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Department of Air Transport

Influence of Relaxation Techniques on Pilots’ Performance

Bachelor Thesis

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ZADÁNÍ BAKALÁŘSKÉ PRÁCE

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Při zpracování bakalářské práce se řiďte následujícími pokyny:

- Cílem práce je výběr vhodných relaxačních technik u pilotů a zhodnocení jejich vlivu na výkonnost při zátěžových situacích
- Analyzujte problematiku současného stavu zaměřenou na využitelnost relaxačních technik pro piloty
- Na základě analýzy vyberte vhodnou techniku, navrhněte a realizujte experiment, při kterém bude možné zhodnotit vliv relaxační techniky na výkonnost pilotů při zátěžových situacích
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BACHELOR'S THESIS ASSIGNMENT

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Student's name and surname (including degrees):

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Theme title (in Czech): **Vliv relaxačních technik na výkonnost pilotů při zátěžových situacích**

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Guidelines for elaboration

During the elaboration of the bachelor's thesis follow the outline below:

- The aim of this work is to select a suitable relaxation technique for pilots in stressful situations and evaluate its impact on performance
- Analyze the current state of the art focused on the usability of relaxation techniques for pilots
- Based on the analysis, select a suitable technique, design and perform an experiment to evaluate the impact of relaxation technique on the performance of pilots in stressful situations
- Evaluate the collected data using appropriate methods
- Interpret and discuss the results of the work
- State conclusions and limitations of the work

Graphical work range: according to the instructions of thesis supervisor

Accompanying report length: minimum of 35 text pages (including figures, graphs and sheets which are part of the main text)

Bibliography:

Perciavalle, Valentina, et al. "The role of deep breathing on stress." Neurological Sciences 38.3 (2017).

Hopper, Susan I., et al. "Effectiveness of diaphragmatic breathing for reducing physiological and psychological stress in adults: a quantitative systematic review.

Bachelor's thesis supervisor: **Ing. Roman Matyáš, Ph.D.**
doc. Ing. Luboš Socha, Ph.D. et Ph.D.

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(date of the first assignment of this work, that has be minimum of 10 months before the deadline of the theses submission based on the standard duration of the study)

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I confirm assumption of bachelor's thesis assignment.

Roi Freudenthal
Student's name and signature

Prague .... October 8, 2021

Declaration

I hereby submit for assessment and defense a bachelor's thesis, prepared at the end of my studies at the Czech Technical University in Prague, the Faculty of Transportation Sciences.

I do not have a compelling reason against the use of this school work within the intention of s. 60 of the Act No. 121/2000 Coll., on Copyright and Rights Related to Copyright and on Amendment to Certain Acts (Copyright Act).

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In Prague on 08.08.2022 ....

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Abstrakt

Stres je faktorem, který významně ovlivňuje letové schopnosti pilota. Tato práce se zaměřila na speciální příklad zátěžové situace – praktickou zkoušku pro piloty ve výcviku a zkoumala možnost implementace techniky krátkodobé relaxace založené na hlubokém dýchání, kterou mohou piloti žáci ve stresových situacích aplikovat před zkušebními lety, a popřípadě při jiných životních událostech se zvýšenou zátěží. Experiment zahrnoval celkem 18 účastníků rozdělených do dvou skupin – analyzovanou a kontrolní. Účastníci museli provést sérii dvou letů (zkušební a hodnotící) s provedením relaxační techniky mezi těmito dvěma lety v případě analyzované skupiny. Během experimentu byla zaznamenávána srdeční frekvence spolu s letovými parametry. Po statistické analýze dat byla zvolená technika hlubokého dýchání shledána účinnou pro krátkodobé snížení stresu, nezlepšila však schopnosti pilotů při zkušebním letu, nejspíše z toho důvodu, že její účinky netrvají dostatečně dlouho.

Klíčová slova: stres, praktické vyšetření, výkon pilota, protistresová opatření, relaxace

Abstract

Stress is a factor significantly affecting the pilot's flying abilities. This thesis focused its scope on a special example of a stressful situation – practical exam for student pilots – and investigated the possibility of implementing a short-term relaxation technique based on deep breathing that can be applied by stressed students before their check rides and possibly before other stressful events in the pilot's life. It involved a total of 18 participants split into equal control and treatment groups who were required to perform a series of two flights (trial and examination) with a treatment period for the treatment group in between. The participants' heart rate data were recorded throughout the experiment, together with their flight performance during simulated flights. After statistical analysis, the selected breathing technique was found effective in short-term stress reduction, however, it did not improve the pilot's ability during the check ride, possibly because its effects last long enough.

Keywords: stress, practical examination, piloting performance, coping, relaxation

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List of Abbreviations

ANOVA	Analysis Of Variance
ANS	Autonomic Nervous System
CDI	Course Deviation Indicator
GAS	General Adaptation Syndrome
FAA	Federal Aviation Administration
$H0_{1(2)}$	Null hypothesis 1 (2)
HRV	Heart Rate Variability
HRVAS	Heart Rate Variability Assessment Software
IFR	Instrument Flight Rules
ILS	Instrument Landing System
NASA	National Aeronautics and Space Administration
mRR	Mean RR interval
PNS	Parasympathetic Nervous System
RMSSD	Root-Mean-Square of consecutive RR interval Differences
SDNN	Standard Deviation of NN intervals
SNS	Sympathetic Nervous System
VOR	Very-High Frequency Omnidirectional Range

Introduction

In this day and age, we take aviation as a basic and integral part of our lives. Although flying has been around for over a century and the industry has achieved tremendous technological progress on its path from the first Wright brothers' flight to a 17-hour non-stop service between Tel Aviv and Melbourne, one element of the whole system has remained unchanged – the human being is fundamentally not suited for flying. In the most basic terms, obviously, people do not have a physical ability to fly and not even sensors, for example, to feel their altitude or speed. However, while these can be compensated for by instruments, the issue does not end here and continues deep into the psychological aspects of the human being. Flying is a challenge – it comes with operating complex systems, difficult weather, competitive market, and a great responsibility for other people's lives. Pilots react naturally to these demands – by showing stress. Despite the crucial role this defensive mechanism played in the evolution of the human species, it has few pros for pilots. Moreover, when the situation demands the most from them, stress can actually impair their performance [1].

