits among air traffic controllers with and without error history. Safety Science, 139, p.105208 is available at https://doi.org/10.1016/j.ssci.2021.105208.

Evaluating Differences in Cognitive Functions and Personality Traits among Air Traffic Controllers with and without Error History

Abstract

Given the growing rate of air transportation, it is necessary to consider the safety of the aviation industry. One of the most sensitive and important jobs in the field of flight safety is air traffic control. Working in such a context requires the use of high levels of cognitive functions, which can be impaired or reduced in speed and accuracy under pressure and stress. Another issue is that cognitive functions also interact with non-cognitive factors. One of these non-cognitive factors is personality traits. Using a causal-comparative method the present study aims to evaluate the effect of cognitive functions, like situational awareness, short-term memory, sustained attention and planning ability, and personality traits, such as extraversion, emotionality and adventurousness, on human error of air traffic controllers by controlling the effect of age. For this purpose, five tests were selected from the Vienna Test System, namely MR, CORSI, DAUF, TOL-F and EPP6, to measure the cognitive functions and personality traits of the controllers. By convenience sampling, 37 controllers from the air control center participated in the tests. Excluding outliers, the groups were as follows: 16 controllers with error history and 15 controllers without error history. In order to control the effect of age on cognitive functions and personality traits, the groups' data were compared using the covariance analysis. According to the results, there is a difference between groups in situational awareness (sig=0.008, $P \leq 0.05$) and sustained attention (sig=0.01, $P \leq 0.05$), with error-free controllers showing higher scores in these functions. However, in other cognitive functions that were studied, namely short-term memory (sig=0.8, $P \leq 0.05$) and planning ability (sig=0.8, $P \leq 0.05$), no difference was shown between the two groups. Moreover, study of personality traits showed that controllers with errors differ from controllers without errors (sig=0.02, $P \leq 0.05$), but in emotionality (sig=0.7, $P \leq 0.05$) and adventurousness (sig=0.6, $P \leq 0.05$) there are no differences between the two groups. With these results in mind, efforts can be made to minimize potential errors in sensitive occupations such as air traffic control by using cognitive and personality screening tools.

Keywords: age, air traffic control, cognitive functions, human error, personality traits

Title Page (with Author Details)

Evaluating Differences in Cognitive Functions and Personality Traits among Air Traffic Controllers with and without Error History

Sepideh Hedayati, Vahid Sadeghi-Firoozabadi, Morteza Bagheri, Mahmoud Heidari, N.N. Sze

Faculty of Education and Psychology, Department of Applied Psychology, Shahid Beheshti University, Tehran, Iran.
Faculty of Education and Psychology, Department of Psychology, Shahid Beheshti University, Tehran, Iran.
School of Railway Engineering, Iran University of Science and Technology, Tehran, Iran.
Faculty of Education and Psychology, Department of Psychology, Shahid Beheshti University, Tehran, Iran.
Department of Civil and Environmental Engineering, Hong Kong Polytechnic University, Hong Kong

Evaluating Differences in Cognitive Functions and Personality Traits among Air Traffic Controllers with and without Error History

Abstract

Given the growing rate of air transportation, it is necessary to consider the safety of the aviation industry. One of the most sensitive and important jobs in the field of flight safety is air traffic control. Working in such a context requires the use of high levels of cognitive functions, which can be impaired or reduced in speed and accuracy under pressure and stress. Another issue is that cognitive functions also interact with non-cognitive factors. One of these non-cognitive factors is personality traits. Using a causal-comparative method the present study aims to evaluate the effect of cognitive functions, like situational awareness, short-term memory, sustained attention and planning ability, and personality traits, such as extraversion, emotionality and adventurousness, on human error of air traffic controllers by controlling the effect of age. For this purpose, five tests were selected from the Vienna Test System, namely MR, CORSI, DAUF, TOL-F and EPP6, to measure the cognitive functions and personality traits of the controllers. By convenience sampling, 37 controllers from the air control center participated in the tests. Excluding outliers, the groups were as follows: 16 controllers with error history and 15 controllers without error history. In order to control the effect of age on cognitive functions and personality traits, the groups' data were compared using the covariance analysis. According to the results, there is a difference between groups in situational awareness (sig=0.008, $P \leq 0.05$) and sustained attention (sig=0.01, $P \leq 0.05$), with error-free controllers showing higher scores in these functions. However, in other cognitive functions that were studied, namely short-term memory (sig=0.8, $P \leq 0.05$) and planning ability (sig=0.8, $P \leq 0.05$), no difference was shown between the two groups. Moreover, study of personality traits showed that controllers with errors differ from controllers without errors (sig=0.02, $P \leq 0.05$), but in emotionality (sig=0.7, $P \leq 0.05$) and adventurousness (sig=0.6, $P \leq 0.05$) there are no differences between the two groups. With these results in mind, efforts can be made to minimize potential errors in sensitive occupations such as air traffic control by using cognitive and personality screening tools.

Keywords: age, air traffic control, cognitive functions, human error, personality traits

1. Introduction

Air transportation is one of the fastest and most convenient modes of transport (Kabiri Rad, 2010; Nasiri Dashtabi & Parastari; 2017). Due to this fact, the use of this mode of transportation increases annually. According to International Air Transport Association (IATA) (2019) there were more than 4.3 billion passengers and 46.1 million flights solely in 2018. These numbers show an increase in flight and passenger rates compared to 2017 (7.5% increase). It is also estimated that the amount of air traffic will rise dramatically up to 7 billion passengers in 2035 (Lovato, Fontes, Embiruçu, & Kalid, 2018; Gallego, Comendador, Nieto, Imaz, & Valdés, 2018).

On the other hand, in 2018, there were 62 air accidents in which 523 people lost their lives. This is the highest number of deaths and fatal air accidents since 2014. In fact, one out of every 740,000 flights crashed in 2018 (IATA, 2019). According to the International Civil Aviation Organization (ICAO) (2019), most air accidents in the world are caused by human error. In aviation transportation, it has been reported that over 80% of accidents are related to human factor (Karimi and Hosseini, 2011; Khazaei, 2018; Moon, Yoo, & Choi, 2011; Harris, 2014). Human error could be described as a wrong action which either prevents achieving a goal or leads to an unwanted consequence. Some researchers have divided the causes of human errors into external and internal categories. Internal category is consisted of cognitive functions (such as errors in thinking and reasoning) and personality traits (like extraversion and emotionality) (Shakerian, Chubineh, Jahangiri, Alimohammadlu, & Nami, 2019). As a matter of fact, the deadliest accident in aviation history, Tenerife airport disaster, resulting in 583 fatalities, happened because of human error, specifically the air traffic controller's error (Dreifus, 1978).

One of the most important careers that is involved in the flights' safety is air traffic control (ATC). Air traffic control pursuits two main goals: 1) safety and 2) efficacy of air traffic flow (Loft, Sanderson, Neal, & Mooij, 2007; Karikawa & Aoyama, 2016). To reach this aim, air traffic controllers should be able to guide and control flights while keeping an efficient balance between controllers and systems. As a result, air traffic controllers must manage their various functions and be able to manage a safe flow of the air traffic simultaneously (Moon, et. al., 2011). People working in this field sometimes face a large amount of information at any given time and work under high stress and work pressure (Lesiuk, 2008).

Air traffic control is a very demanding and stressful job (Chen, Lu, & Mao; 2019). People who work in critical and safety-related environments, like ATC, are usually under a lot of pressure; because any kind of errors in these fields can actually end up with irrecoverable costs, either property damage or fatality (Wang, Bu, Han, Sun, Hu, & Zhu, 2016). The most stressful factors that air traffic controllers face on a daily basis are high traffic volume, unpredictable events (like emergency situations and sudden change in weather conditions), systems' limitations, consequences of making errors and working at night shifts (Bongo, Alimpangog, Loar, Montefalcon, & Ocampo, 2018).

However, air traffic controllers must keep their functions at an optimum level. For doing so, the controllers should manage their mental workload (Loft, et. al., 2007). Mental workload is considered as a way to describe the mental costs of getting something done and is described as the amount of physical, mental and cognitive effort to accomplish a task (Vanderhaegen, 2016). High amount of workload happens when the tasks are more than the individual's capacity and this capacity depends on controllers' selection of priorities, management of cognitive resources and their personal functions (Loft, et. al., 2007). The increase in flight numbers leads to fatigue and higher perceived mental workload which may result in decreased optimized function of controllers (Skaltsas, Rakas, & Karlaftis, 2013). Being able to endure this amount of stress and working conditions, depends on many factors, including age, circadian and sleep cycles, personality traits and psycho-social status (Nazarizadeh, 2010).

Studies have shown that working in such a context requires the use of high levels of cognitive function (US Bureau of Labor Statistics, 2019). Cognitive functions in general mean how people perceive, learn, memorize and think about information (Sternberg, 2015). Functions that are important in air traffic control include selective attention, focus, speed of perception, activity management, auditory attention, planning, decision making, identifying stimuli, reasoning and continuous use of working memory (US Bureau of Labor Statistics, 2019). Working under pressure and stress can impair these cognitive functions or reduce their speed and accuracy. The more difficult and complex the tasks, the higher the likelihood of cognitive errors are (Kasteleijn-Nolst Trenite & Vermeiren, 2005).