As even the most experienced pilots sometimes are unable to keep functioning under the influence of high stress, it comes as no surprise that it can be an enormous factor for student pilots who have just started their professional path [2]. Regardless of the field of studies, education demands create anxiety for any student, but for a student pilot, these two factors combine, especially at the most responsible moments – their practical examinations. The consequences of this phenomenon are visible everywhere – between study results and flight safety [3].

Therefore, this thesis will investigate stress with a focus on the effects of stress on the piloting performance and psychophysiological state of pilot students during practical examination and will aim to test a possible solution to cope with it. It will be done through a detailed review of the available literature followed by a practical experiment trying to prove the viability of a short and simple solution for student pilots in need wherever and whenever they require it.

Chapter 1 – Current State of the Art Analysis

1.1. Literature Review

Stress and stress in aviation in particular represent a broad topic that can be considered from various viewpoints and in different manifestations. Therefore, this literature review will dive deep into the biological mechanisms of stress, its specific effects on human cognitive and physiological abilities, and the way it influences the pilot’s performance in execution of flying tasks. A separate discussion within this chapter will be dedicated to stress in students and during examinations. Various approaches to coping with stress will also be considered.

1.1.1. Physiological background of stress

Sustaining life requires a number of conditions to be maintained. One can view it as supporting a complex equilibrium: living organisms must remain at a certain temperature, keep exchanging energy, and, for instance, run the required chemical reactions in order to remain functional – this is known as homeostasis. However, the surrounding environment might occasionally challenge this balance, necessitating an appropriate response. Thus, for example, humans have evolved sweating as a response to excessive heat. Such adverse conditions, whether internal or external in nature, are called stressors. Hence, the aforementioned adaptive reaction that occurs when the homeostasis is endangered or is perceived to be so is termed stress [4].

For the human being, stressors can be generally categorized as physiological and psychological. A severe bleeding is an example of a physiological stressor, while anxiety a student experiences before an exam illustrates a psychological stressor. The detection mechanisms differ depending on the type of stressor: the former is recognized in the brainstem based on neural signals of pain or inflammation, whereas a response to the latter is triggered by areas of the brain involved in emotional processing. Regardless of the stressor type, the reactions to the aforementioned factors will both lead to activation of the stress system in a coordinated manner [5].

Stress response is largely formed by the activity of the Autonomic Nervous System (ANS). It is the branch of the nervous system that is involved in the regulation of body functions by secretion of hormones – biologically active substances. It is represented by a number of glands throughout the organism, however, in terms of its specific branches involved in this process, Sympathetic Nervous System (SNS) and Parasympathetic Nervous System (PNS) can be distinguished. SNS is often referred to as the "fight or flight system", implying its influence of triggering high arousal and active states. However, the function of PNS is seemingly opposed to it and is termed "rest and digest": it governs processes related to relaxation and resources restoration [6].

Coordinated activity of the two ANS branches addresses a particular stressor. Such responses can be divided into specific and non-specific. The non-specific reaction is basically known as the General Adaptation Syndrome (GAS), which will develop according to the same pattern independent of the reason. GAS normally progresses in three stages: alarm phase, resistance phase, and exhaustion phase [5; 7; 8].

The initial alarm phase is described by researchers as a body's "call to arms" for the organism defense mechanisms against the stressor. This stage is characterized by various manifestations of shock proportional to the threat. The biological mechanism of this phase activation is complex and is facilitated by a release of neuromediators and various hormones, the most notable of which is adrenaline. This process induces changes throughout practically any part of the body. In terms of the cardiovascular system, the cardiac output in increased, the vessels constrict, redistributing the blood across the body, and the blood pressure increases to support the functioning of the skeletal muscles in the anticipated physical activity. Adrenaline releases the reserves of sugar stored in the liver by activating the process of glycogenolysis. Gastrointestinal activity is inhibited in order to free up more blood capacity. From the standpoint of neurobehavioral changes, pupil dilation and an increase in alertness and anxiety can be noted. It results in a general decrease in psychological and muscular fatigue. This arousal and the alarm phase in general cannot be sustained for a prolonged period of time [5; 8; 9].

The second phase, resistance, is attributed to a more controlled reaction and engagement of adequate mechanisms to combat the stressor. The observed response is generally opposed to that during the alarm phase: for instance, blood concentration and body weight tend to return to the normal. The physiological background of this phase largely relies on releasing the hormone of cortisol. It enables the required performance to be maintained as additional energy is made available through break-up of fats into glucose through the process of gluconeogenesis. This hormone additionally suppresses immune and allergic responses. This stage, depending on the available energy reserves, can be maintained for months [5; 8; 10].

As the organism's capabilities to resist the stressor are depleted, the final stage of GAS occurs in the form of exhaustion. Its effects show significant similarity to those displayed during the initial alarm response. If the stressor is removed, the body will eventually return to the homeostatic state, however, if allowed to persist, the stage of exhaustion will lead to an irreversible depletion of adaptation mechanisms and eventual death.

1.1.2. Stress model

As it has been mentioned before, stress is a biological response of an organism to the demands placed on it. However, the relationship between the stressor and the resulting reaction is complex and depends on the past experience of the individual and their biological and psychological properties. This relationship is described by a stress model suggested by Cox in 1978 [11]. Its schematic representation is given below in Figure 1.

As it is visible in the figure, stress starts with the actual stressor and the actual ability to cope with this threat which pass through the individual's perception and undergo further processing and evaluation. It determines the subjective mental picture of the situation which defines the severity of the physiological and psychological responses. Together, they form the resulting outcome of the situation. Since the stress response is largely affected by the perception of the stressor and the subjective ability, the result of previous events affects the perception of future encounters with similar demands and hence the following performance.

To conclude, this stress model views the stress as a subjective phenomenon which, therefore, is different among individuals and is considerably affected by their past experience. It explains how in the same situation as public speaking, one would enjoy the thrill of it while the other one would be paralyzed at the very thought [7; 11].

Another important property of stress is that stressors and the resulting stress are additive and cumulative. Every next stress factor adds up and increases the existing stress load and the respective body response up to a certain threshold. This limit is individual and varies from person to person, depending on various physiological and psychological characteristics. Should this critical level of stress be exceeded, the person's ability to handle the situation reduces tremendously up to a point that they cannot adequately perform even moderate tasks [7; 12; 13].

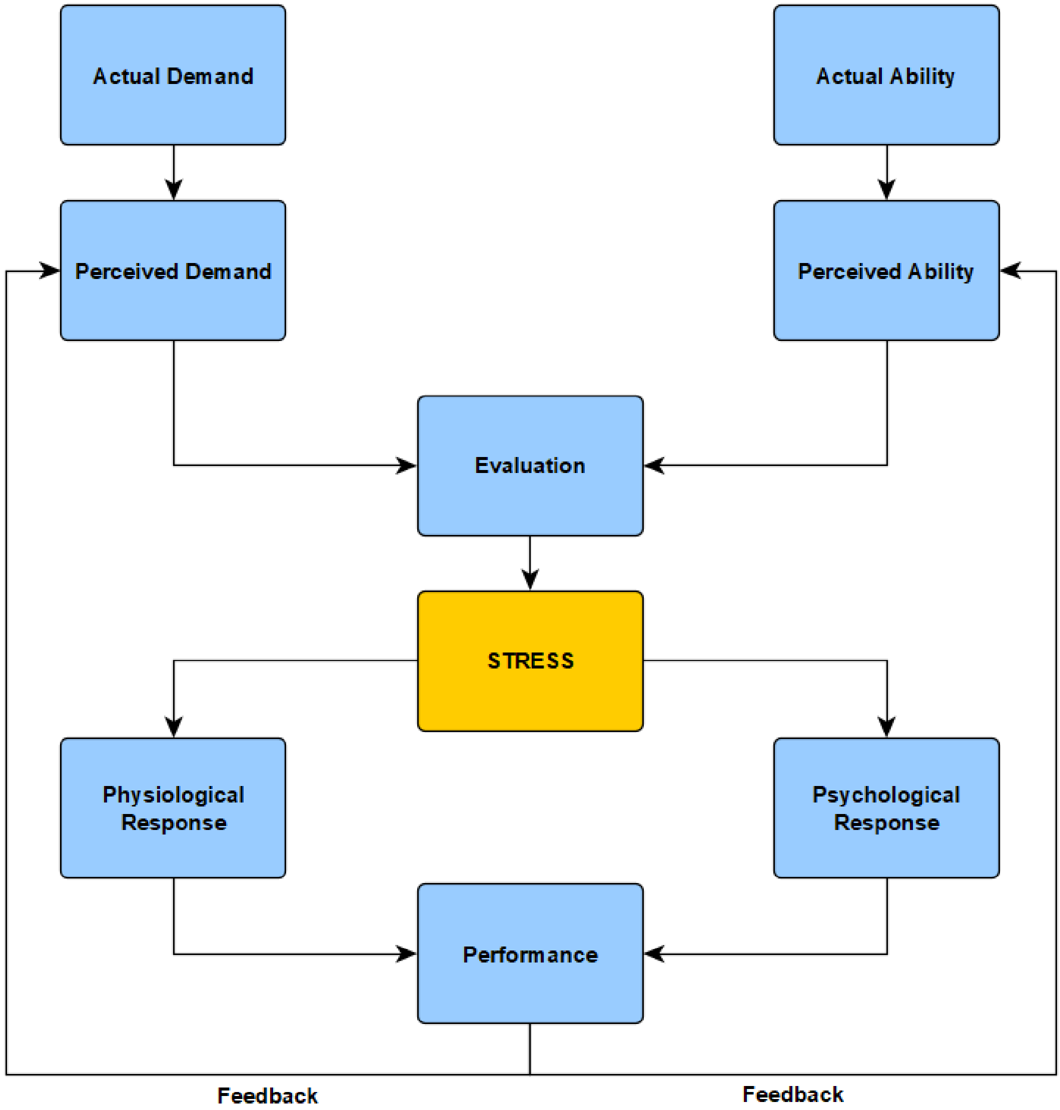

Figure 1. Stress model

Therefore, stress can be subdivided into categories: acute and chronic. Acute stress is a result of a specific event with a discrete beginning and ending whereas chronic stress is a condition induced by a stressful environment (for example, family trouble or high demands in the study process in the university). In the latter case, the effects of multiple challenges accumulate, leading to adverse physiological and psychological consequences. Studies have shown that people experiencing chronic stress are more vulnerable to the acute one. Again, it can be explained by the idea of stress being cumulative as described above [14].

1.1.3. Stress and performance

Stress is known as a factor affecting human performance. In reality, this effect is its biological reason. It increases the arousal and the physical abilities and sharpens the senses to improve the ability to cope with a demanding situation. However, at a high level of stress one can start experiencing adverse symptoms like a loss of concentration and memory, tunneling of attention, spontaneous muscle contractions, and more. The relationship between the level of stress (or arousal) and the resulting task performance is approximated by the Yerkes-Dodson law first described in 1908 [4; 7; 15]. Its visual representation is provided in Figure 2.