Air traffic control is a very complex process. This process is highly dependent on human capabilities and places a heavy responsibility on controllers, not only for human lives, but also for the high economic costs of air operations. Most of the operational complexities of air traffic controllers are due to unplanned issues (such as weather conditions) that require a high cognitive load. Most controller activities are inherently cognitive and occur in a dynamic environment under time pressure (Rodrigues, Paiva, Dias, Aleixo, Filipe, & Cunha, 2018). In fact, air traffic control is an information processing activity that is governed by the rules, programs and knowledge of the controller. Memory functions play a key role in this process (Kallus, Barbarino, & Van Damme, 1997). Cognitive analyzes have shown that controllers must perform many tasks in response to variable air traffic, many of which must be time-managed (Wang et al., 2016). The efficiency and safety of many complex human-machine systems are closely related to the cognitive volume and situational awareness of their operators (Ayaz et al., 2010). Among the functions involved in air traffic control are information processing, decision making, working memory and attention (Borghini et al., 2017). According to the analysis of air accidents from 1985 to 1997, a very common error that occurs between controllers is a lack of attention and memory. At high traffic volumes, 72% of controller errors occur due to errors in perception, which include misidentification or misinterpretation of information (Shorrock, 2007). Controllers perform such cognitive processes in a very short time. Their work experience seems to have a significant effect in this regard (Inoue, Furuta, Nakata, Kanno, Aoyama, & Brown, 2012).

In a series of job analyzes that used 160 experienced controllers on the work requirements of air traffic control, "cognitive abilities" were considered the most important factor in this job. To maintain flight safety, controllers must be able to perform multiple tasks simultaneously, schedule and distribute their attention among various variables, and be able to maintain an optimal level of performance in a stressful environment (US Bureau of Labor Statistics, 2019). Maintaining such abilities in an environment where the person is constantly under time pressure and stress is a difficult task (Arumugam, Ramachandran, & Bhattacharyya, 2014). Therefore, it seems necessary to identify important cognitive functions in errors related to air traffic control and try to reduce these errors to a minimum.

Among the cognitive functions, the requirements for the staff of air traffic controllers include: Short-term memory (ability to store and manipulate information from the recent past) and long-term memory (extensive storage of knowledge and past events), monitoring (ability to pay attention to specific events over long periods of time), problem solving (ability to evaluate current information to conclude or identify solution), planning (ability to determine the appropriate method of activities to achieve a goal), speed of perception (ability to perceive and compare information quickly and accurately), selective attention (ability to perform tasks in the presence of distractive stimuli), multitasking (ability to perform multiple tasks while switching attention between different sources of information) and communication (ability to interpret verbal and written information) (Eißfeldt, 2000; Cowan, 2009).

In a study, the cognitive factors involved in the occurrence of human error in any field of work have been investigated. According to this study, these cognitive factors include: low alertness and concentration, lack of attention, inability to remember information (memory impairment), inability to solve problems and make decisions, neglect, inability to predict, inability to manage emotions and inability to dominate the work environment. Among these factors, the most influential factor was memory impairment. Studies have shown that not forgetting information and processing it properly can help reduce risk factors. Inability to solve problems and make decisions has also been identified as the most influential factor. Also, situational awareness is known as the most important factor in the occurrence of human error in emergencies (Shakerian et al., 2019).

The tasks of air traffic controllers include cognitive tasks that are not directly measurable (Hadley et al., 1999). According to the research background, among these cognitive functions, the four items that had the most repetition in research in this field were selected for study in this research. These functions include situational awareness, short-term memory, sustained attention, and planning ability.

Among these factors, having situational awareness is considered to be the most important feature of an air traffic controller. Situational awareness means understanding the state of the environment, which is the basis of subsequent decisions and actions in complex and dynamic systems. Situational awareness is defined as an individual's perception of the elements of the environment over time and space, understanding their meaning, and predicting their situation in the near future (Endsley, 1995; Mirchi, Vu, Miles, Sturre, Curtis, & Strybel, 2015).

Many accidents in the world occur due to incorrect controller information to the pilot. For example, on April 15, 2010, at Taiwan Taoyuan International Airport, two planes changed course just 11 seconds apart to avoid a collision. This was an example of an impending accident that shows how high the consequences of incorrect information or poor situational awareness of the controllers are (Bongo, et. al., 2018). Tasks performed by controllers that depend on their situational awareness include: avoiding potential interference, avoiding stormy areas, redirecting aircraft, and creating traffic patterns that minimize the need for constant aircraft monitoring. (Malakis, Kontogiannis, 2013). Loss of situational awareness takes the controller out of the information cycle it needs, resulting in an error (Niessen & Eyferth, 2001).

Situational awareness is interrelated with other cognitive functions such as memory, attention, perception, and learning (Endsley, 1995). Situational awareness and visual attention are the most important safety factors in human-machine interaction in air traffic control (Li, Kearney, Braithwaite, & Lin, 2018).

Attention is a cognitive ability that plays an important role in understanding human performance in air traffic control (Rodrigues et al., 2018; Ellis & Liston, 2010). Controllers must be able to distribute their attention across multiple tasks. This raises the concern that wrong or late decisions could be made, specially under high time pressure (Collet, Averty, & Dittmar, 2009). Research has shown that attention disorders persist for at least 30 minutes after the stressor (Rodrigues et al., 2018).

There are several types of attention involved in the air traffic control process: focused (e.g. monitoring only one emergency), selective (e.g. listening to a pilot report and evaluating data), divided (such as listening to radio calls and writing down essentials), and sustained (like radar monitoring in night shifts). Errors can occur when attention sources are inadequate or attention functions are not used properly. For example, the use of focused attention prevents wider monitoring (Shorrock, 2007). In real-time air traffic control, where several aircraft are controlled simultaneously, attention plays a key role. Because if a warning is neglected in this field, it can lead to irrecoverable damage (Giraudet, Imbert, Tremblay, & Causse, 2015).

However, many reports have shown that some human errors occur in situations where air traffic is low, which highlights the need to be vigilant for long periods of time, even when workload is low (Rodrigues et al., 2018). This leads us to the concept of "sustained attention".

Attention is a selection process; because perception and conceptualization are directed and focused on one part of the stimuli that the person encounters. The "sustained" aspect of attention indicates that it becomes more difficult when attention processes are applied continuously. Sustained attention means selective awareness of stimuli that are presented continuously (Puhr, 2010).

When the volume of air traffic is high, this exchange of information takes place from various sources, all of which the controller must pay attention to. Due to the fact that this task requires constant attention change, the difficulty and complexity of the controllers' work increases with increasing workload and it also challenges a person's working memory (Wittbrodt, Gross, & Thüring, 2010).

Alava and Alvarez (1999), found out in countries that had specific requirements for hiring air traffic controllers, short-term memory was an important factor in 79% of them (Eißfeldt, 2000). Despite of various tools in the control center, controllers rely heavily on their working memory. Using working memory, controllers encode, maintain, and retrieve flight and aircraft information. Some of the information needed for controllers is provided to them on a permanent basis, but the controller can only scan this information quickly and keep the perceived information in working memory (Shorrock, 2005).

Many forgetfulness in the field of controllers occurs when information is present in memory but is not retrieved due to insufficient signs. Internal symptoms, such as mood, can also affect information retrieval, but this only happens when the event has a personal connection to the person. Interference is another factor in memory errors and occurs when previous learning interferes with new learning or vice versa (Shorrock, 2005).

To cope with heavy workloads, controllers categorize information, thereby reducing the number of aircraft in working memory (Malakis, Kontogiannis, 2013; Niessen & Eyferth, 2001). Cognitive workload is reduced by reducing the load on working memory, reducing work time, or eliminating tasks (Corver & Aneziris, 2015).

Planning is also extremely important when the air traffic control system is not in a normal state and does not work properly (Eißfeldt, 2000). Planning ability means cognitively modeling possible solutions and evaluating the consequences of an action before it occurs (Kaller, Unterrainer, Kaiser, Weisbrod, Debelak & Aschenbrenner, 2011). To solve complex problems, planning is necessary and it is very important for controllers; because they can manage the workload by predicting the situation and combining it with their cognitive abilities (Crevits, Debernard, & Denecker, 2002).

In this study, cognitive functions such as situational awareness, sustained attention, working memory and planning ability are compared between the two groups of controllers with error and no history of error to determine the differences between these cognitive functions in these two groups.

On the other hand, personality traits also interact with cognitive functions and affect them. For example, a motivated person will show higher performance in the ability to learn and remember than a person who is not (Sternberg, 2015). People enter different jobs with their personality traits and determine their career success with their personality traits. Given that the critical job of air traffic control requires that the people working in it have the motivation to progress, self-awareness, a sense of cooperation and emotional stability (Eißfeldt, 2000), the study of various aspects and dimensions of personality is considered important. "Personality" refers to relatively stable intellectual, emotional, and functional styles that describe a person and is reflected in various aspects of an individual's life, including job performance (Costa & McCrae, 1995).