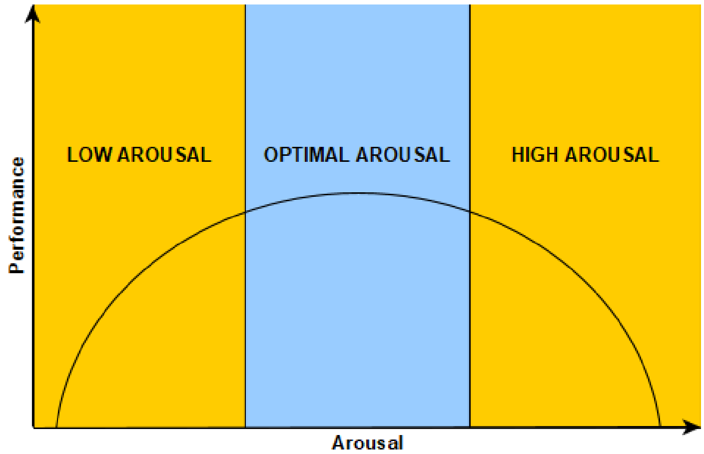

Figure 2. The relationship between stress and performance

The law predicts low performance at high and low levels of arousal and maximum performance reaching its peak in the middle of the inverted U-curve corresponding to the optimum arousal. Therefore, increasing the level of stress or arousal positively contributes to the performance but only up to a certain threshold. A practical example for this theory is a student preparing for a test. A week before the exam, they can experience loss of concentration and ineffectiveness during the process of preparation, while a day before, when the level of anxiety starts to increase, they can study effectively for prolonged periods of time. However, this positive effect may be lost during the exam due to an overly high level of arousal.

Nevertheless, further research aiming to test this hypothesis came to opposing conclusions and questioned the studies supporting this theory as biased. One of the possible reasons is that the terms “stress” and “arousal” are used interchangeably and are assumed to correlate directly. Some studies have suggested that the relationship between those two is more complex and that even though some level of arousal has positive influence, any increased amount of stress degrades the performance linearly. This theory of direct negative correlation has gained support in recent research over the inverted-U law, however, the researchers do not suggest directly dismissing the theory and recommend further investigation [16; 17].

Specific stress effects on performance can be considered from motor and cognitive standpoints. Motor performance is generally degraded for any level of stress. The best example of it can be observed in some professional athletes and is known as “chocking under pressure” or paradoxical performance. It is, for instance, a football player missing a ball at a critical moment of the world championship despite all the efforts to do their best and the fact of being well-trained. As for the reasons behind this phenomenon, it can be explained by the execution of procedural memory. Scientists connect it to the self-focus theory. It states that under a certain amount of anxiety an individual consciously focuses on performing a specific task that otherwise would be automated. Motor programs stored in the procedural memory form through a kind of learning that starts with active cognitive control over a task that later becomes automated. Studies have shown that subjects under stress tend to practically reverse this process and return to its first stage and, therefore, demonstrate the respective standard low level of performance [18]. Another motor effect of stress that may be observed in cases of extreme overload is spontaneous muscle contractions (tremor) and incoordination that can further decrease the performance [7].

In terms of effects of stress on cognitive performance, one can experience an overall decrease in mental capacity and attention. Studies are explaining this behavior using the so-called attentional control theory. It states that under stress the proper functioning of the goal-driven attentional system is impaired, and the information processing is largely affected by the stimulus-driven attentional system. Not only does it lead to a reduction of general attention level but also it increases the amount of attention dedicated to threat-related stimuli. Therefore, the effect is pronounced in four ways: inability to suppress significant false or irrelevant sensory inputs, increased tendency for distraction, impaired task performance on secondary tasks in dual-task situations, and difficulty in switching between various tasks [19; 20].

Another significant condition that affects performance under stress is the startle response. It is a reaction to an unexpected significant stimulus which triggers a specific body feedback. The most pronounced manifestations include sudden skeleton muscle contraction (in other words, momentary freezing), rapid blinking, and activation of the ANS. The biological role of this action is protection – it secures the body from a strike or an impact. However, in the present environment, it can lead to undesired negative outcomes resulting in a decrease in both motor and cognitive performance. For the motor aspect, the startle response obviously interrupts the task and requires additional time to regain the ability and to execute the intended action. In the context of cognitive effects, studies have shown that such performance following a startle response is not affected just momentarily but may be decreased for a relatively prolonged period time. Such a reduction can come in the form of increased reaction time or even impaired decision-making. The strength of startle response increases directly in proportion to the level of anxiety experienced before the introduction of the unexpected stimulus. It is visible in a stronger activation of the ANS in stressful situations [21; 22; 23].

1.1.4. Stress in aviation

As stated above, the phenomenon of stress is of a great significance for the functioning of the human being since it affects all aspects of its activities ranging from cognitive performance and decision making to physical ability. Indeed, people are encountering stress in every industry and environment, however, when it comes to aviation, the matter becomes crucial for several reasons. First of all, aviation is a safety-critical environment where every small deviation from the normal state may potentially constitute a considerable risk as every flight concerns hundreds of lives. The latest studies estimate that between 70% and 80% of all aircraft accidents are contributed to by the human factor, and even though the specific number is impossible to obtain, stress and anxiety surely play a considerable role in these statistics [24; 25].

In addition, the flightdeck provides a variety of unique stress factors which might not be present in other workplaces. As it has been mentioned before, stressors can be categorized as psychological and physiological. This classification can be further expanded by distinguishing between physical and physiological factors, along with psychological and social factors. In terms of physical factors, disturbing vibrations, pressure changes as the aircraft climbs or descends, low humidity, overly high or low temperature, high level of noise, turbulence and gusts, and flashing lights are practically inseparable from the flight deck environment. The challenge of flying also introduces other stressors that are internal and physiological in nature such as a lack of sleep or general fatigue from schedule irregularity and jetlag, hunger, exhaustion due to demanding tasks or the required focus. As to the psychological factors, pilots have to work in a very challenging environment including emergency situations, problematic weather, busy airspaces, and, most importantly, the high responsibility for the other people’s lives [7; 13; 20; 25; 26; 27].

Furthermore, social stressors, despite not being the most obvious factor to consider at the flight deck environment, do exist and require a separate discussion. At the majority of commercial flights, the crew includes at least two members which must work together proficiently in synergy to reach the set goals. Working as a crew raises a few unique considerations. Stress introduced to one of the crewmembers executing a task by the knowledge of their colleagues watching and expecting them to succeed is called "peer pressure". When this crew member is the first officer or, for instance, occupies a low position in the company hierarchy tree, the level of stress can rise also because of the gradient of authority in the cockpit. Further stressors introduced by many airlines are constituted by various deadlines. The instability in the industry also induces a fear of livelihood deprivation. Lastly, in the new era when increasingly more women are entering the cockpit, some tension between the genders can be felt. All these sociological stressors are yet far from being comprehensively documented but are suggested as significant by multiple researchers. Some of these can gain an even greater importance under special circumstances and will be further discussed in the chapter of "Stress during examination" [28].

The significance of stress, as it was explained above in detail, and its importance in the field of aviation have been supported by multiple empirical studies. Therefore, for instance, a study by the University of Otago, New Zealand in 2018 aimed to investigate the correlation between the level of stress and the performance of pilots during an emergency [1]. This research involved a total of 22 general aviation pilots with a varying age, gender, and experience. Each pilot performed seven flights, three of which were uneventful with the remaining four introducing engines failures and stalls. Some of the emergencies were announced beforehand while the rest were unexpected to the pilot. The researchers concluded that even though every emergency came together with a certain increase in the level of stress, the unexpected ones could be attributed to a significantly more pronounced autonomic response, as evidenced by the participants' heart rate and pupil dilation. In the expected events, the participants experienced an increase in the level of arousal indicating a higher workload, compared to the unexpected situations, where the increase of arousal was consistent with startle response. With regards to the performance of the test subjects, while during all the expected emergency landings the pilots landed safely, only 12 out of 22 succeeded in their landings during the surprising engines failures – the rest either crashed or attempted a ditching. One of the reasons for the higher accident rate was the inability to maintain the correct airspeed, which, according to the authors of the article, can be attributed to the attention tunneling and lower cue utilization caused by a higher level of stress.

Another research by the University of Gloucestershire, UK in 2015 confirmed the relationship between the perceived demand and perceived ability [29]. The authors found that pilots who take the situation as a challenge (with their abilities outweighing the demands) perform better than their colleagues who view it as a threat (with the demands overshadowing their abilities). These findings are consistent with the hypothesis that the way an individual perceives the stressor affects the level of anxiety they experience, which directly impacts their performance. Similarly to the study by the University of Otago, the researchers attribute this impairment to the disruption and narrowing of attentional mechanisms.

Even though the two aforementioned studies came to a conclusion regarding the impairment of the performance generally caused by common psychological stressors, stress will impact the pilot's ability and judgement regardless of its origin, whether external or internal in nature. Therefore, similar results were obtained in other research investigating physical [30], psychological [31], financial [32], and social stress factors [33] in pilots. Indeed, each of these stressors taken separately affects the performance, however, a study by the National Aeronautics and Space Administration (NASA) suggested a potential complex relationship when those stressors combine [34]. For example, a high-stress life environment can result in sleep deprivation which of itself would cause increased fatigue and the respective changes in the level of physiological stress.

The significance of this issue can be best illustrated by referring to the available statistics. For instance, the findings from a survey performed among Indian commercial pilots in 2008 confirmed that most pilots suffer from mild to moderate professional stress, with only 13% of the respondents reporting no significant flying stress exposure [27]. The accident statistics are also an important indicator as its interesting correlation with certain stress factors was suggested by the NASA study mentioned above. Some of the publications it reviewed identified a statistically significant connection between the probability of being involved in an accident and certain stressful life conditions such as death of a close person, recent engagement or marriage, difficulties in handling interpersonal relationships, recent issues with superiors or subordinates, or making serious decisions about the future [34]. Even though those articles were not able to fully justify this correlation due to the complexity of all the variables involved, these findings provide an interesting point of view and are worth noting.

1.1.5. Stress during examination

Another special case of stress is the stress students experience before the exam, which is termed "exam anxiety" in the academic world. This phenomenon can be observed in students of any age and field of education. Beside the expected concerns about one's future, the term of exam anxiety also includes elements of social stress. On the one hand, loss of social hours due to investing time into studies can bring a feeling of loneliness to the individual. On the other hand, since exams commonly take place in competitive spirit, one can experience peer-induced stress [35; 36]. This fear is obviously rational but particular effects and their severity are individual and subjective, even within the same setup. The anxiety from examination will induce significant psycho-emotional and physiological effects before, during, and after the event and is largely affected by several factors: student's expectation of the grade, perception of readiness, and the eventual evaluation. This view is consistent with the stress model described before. With regards to the expectation of students, quite interestingly, those having excessively high or low perception of themselves are the ones who appear to be affected the most whereas students with a realistic view on their abilities show the mildest reactions. The restoration after the examination is believed to be affected by the same factors [37].

In terms of the relation between the examination stress and the resulting performance, there is currently a debate among the researchers, just like in the case of the positive and negative effects of stress explained in the chapter of "Stress and performance." Some scientists claim that mild to moderate stress is important for the vigilance and has a positive impact on the student's performance and only the excessive stress is harmful, while others describe linearly negative effects. The second standpoint appears more dominant [35; 36].

Another issue is the self-reinforcing potential of the exam anxiety. Before an important exam, students tend to study for prolonged periods of time, which, combined with the effects of stress, worsen the reduction of concentration and cause frustration, along with a loss of belief in one's abilities. The feeling of losing ability creates further pressure which simply "pours more fuel" into the existing "fire" [36]. Another type of such a self-reinforcing vicious cycle is connected to lack of sleep. When concerns of a student refrain them from falling asleep, this rest deprivation leads to a reduction in the resulting performance. Furthermore, the condition that one is aware of the fact that they have increasingly less time remaining to sleep further raises the total level of stress, which itself, together with equally increasing academic concerns, continues the cycle. Studies have confirmed its role as a factor decreasing examination performance [38].

1.1.6. Stress during check rides

In addition to the general factors listed in the previous chapter, exams in the industry of aviation, namely check rides and proficiency checks, represent a special case of exam with its own unique and significant implications. Passing or failing does not only constitute the matter of receiving an endorsement but also is a matter of the sense of competence. It comes as no surprise that even the most experienced captains have difficulty sleeping before a line check and count the remaining working time until retirement as the number of such examinations remaining [2].