In different analyses that were made in ATC, it has been shown that traits like openness to experience, adaptability, ambition and leadership play an important role in this field (Arumugam, Ramachandran, & Bhattacharyya, 2014). Also aspects like thinking style, team work and flexibility are considered essential for air traffic controllers (Eißfeldt, 2000). These aspects are related to people's personality traits.

Personality is described as a somewhat stable thinking, feeling and functioning style that describes a person. Personality traits can be good predictors of a person's capacity in coping well with his/her job's environment. For example, people high in neuroticism, regardless of their living conditions, are more prone to tension and job dissatisfaction. Generally speaking, it is better that these people apply for jobs that are not stressful and do not need much emotional control (Costa & McCrae, 1995).

Controlling one's emotion under pressure and stress is a difficult thing to do (Epstein, 2006). In ATC, which is a very stressful field, the controllers are required to stay focused and control their stress levels so that their functions are not affected (Lesiuk, 2008). In other words, the controllers are required to have an emotional stability (Miramontes, et. al. 2015). Personality is one of the factors that has an impact on this process. For example, a research has been done on fire fighters, another stressful and demanding job, and it was shown that the firemen who were more introvert, were also more prone to PTSD (post-traumatic stress disorder) (Lesiuk, 2008). Conscientiousness is also a good predictor of a person's performance in their jobs. People with higher score in this scale, are probably more creative, resistant and organized (Costa & McCrae, 1995).

Another issue is that ATC is a dynamic and complicated system that relies on team, rather than individual, performance. No one person can control the whole air traffic system on their own (Cox, Sharples, Stedmon, & Wilson, 2007).

Although researches have revealed different aspects of personality in different job environments, it is still not clear that what personality differences are there between the air traffic controllers that have had error history and those who did not. Since ATC is a vital and critical job in maintaining a safe and efficient flight flow, and the consequences of any mistakes in this field might be even fatal, it is important to pinpoint and highlight the risk factors that may prevent the controllers' efficient functioning. Due to the fact that personality differences are considered as an important issue in job performance, this research aimed to compare the air traffic controllers' personality traits between the controllers with and without human error history, so that the risk factors of error-prone controllers would be revealed and guarantee a safer and better air traffic worldwide.

For achieving this purpose, the first thing needed is a personality theory so that the right tools would be chosen accordingly for measuring and analyzing the personality traits. Among all the personality theories, Eysenck's theory was chosen, because of its comprehensiveness, strong psychometric and biological components (Feist, Feist & Roberts, 2013). Hans Eysenck is a pioneer in theorizing in personality and individual differences during 20th century (Revelle, 2016). He divides personality into three dimensions: extraversion, neuroticism, and psychoticism. The dimensions of neuroticism and psychoticism are not limited to mental disorders, but all three factors are used to measure parts of the normal personality structure. If we want to look at these dimensions from a hierarchical structure, extraversion includes traits such as excitement, courage, activism, vitality, sociability, adventure, domination and carelessness. The opposite of these traits is descriptive of introverts; they are calm, inactive, unsocial, cautious, restrained, thoughtful, pessimistic, pacifist, vigilant and constrained. Psychosis also includes people who are impulsive, soulless, self-centered, insensitive, aggressive, hard-thinking, creative, lacking empathy and antisocial. People who score lower in this dimension, act towards self-function, are altruistic, social, empathetic, compassionate, helpful, and normal. Neuroticism also includes stress, low self-esteem, guilt, depression, anxiety, excitement, capriciousness, shyness and irrationality (Feist, et. al., 2015).

Moreover, due to the importance of personality traits and their effects on cognitive functions, these traits are also examined in controllers to distinguish between controllers with a history of error and no history of error and to clarify whether there is a difference in personality traits between the two groups.

Additionally, one of the factors that can affect both cognitive functions and personality traits is the aging. Some cognitive functions decline with age. Also, personality traits are not fixed and stable throughout their lives and with age, at least in some aspects of personality, they change. On the other hand, some studies show that with increasing experience and aging, the performance of people in that field of work improves and can even lead to a reduction in errors (Vaseli Khabbaz, Ramezani Zadeh and Nayebi, 2018).

Various results have been found regarding the effect of age on cognitive functions and personality traits. Some researchers believe that age has a negative effect on cognitive functions and this may lead to errors in them. On the other hand, some others have come to the conclusion that older people are less likely to make mistakes due to their higher experience (Vaseli Khabbaz, et. al., 2018). Also, the age of people causes some of their personality traits to change. For example, research has shown that middle-aged people (i.e. ages 40 to 65) have better self-knowledge and cope with failures better than younger people (20 to 40 years) (Kianpour Ghahfarkhi, Haghighi, Shokrkan, Najarian, 2002).

Given that selecting personnel for safety-sensitive occupations, such as air traffic control, is an important issue, and mistakes by air traffic controllers can cause extensive and even fatal damage, keeping their cognitive performance at an optimal level is important (Arumugam, Ramachandran, & Bhattacharyya, 2014). However, to our knowledge, there are no studies to explicitly state which of the cognitive functions of controllers with a history of error is weaker and which of the cognitive functions differ between the air traffic controllers with and without error history. Also, research has not yet stated that in what aspects of their personalities do controllers with error history and controllers without it differ nor has it been stated which aspect of personality trait is associated with human error in air traffic controllers. Due to the high sensitivity of air traffic control and the high consequences of making mistakes in this field, this study examined cognitive functions and personality traits in air traffic controllers and compared these functions and traits between the controllers with and without human error history by controlling the effect of age on these functions and personality traits. Determining which of the cognitive functions and personality traits distinguishes between these two groups of air traffic controllers, efforts can be made to minimize potential errors in critical jobs such as aviation control. Moreover, due to different results in the field of the effect of age on research variables, the effect of age is controlled so that as much as possible the comparison between the two groups can be done only in the main research variables to determine whether situational awareness, sustainable attention, working memory and planning ability, as well as personality traits affect the human error of controllers.

This study aims to answer the following questions: A) Is there a difference between air traffic controllers with error history and the controllers without it in situational awareness, sustained attention, short-term memory and planning ability? B) Is there a difference between air traffic controllers with error history and the controllers without it in extraversion, emotionality and adventurousness?

According to research background, this research’s hypothesis was that the controllers with errors and controllers without it were different in cognitive functions and personality differences.

2. Materials and Method

In humanities and social sciences, due to the numerous limitations for applying and manipulating some variables, researchers cannot always use experimental method. Therefore, causal-comparative method is used in these circumstances, as for the present study, so that the effect is examined to extract the cause (Delavar, 2015).

1.2 Participants

The target population of this research is air traffic controllers in Iran, which according to the deputy director of education of air traffic control, includes a thousand people. Due to the limited access to all the airports and air control centers in Iran and the high cost of this issue and restrictions on access to all of the air traffic control units, sampling was carried out in Tehran's air control center, adjacent to Mehrabad Airport, the busiest airport in Iran with 20.92% of the share of landings and take-offs in the whole country in 2018 (Office of Information Technology and Statistical Surveys, Deputy of Management and Resources Development, 2019). By available sampling method, 37 controllers participated in the tests. To avoid the possible gender effect on the results, the data were only collected from male controllers.

Given that one of the prerequisites for the controllers' job is physical and mental health, it was ensured that none of them had any physical or mental illness. One of the criteria for entering the sampling process was at least one year of work experience in the field of ATC. The error history of these individuals has been examined through a semi structural interview with the deputy director of education of air traffic control. Among them, 17 controllers had a history of human error and 20 did not.

2.2 Measures

In order to pursue the aims of this study, it was decided to use the Vienna test systems (VTS). VTS is a set of various computer-based tests that includes more than 80 reliable and valid psychological and cognitive assessment tools. These tests include special ability, personality, comparative and multimedia tests that have been translated into more than 25 languages worldwide. These tests are very user-friendly, and their norms are constantly updated. VTS is used in various fields including clinical psychology, neuropsychology, industrial-organizational psychology, traffic psychology, sports and educational psychology (Schuhfried, 2013). In the present study, four cognitive tests and one personality test from this test system have been used, which are described fully below.

The CORSI test is one of Vienna tests developed by Dieter Schellig and has been reviewed many times. The 24th version of this test, published in 2011, was used in the present study to assess and measure memory. This test has three different forms and in this research, its S1 form was used. In this test, 9 cubes that are irregularly placed in different places on the screen are displayed. A hand-shaped cursor moves on a specific number of cubes, respectively. The respondent's task is to click on the cubes in the same order in which they were selected. After three answers, one cube is added to the number of selected cubes. If the respondent gives a wrong answer to three consecutive cases, the test ends. The number of test cases depends on the number of correct answers of the respondent. This test measures different variables, but the main variable of this test used in the present study is immediate block span. This variable examines the capacity of short-term memory and, consequently, the storage capacity of spatial working memory and is associated with the longest sequence that a person correctly recalls in at least two of the three items presented. The reliability of this test is high; The internal consistency based on the evaluated sample is 0.76. This test is the standard test for measuring spatial memory capacity. For more than three decades, the validity of this test has been repeatedly validated in neuropsychological research and is widely used in clinical contexts (Schellig, 2011).

The DAUF test is used to measure sustained attention in clinical and healthy groups. The test was developed by Schuhfried Company in Vienna and was standardized between 2008 and 2009. This test is for measuring sustained attention and focus and can be used for people over 15 years old. DAUF also has different forms. In this research, S3 form has been used. In this test, on a black background, seven white triangles are displayed in a row, each of which can be up or down. The position of the rows of triangles changes irregularly. The participant is asked to immediately press a key when only three triangles in a row are facing down. This test takes 35 minutes and the test time does not depend on the performance of the respondent. This test has two main variables: sum correct (the number of all correct responses), mean time correct (the average response time to variables that have been correctly responded to). Cronbach's alpha of this test for the main variables, i.e. the sum of correct answers and the mean time of correct answers, are 0.98 and 0.97, respectively. Criterion validity of this test is presented. Sustained attention is a psychological construct that generally refers to a prerequisite for performance. This test examines the stability of a person's sustained attention function as the basis of cognitive abilities under conditions that require speed of action (Puhr, 2010).

The MR test, or mental rotation test, is designed to measure spatial perception. In 1977, a group of psychologists were asked to design a test to measure military pilots, which eventually led to the design of a test to measure spatial perception, which means creating mental images of visuo-spatial information and manipulating or altering this information. This test was developed by Herbert Bauer, Giselher Guttmann, Leodolter M. and Leodolter U., and standardized in 2002. MR is a computer test used to measure spatial perception and duration. In other words, this test measures the ability of individuals to visualize and manipulate spatial information. This test is such that each time a figure is presented to the person at the top of the page. Below this figure, a three-dimensional image is provided and the person is asked to specify how and in what direction this shape should be viewed to match the shape of the target presented at the top of the page. In total, 20 pictures are presented to the person and the person has one minute to respond to each of them. It is not possible to correct previously answered items. This test takes approximately 20 minutes to run and has one main variable: number of correctly solved items. Items are considered correct when the total vertical and horizontal deviations are less than 40 degrees. Cronbach's alpha is 0.81 for internal reliability and correlation-based analyzes confirm the convergent and divergent validity of this test (Prieler, 2003).

The TOL-F (Tower of London - Freiburg Version) test is based on the Tower of London or Tower of Hanoi test, and is a modified version of the test that Kaller, Unterrainer, Kaiser, Weisbrod, Debelak & Aschenbrenner designed and standardized in 2011 for the Vienna Test System. This test is used to measure planning ability in healthy people and patients with psychiatric and neurological problems. This test has a wide range of difficulty and therefore includes a large number of different problems to solve. The test is a three-dimensional image of three bars with colored balls inside. Three balls can be placed on the left bar, two balls in the middle bar and one ball on the right bar. The person is asked to arrange the balls in a way that resembles the image presented to them at the top of the page and is called the goal image. The minimum movements required to do this are also displayed to the person. Solving each of the problems takes one minute, and if a longer time is spent solving each of the problems, this time is recorded. In TOL-F, planning is tested by the number of problems that can be solved in at least four to six moves. This test has two forms: standard and short form. In the present study, the short version was used. In the short version of this test, 14 items are displayed to the person, which includes two three-movement problems, two four-movement problems, five five-movement problems and five six-movement problems. It takes about 11 minutes to run the short form of this test. Planning ability is the main variable of this test and it is the number of cases of 4 to 6 moves problems that are solved with the least possible moves. This variable describes a person's ability to plan ahead in a context defined by rules and thus achieve an optimal result in time. Cronbach's alpha for planning ability as the main variable is calculated to be 0.7. Extensive research background supports the validity of this test. TOL-F test variables are used in various groups of patients, healthy individuals and children (Kaller, et. al., 2011).

Eysenck Personality Profiler Version 6 (EPP6) is one of the VTS tests that measures the personality traits. The EPP6 test is a multidimensional inventory of personality that examines the three dimensions of extraversion, emotionality (neuroticism), and adventurousness (psychoticism) based on Eysenck’s theory (Antonius, 2011).

The short form of this inventory consists of 200 items and 9 subscales including: extraversion (activity, sociability, assertiveness), emotionality (inferiority, unhappiness, anxiety) and adventurousness (risk-taking, impulsiveness, irresponsibility). After a general explanation of how to respond, the test items are displayed one by one. Respondents enter their answer on a three-value scale (yes, no, I can’t decide). As soon as one item is answered, the next item is displayed. It is not possible to change previous answers (Antonius, 2011). In this study the Persian version of the test was used, which is the native language in Iran.

The reliability of the short form of the EPP6 used in this study was calculated from 0.68 for irresponsibility, to 0.89 for unhappiness in women and from 0.74 for assertiveness, to 0.85 for dissatisfaction in men. In case of validity emotionality determines 27.2%, adventurousness shows 17.9% and extraversion explains 10.1% of the variance. In addition, the factor validity of this test has shown that it is applicable in different cultures and different age groups (Antonius, 2011).

In order to collect information about history of errors of the controllers, a semi-structured interview was designed based on two topics: the work experience of controllers and their error history. The deputy director of education of air traffic control was interviewed due to their access and accurate information about the level of experience of individuals and the error history of controllers. The interview’s questions are as follows: How long has the "intended person" served as an air traffic controller? Has the controller had a history of human error during his/her years of service?

2.3 Procedure

This research has been done in two parts: the first part is a review of previous research to identify important cognitive functions and personality traits in careers such as air traffic control and the effect of age on these factors. In the second part, with the aim of answering the questions, data were collected using a causal-comparative method. The reason for using this method is to reach the possible causes of human errors of air traffic controllers to determine whether these cognitive functions and personality traits are involved in this issue or not.

The sampling was done for 11 days and a total of 121 hours. General explanations about the research were given to all controllers participating in the study before starting to answer the tests without revealing the main purpose of the study and ensuring the confidentiality of the results. In order to prevent the effect of knowledge of the examiner about history of human error in the way of explaining or dealing with controllers, the history of error of the participants was investigated after the tests. In addition, none of the controllers were informed that the classification is based on their error history so that knowledge of this issue does not affect their answers. Also, one of the reasons that air traffic controllers themselves were not asked about their error history was the probable low reliability of their error reports. After the initial explanations, the selected tests in Vienna software were performed as follows: CORSI, TOL-F, MR, EPP6 and DAUF tests. It should be noted that before the start of each test, the participants were given the necessary explanations on how to answer it, and before the start of the main test, a short section was provided to the person for practicing. Also, after performing the TOL-F and EPP6 tests, the controllers were given five minutes to rest. After data collection, data were extracted from the Vienna system for statistical analysis.

3. Results

The results were analyzed using analysis of univariate analysis of variance in SPSS (Statistical Package for the Social Sciences) software. In this method, factors that may be involved in the relationship between independent and dependent variables are considered (Delavar, 2015). Accordingly, the age factor was controlled as a variable that could affect the influence of cognitive functions and personality traits on human error in controllers.

Among the 37 participants in the tests, 20 controllers did not have a history of human error and 17 of them did. To avoid the possible gender effect on the results, the data were only collected from male controllers. Also, those who obtained scores that were more than two standard deviations from the mean were recognized as outlier data and were excluded from the analysis. The final data is as follows: 14 controllers with error history and 16 people without it. The results are shown in the tables below. Table 1 shows the mean, standard deviation, maximum and minimum scores of the controllers in main variables of CORSI, DAUF, MR and TOL-F.

* Immediate Block Span

Table 1. Descriptive Statistics of Cognitive Tests

Variables	Controllers with errors				Controllers without errors			
	Mean	Std. Deviation	Maximum	Minimum	Mean	Std. Deviation	Maximum	Minimum
CORSI (IBS*)	5.4	.73	7	4	5.56	.96	7	4
DAUF								
Sum Correct	236.92	39.58	270	124	258.56	22.42	280	205
Mean Time Correct	.79	.06	.92	.7	.74	.05	.82	.66
MR (Correct Items)	7.5	2.87	13	4	10.93	3.67	16	5
TOL-F (Planning)	4.64	1.64	7	2	4.86	2.16	9	1

This table shows that the average of controllers with a history of error is slightly lower than the controllers without a history of error in the immediate block span and their standard deviation shows a lower value than the group of controllers without error. As you can see, the two groups did not differ in the lowest and highest scores of CORSI's main variable.

As for DAUF, mean scores of controllers without error in the number of correct responses is higher than the controllers with error history (258 in controllers without errors and 236 in controllers with errors). Controllers without error history also reacted slightly faster than the controllers with errors (.74 in controllers without error history and .79 in controllers with error history).

Table 1 also shows the results of MR test. The mean and standard deviation of controllers without errors in this test's main variable are 10.93 and 3.67, respectively. The lowest score in this group is 5 and the highest score in this group is 16. Also, according to this table, the mean and standard deviation of the controllers with a history of error in this variable is 7.5 and 2.57, respectively, which is lower in both statistical indices than the group without a history of error. The lowest and highest scores of the people in this group are 4 and 13, respectively, which shows a slight difference with the group without errors.