To make the matters worse, the way the interaction between the examiner and the examinee is set is contributing to an even greater build-up of pressure. In many examination standard operating procedures, it is common to require the examiner to avoid showing any emotions and live feedback with respect to the examinee's performance. While theoretically this method helps prevent interference between the check airman's personality and the examination outcome, in practice, this emotionless behavior is a non-natural response that goes against the pilot's expectations from the interaction. When the pilot expects feedback and does not get it, they tend to consider it as indicator of their deviation from the required performance, which increases their level of stress. While it is normal feel this way, since, as the researchers note, "examinees are aware of many more ways to lose points than to gain them", it triggers an undesirable shame-response. It results in a perception of helplessness and failure phobia that together contribute to development of the anxious state with a resulting decrease in performance [2].

Similarly to the aforementioned findings, a study by the Federal Aviation Administration (FAA) focused specifically on the issue of check rides and confirmed the generally negative effects of stress on the pilot performance. The study involved the total of 312 helicopter student pilots who were evaluated independently by their instructors and, in the course of two check rides, by a certified examiner. The results compared the level of stress between students and revealed that as the level of anxiety increases, the deviation from the expected performance increases proportionally during the check ride. Therefore, the findings support the direct negative correlation. At the time when this research was published (in 1991), the inverted U-curve Yerkes-Dodson theory was still considered as the main approach to this issue. Therefore, the authors provided two possible explanations for the observed findings. Firstly, the check ride introduces a significant amount of stress to anyone involved and that is why the research might have sampled only the right-low part of inverted-U curve. Secondly, the researchers suggest that while this relationship may hold for other stress and task performance domains, it might not be valid for the flight deck environment [3]. In either case, such results are consistent with the more recent studies challenging the Yerkes-Dodson law in a wider range of applications [17]. Such relationship was generally supported by the findings of other research in the same check ride branch [39].

Such findings are practically reflected by the pilots' attitudes to various stressors. Two independent studies asking a total of over 200 student pilots to rank stress factors they face by their severity found that practical check rides are the most significant stressor in the process of their flight training, at the same level (the smaller study) [40] or even greater than financial concerns (larger sample size) [41]. Quite ironically, in both cases, the majority of students considered stress as a positive factor for their performance. Another interesting conclusion is that students without experience of practical flight examination were less stressed about it than experienced students who had taken some check rides.

Even though practical exams are the main concern for student pilots, this fear is far from disappearing also in the category of experienced aviators involved in commercial flights. Surprisingly, the exam anxiety appears to gain its significance with age, with the oldest commercial pilots showing the greatest effects. Researchers explain this phenomenon with the importance of the perception of ability in determination of the level of stress during exams, which was described earlier in the chapter of "Stress during examination". Due to this reason, together with old pilots, also pilots who fly less than they desire experience similar worries [25].

1.1.7. Coping with stress

As it is evident from the discussion in the previous chapters, stress has a negative influence on human task performance, and therefore, may necessitate adequate coping and reaction. These actions have two aims: on the one hand, directly solving the problem causing the stress, and, on the other hand, controlling the emotional response it creates. Such coping strategies can be subdivided into two general types: problem-focused coping and emotion-focused coping. Problem-focused coping is an active way to address the source of stress. It suggests to think of solutions to the root of the issue, considering potential benefits and losses, and assessing the possible options. Emotion-focused coping strategies might appear more intuitive as they generally require less cognitive efforts and target the disturbing emotional experiences arising from the stress factor. It offers a broad range of reactions including denial, venting out, social support seeking, and re-interpretation of the events in a positive manner. Thus, it comes as no surprise that the effectiveness of methods within the latter strategy is greatly variable between different approaches and individuals. Some emotion-focused strategies are believed to partially reduce the human ability to effectively adapt to the current situation [42].

Due to the reasons listed in the paragraph above, pilots have a tendency to use more problem-focused coping strategies in order to overcome problematic situations. The most obvious one is basically professional training. Pilots are taught for numerous complex situations in their different variations and, based on this preparation, experience a lower level of stress when facing them in reality. This technique goes along with the stress model approach which was mentioned in the respective stress chapter. Practicing actions for specific scenarios has a dual positive impact on pilots. On the one hand, when encountering a problem several times, the actual ability of the airman is obviously improved. On the other hand, their perceived ability, along with perceived demand, adjust to the situation, subsequently decreasing the level of stress. Another type of problem-focused strategy that can support other traditional forms of preparation is stress exposure training. Studies have found that intentionally inducing more stress during a dedicated simulator session has a potential to improve the performance of the pilot in real flight. Overall, pilots tend to focus on the structure and organization in addressing existing issues [43; 44].

However, problem-focused strategies are not always sufficient since it is a common fact that every student passes through adequate training prior to attempting a check ride. The same also applies to professional commercial pilots that, despite being well-prepared to perform their duties, as mentioned before, similarly suffer from stress related to regular practical examinations. As Baker and Berenbaum, scientists at the University of Illinois, note: “Problem-focused coping can be counter-productive if one hastily decides on a particular strategy without using one’s emotions as a guide to help solve the problem.” Therefore, one might find it reasonable to consider emotion-focused strategies. Emotion-focused approach can be subdivided into two different categories: active and avoidant. The active coping approach is concentrated on controlling the emotions and their effects. One of the examples of such a technique is the aforementioned positive reframing. It has a positive impact and is believed to improve adaptation. The avoidant technique, opposite from the active, focuses on "running away" from the problem, being busy with other tasks, and attempting to ignore and to forget the issue. As it has been mentioned before, the avoidant emotion-focused approach impairs the adaptive mechanisms [42; 45].