This table also shows the performance of controllers in the main variable of the TOL-F test, namely planning ability. According to the table, the mean and standard deviation of controllers without errors in this variable are 4.86 and 2.16, respectively. The lowest score obtained in this group is 1 and the highest score is 9, and it indicates the number of problems that have been correctly solved in a given period of time and solved with the least possible movements. Also, the average of controllers with error in planning ability is equal to 4.64 and the standard deviation of this group is equal to 1.64. The mean of this group is slightly lower than the group of controllers without errors. The lowest score in this group is 2, which is slightly higher than the other group. The highest score is 7, which is slightly lower than the controllers without errors.

Table 2. Descriptive Statistics of EPP6 Scales

Variables	Controllers with errors				Controllers without errors			
	Mean	Std. Deviation	Maximum	Minimum	Mean	Std. Deviation	Maximum	Minimum
Extraversion	22.64	5.90	31	10	19.25	5.17	28	7
Activity	24.5	6.79	36	10	21.31	7.66	32	6
Sociability	23.14	6.63	32	10	19.5	7.74	28	4
Assertiveness	20.35	7.32	32	6	16.62	6.39	30	6
Emotionality	13.64	10.58	37	2	11.43	9.04	36	1
Inferiority	12.85	11.85	40	2	10.18	9.04	34	0
Unhappiness	11.71	10.15	34	0	9.12	10.43	38	0
Anxiety	16.07	11.61	38	2	15.06	10.10	37	2
Adventurousness	13.92	5.25	24	6	12.81	4.33	23	6
Risk-taking	14.57	4.91	22	6	15	5.16	24	4
Impulsiveness	14.78	8.88	32	4	12.31	8.41	33	4
Irresponsibility	12.5	5.91	22	2	11.25	4.68	20	4

Table 2 shows the mean and standard deviation of the controllers on the extraversion scale and its subscales. The average of error-free controllers in the scales of extraversion, activity, sociability and assertiveness are 19.25, 21.31, 19.5 and 16.62, respectively. The standard deviation of this group in the mentioned scales is as follows: 5.17, 7.66, 7.74 and 6.39. Also, the average of controllers with errors in the scales of extraversion, activity, sociability and assertiveness are 22.64, 24.5, 23.14 and 20.35, respectively. Also, their standard deviation in the mentioned scales was calculated as 5.9, 6.79, 6.63 and 7.32, respectively. According to the presented data, controllers with errors seem more extraverted than controllers without errors and have scored higher in all subscales of activity, sociability and assertiveness.

The mean of controllers without error on emotionality scale and the subscales of inferiority, unhappiness, and anxiety are 11.43, 10.18, 9.12, and 15.06, respectively. The standard deviation of the controllers in these scales is 9.04, 9.04, 10.43 and 10.1, respectively. According to this table, the mean scores of the controllers with errors in the mentioned scales are equal to 13.64, 12.85, 11.71 and 16.07, respectively. The standard deviation of this group is 10.58, 11.85, 10.15 and 11.61, respectively. As can be seen from the comparison of the two groups, the group of controllers with a history of error had higher mean scores on emotionality scale and all its subscales than the group of controllers without error.

The table also shows the mean and standard deviation of the controllers' scores on adventurousness and its subscales, i.e. risk-taking, impulsivity and irresponsibility. According to the data in the table, the average of controllers without errors in the above mentioned scales is 12.81, 15, 12.31 and 11.25, respectively. Their standard deviations are 4.33, 5.16, 8.41 and 4.68, respectively. Also, the mean score of controllers with errors in adventurousness and the subscales of risk-taking, impulsivity and irresponsibility are equal to 13.92, 14.57, 14.78 and 12.5, respectively. The standard deviation of this group in the mentioned scales is calculated 5.25, 4.91, 8.88 and 5.91, respectively. Comparisons of data between the two groups show that controllers with a history of error are higher than controllers without errors in adventurousness and its subscales, except for risk-taking.

To investigate this research aim, analysis of covariance of the tests' results with controlling the effect of age has been used. To use analysis of covariance, equality of variances in the two groups must be obtained. For this purpose, the Levene's test is used in SPSS. The results of this test for the tests' main variables and EPP6's scales are shown in Table 3 below.

Table 3. Levene's Test of Equality of Variances

Scales	F.	df1	df2	Sig.
CORSI	.74	1	29	.39
DAUF				
Sum Correct	.65	1	28	.42
Mean Time Correct	1.91	1	28	.17
MR	1.50	1	28	.23
TOL-F	1.71	1	27	.20
EPP6				
Extraversion	0.08	1	28	.77
Emotionality	1.38	1	28	.25
Adventurousness	3.06	1	28	.09

According to Table 3, the assumption of homogeneity of variance is confirmed for all of the tests and scales (CORSI=.39, DAUF=.42 and .17, MR=.23, TOL-F=.20, extraversion=.77, emotionality=.25, and adventurousness=.09), so we can proceed to tables 4 and 5 for analysis of covariance.

Table 4. Tests of Between-Subjects Effects in Cognitive Tests

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
CORSI						
Age	2.20	1	2.20	3.19	.08	.10
Error	.01	1	.01	.02	.87	.00
DAUF						
Sum Correct						
Age	4356.81	1	4356.81	4.99	.03	.15
Error	6711.01	1	6711.01	7.69	.01	.22
Mean Time Correct						
Age	.00	1	.00	2.33	.13	.08
Error	.02	1	.02	7.08	.01	.20
MR						
Age	7.33	1	7.33	.65	.42	.02
Error	92.86	1	92.86	8.27	.00	.23
TOL-F						
Age	4.66	1	4.66	1.26	.27	.04
Error	.08	1	.08	.02	.88	.00

To test the research hypothesis, data of Table 4 should be analyzed. According to this table, the effect of age factor on the main variable of CORSI test (immediate block span) is not statistically significant (sig = 0.08, $p < 0.05$). Moreover, regardless of the effect of age, there was no significant difference between the two groups of controllers with and without error (sig = 0.87, $p < 0.05$). As a result, it seems that there are no significant differences in immediate block span between controllers with a history of error and the controllers without it. As a result, the null hypothesis is confirmed. According to Table 1, which is related to the descriptive data of this test between the two groups, the controllers who did not have a history of error performed better than the controllers with a history of error on average, but their performance is not significantly different according to covariance analysis.

To determine the differences between the two groups in sustained attention, the main variables of DAUF are examined. According to Table 4, the effect of age on the number of correct answers of DAUF test was significant (sig = 0.03, $p < 0.05$). Also, regardless of the effect of age on this variable, the differences between the two groups with and without errors was statistically significant (sig = 0.01, $p < 0.05$). Also, age had no significant effect on reaction times of the controllers (sig = 0.13, $p < 0.05$) but regardless of the effect of age, the difference between the two groups was significant (sig = 0.01, $p < 0.05$). Accordingly, it seems that the two main variables of DAUF show a significant difference between the two groups of controllers. Therefore, the null hypothesis, that there is no difference between controllers with and without errors in sustained attention, is rejected. According to Table 1, the performance of controllers without errors was better in both variables; they had more correct responses and reacted faster than the controllers with errors.

Another cognitive function examined in this study was situational awareness which was measured by MR. As can be seen in Table 4, there is a significant difference in the scores of this test between the group of controllers with a history of error and the controllers who do not have such a history (sig = 0.008, $p < 0.05$).

According to Table 1, controllers with no history of human error performed better than controllers with this history. Therefore, the null hypothesis, i.e. there is no difference between two groups of controllers in their situational awareness, is rejected and it can be claimed that there is a significant difference in situational awareness between these two groups of controllers.

Lastly, to examine planning ability between the two groups, the main variable of TOL-F is analyzed. According to Table 4, the effect of age on planning ability is not significant (sig = 0.27, $p < 0.05$). Also, regardless of the age effect, controllers with and without error history do not have a significant difference in planning ability (sig = 0.88, $p < 0.05$). Therefore, the answer to the research question has been determined and it has been shown that there is no significant difference between the two groups of controllers with and without error; As a result, the null hypothesis is confirmed. As shown in Table 1, controllers with no history of human error performed slightly better on average in planning than the other group, but this difference was not statistically significant.

Given the results of cognitive tests that have been described so far, it can be concluded that the controllers without error history were significantly different from the other controllers in sustained attention and situational awareness, but there were no significant differences between the two groups in short-term memory and planning ability. This study also examined personality traits in air traffic controllers. Table 5 is the covariance analysis of EPP6 scales.

Table 5. Tests of Between-Subjects Effects in EPP6 Scales

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Extraversion						
Age	105.89	1	105.89	3.82	.06	.12
Error	164.38	1	164.38	5.93	.02	.18
Emotionality						
Age	330.55	1	330.55	3.79	.06	.12
Error	6.10	1	6.10	.07	.79	.00
Adventurousness						
Age	130.61	1	130.61	6.90	.01	.20
Error	4.92	1	4.92	.26	.61	.01

According to Table 5, the effect of age on extraversion cannot be considered statistically significant (sig=0.06), but regardless of age, the controllers of the two groups are significantly different in terms of extraversion (sig=0.02). These results show that the null hypothesis that there is no difference between the two groups in the dimension of extraversion is rejected. As Table 2 shows, controllers with a history of error (mean=22) are more extraverted than controllers without a history of error (mean=20) and scored higher on extraversion and all its subscales.

As for emotionality, the effect of age cannot be considered statistically significant (sig=0.06) and there is no difference between the two groups of controllers without considering the effect of age (sig=0.79). As a result, the null hypothesis on no difference between the controllers of the two groups in terms of emotionality is confirmed. Although controllers with a history of error have scored higher than controllers without error on emotionality and all its subscales, this difference is not considered statistically significant.

In adventurousness, the effect of age was significant (sig=0.01), but without considering the effect of age between the two groups of controllers with and without error, there is no significant difference in adventurousness (sig=0.61). Therefore, the null hypothesis regarding the lack of difference between the two groups of controllers is confirmed. Also according to Table 2, although the controllers with error history scored higher than the controllers without error in adventurousness, impulsiveness and irresponsibility subscales, this difference is not considered statistically significant. Moreover, in the subscale of risk-taking, the controllers without error had higher scores than the controllers of the other group, but this difference is not statistically significant.

4. Discussion

This study sought to investigate the effect of cognitive functions and personality traits on occurrence of human error in air traffic controllers. According to the research background, four of the most important cognitive functions, including situational awareness, sustained attention, short-term memory and planning ability, were selected. To examine the research questions, the controllers were divided into two groups in terms of having or not having error history using semi-structured interviews, and their cognitive abilities and personality traits were measured using a set of Vienna Test System. MR was used to assess situational awareness, DAUF was used to measure sustained attention, CORSI was used for short-term memory, and TOL-F was used to measure the planning ability. According to Eysenck's theory, EPP6 (one of VTS's tests) was used to measure personality traits.

In order to prevent the possible effect of age on cognitive functions and personality traits, analysis of covariance was used to control this effect. According to the results obtained from statistical analysis of covariance, , in situational awareness and sustained attention, the difference between the two groups is significant (0.008 for situational awareness and 0.01 and 0.01 for the main variables of the DAUF test, which measures sustained attention). However there is no significant difference between short-term memory and planning ability (0.87 and 0.88, respectively) between controllers with and without errors with controlling the age effect. In fact, sustained attention and situational awareness of controllers without errors are higher than controllers with error history, and these results are consistent with studies that consider situational awareness (Li, et. al., 2018; Kraemer & Süß, 2015; Malakis & Kontogiannis, 2013; Bacon, & Strybel, 2013; Loft, et. al., 2007; Eißfeldt, 2000) and sustainable attention (Rodrigues, et. al., 2018; Giraudet, et. al., 2015; Ellis & Liston, 2010; Wittbrodt, Gross, & Thüring, 2010; Shorrock, 2007) important in air traffic control.

There is no doubt about the importance of functions such as planning ability and short-term memory in air traffic control. The importance of these cognitive functions has also been confirmed in various studies (e.g. Rodrigues et. al., 2018; Kearney, Li, & Lin, 2016; Corver & Aneziris, 2015; Malakis & Kontogiannis, 2013; Tremblay, Parmentier, Hodgetts, Hughes, & Jones, 2012; Shorrock, 2005; Crevits, Debernard, & Denecker, 2002; Niessen & Eyferth, 2001; Eißfeldt, 2000). However, according to the results of this study, these functions have not had a significant effect on human error of air traffic controllers.

Studies in cognitive field including studies in memory, perception, problem solving, and reaction times are very valuable. However, in real life, people sometimes act differently; therefore, explaining cognitive phenomena by breaking them down into hypothetical cognitive blocks may not always be appropriate. Cognition is highly dependent on the context, and cognitive activities are not seen solely as the result of mental activity and are largely dependent on environmental aspects (Cox, et. al., 2007). For studying issues of human factor in workplace, understanding the real work environment is very important (Inoue, et. al., 2012). In this study, the tests taken from air traffic controllers were in a calm and stress-free environment.

Controllers face a lot of stress in their real work environment and, as mentioned earlier, cognitive functions decline under stress. Therefore, the lack of difference between the two groups in short-term memory and planning ability should be interpreted with caution.

This study also examined personality traits in air traffic controllers. EPP6 was used in this study and by using analysis of covariance, the test's scales (extraversion, emotionality, adventurousness) were analyzed. The differences between the controllers with and without errors in the mentioned scales are as follows: controllers with error history scored higher than the other group in extraversion (0.02). In emotionality, although controllers with errors had higher mean scores than controllers without group, this difference was not significant and could not be used to distinguish between the two groups in terms of emotionality (0.79). Also in adventurousness, the controllers with error, despite the higher mean score compared to the controllers without error, had no significant differences with them in this scale (0.61).

The higher extroversion of air traffic controllers with error history can be explained by the fact that the more extroverted a person is, the more they dislike being alone. They are easygoing, low-tempered, aggressive and more impulsive and seek excitement. They tend to be constantly on the move and doing something. In contrast, more introverted people are usually more focused. These people usually plan ahead and are more prudent and non-impulsive, and do not like too much excitement. Introverts take daily tasks seriously, like a regular routine of life, are in control of their emotions, and do not get angry easily (Antonius, 2011).

For sensitive fields such as air traffic control, which require people to focus on their work environment and perform well under high work stress, people with good emotion management, planning, seriousness and discipline are likely to perform better. These traits, as mentioned above, describe introverts. Therefore, according to the results of this study, which shows that controllers with a history of error are more extroverted than the ones without error, it appears that people who do not have high scores in extroversion are better for working as air traffic controllers.

Regarding the other scale, i.e. emotionality, people with high scores in this scale are anxious, moody and usually depressed and impulsive. They usually find it difficult to cope with emotional situations. Their intense emotional reactions interfere with their proper judgment and cause them to react in irrational or even fanatical ways. High emotionality in combination with extraversion describes a sensitive, restless, emotional, and even aggressive person. On the other hand, people with lower scores on this scale, respond to a variety of issues less emotionally and more slowly. They can return to their normal state more quickly after experiencing an emotional event (Antonius, 2011). Although in this study, people with error history had higher scores than controllers without error on the emotionality and all its subscales, namely inferiority, unhappiness and anxiety, this difference was not sufficient to make a significant difference between the two groups.

The same is true for the adventurousness. A high level of adventurousness describes a reclusive, insensitive, ruthless person, and often troublesome. These people usually do not have empathy and are aggressive even towards those they love. Such a person is not afraid to take risks and enjoys being ridiculed and upset by others (Antonius, 2011). Air traffic control requires controllers to be able to interact positively and constructively with each other and engage in appropriate teamwork in order to maintain a safe and efficient air traffic flow (Eißfeldt, 2000). To reduce the occurrence of accidents and the optimal management of emergencies, it is necessary for people who work with each other to have a constructive and trusting interaction, transfer their knowledge to each other, and make decisions in critical situations (Irandoost, Alvaani, Memarzadeh, & Manteghi, 2017). It seems that a person with high adventurousness is not suitable for jobs such as air traffic control. However, according to the findings of this study, despite the higher scores of controllers with errors in adventurousness, impulsivity and irresponsibility subscales, as well as lower scores in risk-taking, these differences were not significant and cannot be noted that these characteristics make a difference between the two groups.

Air traffic is predicted to increase in the coming decades, which will increase the workload on air traffic controllers. Therefore, efforts are made to increase the automation of systems in this area so that the working pressure, despite the increase in air traffic flow, does not increase the burden on the controllers, resulting in fewer errors. One of the factors that can affect people's trust in automation is personality traits. Research has shown that greater emotional stability and less neuroticism are associated with greater reliance on automated systems; because people with high neuroticism are more cautious in making decisions (Miramontes et. al., 2015). Like many areas where complexity and timing play a major role, air traffic control needs to be automated and improved (Westin, Borst, & Hilborn, 2016). Cognitive and functional analyzes show that automation of controllers' activities can help to better manage their workload (Edwards, Fuller, Vertek, & Manning, 1995).

However, the aviation industry in Iran faces several challenges for political-economic reasons. Worn-out fleet, which causes disruptions in flight operations such as long delays, poor flight quality and reduced safety, lack of proper planning and policies in this area, lack of principles of some airports and lack of adequate equipment to maximize the use of transport lines, are some of the barriers in the way of improving the aviation industry in Iran. However, considering the geographical location of Iran and regional and international cooperation, it is possible to obtain a good source of foreign exchange for the country through the expansion of aviation industry (Zarrabi, Mohammadi and Saghaei, 2009).

5. Conclusion

This study evaluated the differences between air traffic controllers with and without error history in cognitive functions and personality traits. According to the results, there were differences between the two groups in sustained attention and situational awareness and controllers without error history scored higher in these variables than the controllers of the other group. However, there were no differences between the two groups in short-term memory and planning ability. Also, considering personality traits, air traffic controllers with error history scored higher in extraversion than the controllers without error history, but there were no differences between the two groups in emotionality and adventurousness.