Overall, some emotion-focused coping techniques may appear intuitive and be used spontaneously like venting the feelings out or looking for social support. Nevertheless, some other more conscious techniques would be more suited for the pro-active approach. For instance, special diets and eating techniques were found as factors reducing sensitivity to stress. When the level of sugar in the blood drops, the human tends to partially lose the ability to handle complex situations. Therefore, eating smaller amounts of food in shorter intervals rather than the standard three-meals-a-day approach helps to correctly manage the level of glucose. In addition, eating complex carbohydrates instead of simple sugars readily available in products such as candy bars or donuts, is preferrable for the pancreas to correctly regulate the insulin levels and subsequently the blood sugar [46]. Another possibility is physical exercises. A study compared the stress levels of pilots who regularly practice various physical activities with pilots who do not found that the athletes experienced less anxiety than non-athletes [47]. Lastly, religious practices and spirituality are also believed to be beneficial with regards to stress regulation, however, the particular connection is yet to be found [48]. All the aforementioned techniques are proven and recommended but require long-lasting commitment that some individuals might not find practical. That is where short-term relaxation techniques could suit.

1.1.8. Mindful breathing as a relaxation technique

The term of relaxation refers to actions intended to induce parasympathetic reactions which oppose and suppress sympathetic nervous activities (flight or fight behavior) [48]. The most common relaxation techniques are yoga and meditation (or mindfulness), progressive muscle relaxation, and guided imagery. While some of them, as mentioned before, require longer-term practice and preparation, others, specifically mindful breathing, can be helpful even after a short exercise [49].

Mindful breathing for relaxation was developed intuitively ages and ages ago before science could approve and explain it. For instance, the so-called “pranayama”, which is an element of yoga, appeared in Asia thousands of years ago. In the modern world, it has not disappeared, but in fact, the opposite holds true. Today, increasingly more researchers are trying to validate the benefits of slow controlled breathing techniques. It is theorized to help through two channels. On the one hand, the mindful part of it assists by psychologically reducing the anxiety levels through intentionally focusing the attention, and therefore, suppressing repetitive thoughts, which causes a noticeable neurophysiological response. On the other hand, it relies on the biological mechanism of the connection between breathing and the heart rate to control the activation of the PNS [48; 49].

As it has been mentioned in the paragraph above, the mindful part of regulated breathing is an active participant in reducing the level of anxiety. It was proven that mindfulness increases the activation of the part of the brain responsible for emotion regulation. The mechanism behind these effects is still not fully clear. However, the main belief is that it functions on the principles of “extinction”. When one is breathing mindfully, their internal response to the stressor is suppressed and they become fully exposed to the situation both in terms of their internal feelings and the perception of the environment. Therefore, while mindfulness might appear to be an avoidant strategy, it is an active way of facing a problem [49].

Regarding the physiological effects of breathing, it has a direct correlation with regulation of cardiovascular system. During one full cycle of inspiration-expiration, one can observe a great number of changes throughout it. In the process of one breath, the blood pressure distribution in the heart is constantly changing when inhaling or exhaling to assist the blood delivery. In addition, blood vessels constrict and dilate for further flow optimization. When one intentionally reduces the frequency of breathing, as a part of homeostatic response, their body’s reaction will be the demand of hyperventilation. Therefore, for keeping the same low respiratory frequency, the individual must breathe deeper. It has been proven that breathing at the frequency of six cycles per minute reduces the hyperventilation demand of the body. During a normal breathing cycle, the volume of air can be divided into tidal volume (the air that actually diffuses with blood) and dead space, which is subdivided into anatomical (volume of air where no gas exchange is possible – e.g. trachea) and alveolar (alveoli that are not filled). In terms of the anatomical dead space, there is practically nothing to do to reduce it. However, deep breathing reduces the alveolar dead space and, therefore, improves the breathing efficiency. The best efficiency of breathing is achieved at a frequency of six cycles per minute, as experimentally reflected by the blood oxygen saturation [50].

It is also important to note the relation between the breathing and the heart rate. This dependency is called the respiratory sinus arrhythmia. The heart rate under breathing can be illustrated as a sinus wave where the highest frequency of heart beats can generally be observed during inhalation and the lowest – during exhalation. The exact relationship between the respiratory curve and this arrythmia curve varies with the frequency of breathing and creates a phase shift when there is a delay between the breathing phase and the response of the heart. Since the heart rate is primarily regulated by the ANS, it is evident that breathing has a direct effect on this branch of the nervous system and on its relevant parts – namely, SNS and PNS. The particular effects directly depend on the aforementioned phase difference. The curves practically match each other at four breaths per minute but the greatest effects are observed at six breaths per minute which corresponds to a phase difference of 90 degrees. These effects are represented by suppression of the SNS and activation of the PNS – in other words, relaxation. Therefore, this breathing frequency of six times a minute is known as the resonant frequency, however, its exact value varies among individuals [50].

These statements were verified experimentally. Therefore, a study by the Himalayan Institute of Medical Sciences in 2006 aimed to validate the efficiency of slow breathing (at six breaths per minute) for treatment of patients with hypertension. The study involved 100 participants of varying age and asked them to practice slow a breathing technique of a five-second inhalation followed by a five-second exhalation. The authors found that even after a single ten-minute session there was a statistically significant decrease of hypertension symptoms. The observed drop in systolic and diastolic blood pressure, together with heart and respiratory rate were explained by the activation of the PNS [51]. With slight variations in the breathing frequency, similar results were obtained also by some other studies. For example, another study claimed positive results for pain reduction in burn patients [52]. Therefore, to conclude, slow breathing appears to be an efficient tool for relaxation.

1.2. Limitations of the Current State of the Art

Stress has been in the focus of researchers for over a century, making it a very well-investigated phenomenon. Many of the issues have already been comprehensively solved, however, a number of questions remain open. Indeed, the human factor of stress in aviation has been deeply investigated owing to its importance for flight safety and numerous human lives as it is evident from the previous chapters, but this literature review has revealed certain relevant areas that previously have not been documented to a large extent.

As it is visible through the literature review, despite the interest towards the stress effects during emergencies and normal pilot's life, specifically the field of flight examination was covered by just a few studies. In terms of the relationship between the stress and flight performance during check rides, only one study was found [3]. Moreover, its results relied only on the subjective evaluation of the instructor and the examiner and were not verified by the actual objective flight parameters. Another article dealt with the relationship between stress and the general rate of success of students in a flight program [39]. This generally limited experimental evidence for the issue of practical exams can be considered as a limitation in the state of the art.