According to the results of this study, one suggestion for air traffic control centers is that they can use screening and cognitive tests are a prerequisite for hiring controllers in this field. The need to examine the personality and cognitive functions of controllers working in this field is determined in this study, because it was shown that functions like situational awareness and sustained attention and also extraversion, were different in controllers with and without error history and these variables can affect occurrence of human error in air traffic control. Also, because age can affect these functions as well as some personality traits, it is recommended that these screening tests be performed once in a while so that in case of any impairments in important cognitive functions and changes in personality traits, the problem be identified as soon as possible and the necessary procedures, like cognitive rehabilitation, be performed to improve their functions.

However, this study has faced some limitations. In this research, a causal-comparative method has been used. Despite all the advantages of this research method, it also faces disadvantages and limitations; These include the impossibility of direct control, the uncertainty of causal relationships, the conclusion based on limited events or samples, and the impossibility of identifying events with multiple causes. Another limitation of this method is self-selection and it means that the replacement of individuals in research groups is not under the control of the researcher and individuals belong to a specific group according to their specific characteristics (Delavar, 2015). In the present study, controllers were divided into two groups based on their error history. Given that the researcher has no role in assigning people to different groups, this causes controllers to not be the same in one or more variables. Although individuals were controlled in terms of age, other issues such as socio-economic status, marital status, number of children, etc., can still affect the results which could not be controlled.

Another limitation was that, unfortunately, it was not possible to investigate the type of error committed in controllers with a history of error. In other words, it is not possible to determine exactly what functions were impaired that led the controller to making a mistake. On the other hand, all the controllers who participated in the tests were examined for the test process in the period of 8 am to 7 pm, and it was not possible to perform the tests among the controllers working at night shifts.

Last but not least, is the low sample size. The limited work shifts of the controllers and their limited presence in the control center, the impossibility of performing tests with several controllers simultaneously and the increasing prevalence of Covid-19 in the country as well as among air traffic controllers prevented the increase in sample size.

One of the issues that could not be studied in this research was lack of access to tower and radar control centers. For the present study, only the controllers of the air control center, the highest level of air traffic control, have been examined. Due to the similarities in the tasks related to each of these centers and at the same time the differences in work environments, it is suggested to examine the cognitive functions and personality traits of the controllers of other centers and compare them with the results of the present study to determine the importance of cognitive functions and personality traits in controllers who work in radar and tower control centers.

Another issue that may have affected the results of this study is that all controllers were tested for the testing process between 8 am and 7 pm. Because of the possible effects of night shifts and fatigue on cognitive function, different results may be obtained if the tests are taken at night. Among the negative effects of fatigue on cognitive functions, we can mention the reduction of short-term memory efficiency and incorrect judgments and decisions, and these are the functions that in the present study were not significantly different between the two groups. It is recommended that other researchers examine these functions by changing the tests' times, to determine whether this factor can affect the results of these tests' results between the two groups of controllers with error and without error.

6. Acknowledgements

We would like to express my very great appreciation to Iran's Airport and Air Navigation Company, General Directorate of Air Traffic Management, for their cooperation and constructive suggestions. We would also like to thank all the air traffic controllers who had kindly cooperated and participated in this study.

1.6 Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

7. References

- Kabiri Rad, S. (2010). *Estimation of Domestic Air Travel Demand function in Iran* (Master’s Thesis). Shahid Beheshti University, Tehran, Iran.

- Nasiri Dashtabi, Z., Parastari, J. (2017, February 21-23). *Predicting route and collision avoidance using uncertain hybrid models in air traffic control*. Sixteenth International Conference of the Iranian Aerospace Association. Khajeh Nasir al-Din Tusi University of Technology.

- Lovato, A. V., Fontes, C. H., Embiruçu, M., & Kalid, R. (2018). A fuzzy modeling approach to optimize control and decision making in conflict management in air traffic control. *Computers & Industrial Engineering*, *115*, 167-189.

- Gallego, C. E. V., Comendador, V. F. G., Nieto, F. J. S., Imaz, G. O., & Valdés, R. M. A. (2018). Analysis of air traffic control operational impact on aircraft vertical profiles supported by machine learning. *Transportation research part C: emerging technologies*, *95*, 883-903.

- Loft, S., Sanderson, P., Neal, A., & Mooij, M. (2007). Modeling and Predicting Mental Workload in En Route Air Traffic Control: Critical Review and Broader Implications, *Human Factors: The Journal of the Human Factors and Ergonomics Society*, *49*(3), 376-399, DOI: 10.1518/001872007X197017

- Karikawa, D., & Aoyama, H. (2016). Analysis of Controllers' Working Methods Supporting Safe and Efficient Air Traffic Operations, *IFAC-PapersOnLine*, *49*(19), 319-324.

- Moon, W., Yoo, K., & Choi Y. (2011). Air Traffic Volume and Air Traffic Control Human Errors. *Journal of Transportation Technologies*, *1*(03), 47-53

- Chen, M. L., Lu, S. Y., & Mao, I. F. (2019). Subjective symptoms and physiological measures of fatigue in air traffic controllers. *International journal of industrial ergonomics*, *70*, 1-8.

- Wang, Y., Bu, J., Han, K., Sun, R., Hu, M., & Zhu, C. (2016). A novel network approach to study communication activities of air traffic controllers. *Transportation research part C: emerging technologies*, *68*, 369-388.

- Bongo, M. F., Alimpangog, K. M. S., Loar, J. F., Montefalcon, J. A., & Ocampo, L. A. (2018). An application of DEMATEL-ANP and PROMETHEE II approach for air traffic controllers’ workload stress problem: A case of Mactan Civil Aviation Authority of the Philippines. *Journal of Air Transport Management*, *68*, 198-213.

- Harris, D. (2014). Improving aircraft safety, *aviation psychology*, *27*(2), 90-95.

- Shakerian, M., Choobineh, A., Jahangiri, M., Alimohammadlou, M., & Nami, M. (2019). Introducing a new model for individual cognitive factors influencing human error based on DEMATEL approach. *Iranian Journal of Ergonomics*, *6*(4), 66-74.

- Vanderhaegen, F. (2016). Mirror Effect Based Learning Systems to Predict Human Errors-Application to the Air Traffic Control. *IFAC-PapersOnLine*, *49*(19), 295-300.

- Skaltsas, G., Rakas, J., & Karlaftis, M. G. (2013). An analysis of air traffic controller-pilot miscommunication in the NextGen environment. *Journal of Air Transport Management, 27*, 46-51.

- Nazarizadeh, A. A. (2010). *Review and explain the impact of distress on commitment of human error among air traffic control personnel in Iranian Airports Company* (Master's Thesis). Shahid Beheshti University, Tehran, Iran.

- Arumugam, S., Ramachandran, K, & Bhattacharyya, A. (2014). Suitability Screening Test for Air Traffic Controllers. *Global Journal of HUMAN-SOCIAL SCIENCE: A*, 14, 11-18

- Eißfeldt, H. (2000). Ability requirements for air traffic controllers - review and integration, [Conference Paper] The 24th EAAP Conference.

- Costa, P. T., & McCrae, R. R. (1995). Persons, Places and Personality: Career Assessment Using the Revised NEO Personality Inventory. *Journal of Career Assessment.* 3(2), 123-139

- Epstein, R. A. (2006). Behavioral Economics: Human Errors and Market Corrections, *The University of Chicago Law Review, 73*(1), 111-132.

- Lesiuk, T. (2008). The effect of preferred music listening on stress levels of air traffic controllers. *The Arts in Psychotherapy, 35*(1), 1-10.

- Miramontes, A., et. al. (2015). Training student air traffic controllers to trust automation. *Procedia Manufacturing, 3,* 3005-3010.

- Cox, G., Sharples, S., Stedmon, A., & Wilson, J. (2007). An observation tool to study air traffic control and flightdeck collaboration, *Applied Ergonomics, 38*(4), 425–435.

- Feist, G. J., Feist, J., & Roberts T. A. (2013). *Theories of Personality*, 8th edition, Seyed Mohammadi, Y., Tehran, Ravan Publication.

- Revelle, W. (2016). Hans Eysenck: Personality theorist. *Personality and Individual Differences, 103*, 32–39.

- Delavar, A. (2015). *Educational and Psychological Research,* 4th edition, Tehran, Virayesh Publication Institute.

- Office of Information Technology and Statistical Surveys, Deputy of Management and Resources Development (2019). *Iran Aviation Statistics Book 1397*. Tehran: National Aviation Organization.

- Schuhfried, G. (2013). Vienna test system: Psychological assessment. *Moedling, Austria: Schuhfried*.

- Antonius, K. (2011). Eysenck Personality Profiler V6: Test Label EPP6 Manual. *Austria: Schuhfried*.

- Irandoost, E., Alvaani, S. M., Memarzadeh, G., Manteghi, K. (2017). *Incident Management in Social Service Organizations Adopting High Reliability Approach.* Journal of Emergency Management, 11, 63-75.

- Westin, C., Borst, C., & Hilburn, B. (2016). Automation Transparency and Personalized Decision Support: Air Traffic Controller Interaction with a Resolution Advisory System, *IFAC-PapersOnLine, 49*(19), 201–206.

- Edwards, M. B., Fuller, D. K., Vortac, O. U., & Manning, C. A. (1995). The role of flight progress strips in en route air traffic control: a time-series analysis. *International Journal of Human-Computer Studies*, *43*(1), 1-13.

- Zarrabi, A., Mohammadi, J., and Saghaei, M. (2009). Challenges of the Air Transportation Industry in Iran – The Case of Air Traffic at Isfahan International Airport. *Geographic and Environmental Planning, 1*(33), 23-42.

- Karimi, H., and Hosseini, A. (2011). Investigating the causes of human error in the occurrence of air accidents, *Second National Conference on Road, Rail and Air Accidents*, Zanjan, Islamic Azad University, Zanjan Branch.

- Khazaei, S. A. (2018). Implementation of satellite navigation systems in Iran; Opportunities and challenges. Public Law Studies Quarterly, 4 (48), 909-926.

- Dreifus, D. (1978). Correction of the Report on the accident involving aircraft BOEING 747 PH-BUF of KLM and BOEING 747 N 736 PA of PANAM. Ministerio de transportes y comunicaciones, Madrid, Spain.

- Bureau of Labor Statistics, U.S. Department of Labor, Occupational Outlook Handbook, Air Traffic Controllers, retrieved from https://www.bls.gov/ooh/transportation-and-material-moving/air-traffic-controllers.htm (May 20, 2019)

- Sternberg, R. (2015). *Cognitive Psychology*, 4th edition, Kharrazi, S. K. & Hejazi, E., Tehran, Organization for the Study and Compilation of Humanities University Books (Samt).

- Kasteleijn-Nolst Trenite, D. G., Vermeiren, R. (2005). The impact of subclinical epileptiform discharges on complex tasks and cognition: relevance for aircrew and air traffic controllers, *Epilepsy & Behavior*, 6, 31–34

- Rodrigues, S., Paiva, J. S., Dias, D., Aleixo, M., Filipe, R. M., & Cunha, J. P. S. (2018). Cognitive impact and psychophysiological effects of stress using a biomonitoring platform. *International journal of environmental research and public health, 15*(6), 1080.

- Kallus, K. W., Barbarino, M., & Van Damme, D. (1997). Model of the cognitive aspects of air traffic control.

- Ayaz, H., et al. (2010). Cognitive Workload Assessment of Air Traffic Controllers Using Optical Brain Imaging Sensors. *Advances in Understanding Human Performance: Neuroergonomics, Human Factors Design, and Special Populations*, 21-31.

- Borghini, G., Aricò, P., Di Flumeri, G., Cartocci, G., Colosimo, A., Bonelli, S., ... & Pozzi, S. (2017). EEG-based cognitive control behaviour assessment: an ecological study with professional air traffic controllers. *Scientific reports, 7*(1), 1-16.

- Shorrock, S. T. (2007). Errors of perception in air traffic control. *Safety science*, *45*(8), 890-904.

- Shorrock, S. T. (2005). Errors of memory in air traffic control. *Safety science*, *43*(8), 571-588.

- Inoue, S., Furuta, K., Nakata, K., Kanno, T., Aoyama, H., & Brown, M. (2012). Cognitive process modelling of controllers in en route air traffic control. *Ergonomics*, *55*(4), 450-464.

- Cowan, N. (2008). What are the differences between long-term, short-term, and working memory? *Progress in Brain Research*, 169, 323-338, doi: 10.1016/S0079-6123(07)00020-9

- Hadley, G. A., et al. (1999). *Air Traffic Control Specialist Performance Measurement Database* (Report No. DOT/FAA/CT-TN99/17). Retrieved from U.S. Department of Transportation Federal Aviation Administration

- Endsley, M. R. (1995). Measurement of situation awareness in dynamic systems. *Human factors*, *37*(1), 65-84.

- Endsley, M. R. (1995). Toward a theory of situation awareness in dynamic systems. *Human factors*, *37*(1), 32-64.

- Mirchi, T., Vu, K. P., Miles, J., Sturre, L., Curtis, S., & Strybel, T. Z. (2015). Air traffic controller trust in automation in NextGen. *Procedia Manufacturing*, *3*, 2482-2488.

- Niessen, C., & Eyferth, K. (2001). A model of the air traffic controller's picture. *Safety Science*, *37*(2-3), 187-202.

- Kearney, P., Li, W. C., & Lin, J. J. (2016). The impact of alerting design on air traffic controllers' response to conflict detection and resolution. *International journal of industrial ergonomics*, *56*, 51-58.

- Li, W. C., Kearney, P., Braithwaite, G., & Lin, J. J. (2018). How much is too much on monitoring tasks? Visual scan patterns of single air traffic controller performing multiple remote tower operations. *International journal of industrial ergonomics*, *67*, 135-144.

- Ellis, S. R., & Liston, D. (2010). Visual features involving motion seen from airport control towers. *IFAC Proceedings Volumes*, *43*(13), 152-157.

- Collet, C., Averty, P., & Dittmar, A. (2009). Autonomic nervous system and subjective ratings of strain in air-traffic control, *Applied Ergonomics, 40*(1), 23–32.

- Giraudet, L., Imbert, J. P., Tremblay, S., & Causse, M. (2015). High rate of inattentional deafness in simulated air traffic control tasks. *Procedia Manufacturing*, *3*, 5169-5175.

- Puhr, U. (2010). Sustained Attention: Test Label DAUF Manual. *Austria: Schuhfried*.

- Wittbrodt, N., Gross, A., & Thüring, M. (2010). Challenges for the Communication Environment and Communication Concept for Remote Airport Traffic Control Centres, *IFAC Proceedings Volumes*, *43*(13), 129-134.

- Malakis, S., & Kontogiannis, T. (2013). A sensemaking perspective on framing the mental picture of air traffic controllers, *Applied Ergonomics, 44*(2), 327-339.

- Corver, S. C., & Aneziris, O. N. (2015). The impact of controller support tools in enroute air traffic control on cognitive error modes: A comparative analysis in two operational environments. *Safety Science*, *71*, 2–15.

- Kaller, C. P. et al. (2011) Tower of London - Freiburg Version Manual. *Austria: Schuhfried*.

- Crevits, I., Debernard, S., & Denecker, P. (2002). Model building for air-traffic controllers’ workload regulation. *European Journal of Operational Research*, *136*(2), 324-332.

- Vaseli Khabbaz, M., Ramezani Zadeh, M., Nayebi, A. (2018). Investigating the effects of age, fatigue, experience and training on pilot human error in the occurrence of air accidents in the world. *Journal of Human Resource Studies*, 8 (28), 71-104.

- Kianpour Ghahfarkhi, F., Haghighi, J., Shokrkon, H., Najarian, B. (2002). Relationship between the first seven stages of Erickson's theory of psychosocial development and its eighth stage - integrity vs. despair - in the elderly of Khuzestan province. Journal of Education and Psychology. 9 (3). 17-52

- Schellig, D. (2011). CORSI: Block-Tapping Test Forwards, Block-Tapping Test Backwards, Supra-Block Span Test Manual. *Austria: Schuhfried*.

- Prieler, J. (2003). Mental Rotation Manual. *Austria: Schuhfried*.

- Kraemer, J., & Süß, H. M. (2015). Real time validation of online situation awareness questionnaires in simulated approach air traffic control. *Procedia Manufacturing*, *3,* 3152-3159.

- Bacon, L. P., & Strybel, T. Z. (2013). Assessment of the validity and intrusiveness of online-probe questions for situation awareness in a simulated air-traffic-management task with student air-traffic controllers, *Safety Science*, *56*, 89–95.

- Tremblay, S., Parmentier, F. B., Hodgetts, H. M., Hughes, R. W., & Jones, D. M. (2012). Disruption of verbal-spatial serial memory by extraneous air-traffic speech. *Journal of Applied Research in Memory and Cognition*, *1*(2), 73-79.

Conflict of Interest and Authorship Conformation Form

Please check the following as appropriate:

o All authors have participated in (a) conception and design, or analysis and interpretation of the data; (b) drafting the article or revising it critically for important intellectual content; and (c) approval of the final version.

- This manuscript has not been submitted to, nor is under review at, another journal or other publishing venue.
- The authors have no affiliation with any organization with a direct or indirect financial interest in the subject matter discussed in the manuscript
- The following authors have affiliations with organizations with direct or indirect financial interest in the subject matter discussed in the manuscript:

<u>Author's name & Affiliation</u>

Sepideh Hedayati[1], Vahid Sadeghi-Firoozabadi[2], Morteza Bagheri[3], Mahmoud Heidari[4], N.N. Sze[5]

1. Faculty of Education and Psychology, Department of Applied Psychology, Shahid Beheshti University, Tehran, Iran.
2. Faculty of Education and Psychology, Department of Psychology, Shahid Beheshti University, Tehran, Iran.
3. School of Railway Engineering, Iran University of Science and Technology, Tehran, Iran.
4. Faculty of Education and Psychology, Department of Psychology, Shahid Beheshti University, Tehran, Iran.
5. Department of Civil and Environmental Engineering, Hong Kong Polytechnic University, Hong Kong