With regards to stress coping, the available recommendations for pilots tend to focus on long-term strategies and involve a lasting commitment. Practically no short-term solutions verified in the flight deck environment were found within this literature review. In terms of the existing information, the actual efficiency of the techniques was not investigated in some cases [46]. More importantly, the impact of the coping strategies was assessed by the extent of relaxation they induce and not the resulting piloting performance, as, for example, in the study comparing athlete and non-athlete pilots [47]. Moreover, the aforementioned study, like many others, based its conclusions on subjective questionnaires, leaving space for further experimental validation of the results.

Consequently, no studies evaluating the effectiveness of pre-relaxation techniques during practical exams in aviation were found, despite the visible significance of the issue and promising results from other fields. As a result, there is no suggested solutions and correlations with other secondary factors such as the flight experience, which, combined with the importance of the problem, require further investigation.

Chapter 2 – Goals and Hypotheses

As it is described in the subchapter of limitations of the state of the art, the topic of "Influence of relaxation techniques on pilots' performance" has numerous questions that remain open. These limitations create the basis and interest for investigation of the existing issues, which will be covered by the present thesis, using student pilots as the focus group and practical examination as the stress factor.

2.1. Goals and Partial Goals

The main goal of this thesis is to investigate the influence of a selected short-term breathing relaxation technique on the piloting performance during practical examination.

In order to achieve this target, the following partial goals were selected. Firstly, it is to create an experimental setup that will simulate for the participants a real examination situation as much as possible and will induce similar emotions and behavior in them. The second partial goal included involving participants with equal experience and collecting both piloting performance and physiological data from them for further analysis. Finally, the third partial goal was set to be the analysis of this data and interpretation of respective results both in terms of the psychophysiological state of the participants and any observed changes in their flying ability.

2.2. Research Questions

In order to achieve the primary goal of the present thesis, two research questions were prepared:

1. What is the psychophysiological response of pilots to relaxation before examination?
2. What are the effects of relaxation on piloting performance during a check ride?

2.2. Hypothesis

The following null hypotheses were assumed for the purposes of research:

$H0_1$. The participants will not experience an SNS suppression and PNS activation with a decrease in the level of stress.

$H0_2$. The examination piloting performance will not improve overall.

Chapter 3 – Materials and Methods

Based on the results of the state of the art review and its limitations, together with the final goals and hypothesis, practical research was prepared to address the issues. The following chapter will focus on every of its elements: it will consider the selected participants, describe the developed experimental setup, list the equipment in use, and discuss the process of data collection and analysis.

3.1. Participants

18 subjects volunteered for participation in the study. All of them were full-time bachelor pilot students at the Faculty of Transportation of Czech Technical University in Prague. All the participants had significant flying experience as students and had started their instrument training. Despite certain differences in the flight time, all the subjects were proficient to fly an instrument profile with an Instrument Landing System (ILS) approach. Each of these volunteers trained in one of two flight schools. Depending on their flying academy, they operated either Tecnam P92, Tecnam P2008, Tecnam P2002, and Tecnam P2006, or Cessna 150, Cessna 152, and Cessna 172. However, regardless of their school, everyone had glass cockpit experience.

Prior to data collection, every subject signed an agreement for processing of their experimental results and personal information according to ethical principles of medical research involving human subjects [53]. All the subjects were physically and mentally fit, as confirmed by their medical class 1 certificates issued according to Commission Regulation (EU) No 1178/2011, Annex IV (Part-MED).

The subjects were divided into two separate groups: Group A and Group B.

Group A served as the control group and was used to assess the baseline performance without any intervention in the form of relaxation practice. It included a total of 9 participants (8 males and 1 female). Their average age was determined to be 23.7 ± 2.2 years. The subjects in this group had 148 ± 21 flying hours on average. 6 subjects in this group were holders of private pilot's license.

Group B acted as the treatment group. They were the ones to practice relaxation. Their results were used to determine the performance and psychophysiological state resulting from mindful breathing. Similarly to Group A, Group B involved 8 male and 1 female participants, a total of 9 subjects. Their average age was calculated to be 22 ± 0.5 years. The average flying experience of participants in this group was 158 ± 35 hours. 8 subjects from Group B had previous check ride experience as they had a private pilot's license.

3.2. Experimental Setup

Since the present thesis deals with the issue of stress, efforts were taken to ensure their actual exposure to it. All the participants from Group A and Group B were coming to their final simulator assessment in the university required to complete their studies. The subjects were then offered to participate in the present experiment before, and therefore get a chance to practice their flying skills before the practical exam in similar settings, with the condition that their performance will be recorded.

The experiment included 5 phases performed in the following order: baseline heart rate measurement and trial Instrument Flight Rules (IFR) approach profile, followed by a break or a session of relaxation practice (depending on the group), with a subsequent examination flight, followed by a subjective questionnaire. In addition, heart rate was measured during the simulator sessions. On average, every measurement took approximately one and a half hours to complete.

3.2.1. Pre-flight activities

The experiment started with a heart rate measurement, where every subject was asked to sit still for 5 minutes. It was used for baseline heart rate collection so that their state before any intervention can be compared to further measurements. At the meantime, they were briefed about the flight rules and simulator operation. The 5-minute duration was required because of the specifics of the measurement techniques applied, which will be further detailed in the chapter of "Data collection and processing".

After the baseline heart rate measurement, the subjects were given a 3-minute period of flying at their own discretion. This ensured that they had a chance to familiarize themselves with the airplane handling and avionics operations before the flights used for measurements

.

3.2.2. Flight 1 – Introductory flight

As the familiarization flight was complete, the introductory flight commenced (Flight 1). The participants were informed that the following flight would not affect their exam in any way. The purpose of this flight was to determine the piloting performance of the participants under given conditions without any pressure induced by the check ride.

In terms of the task for the flight, the participants were required to fly the first of the 2 selected profiles. The approaches for the experiment were intentionally chosen to be similar in order to eliminate differences in complexity with their subsequent potential effects on performance and physiological state. These profiles were slightly adjusted in terms of their name and designators to avoid a possibility of subjects sharing and preparing for the flights beforehand.

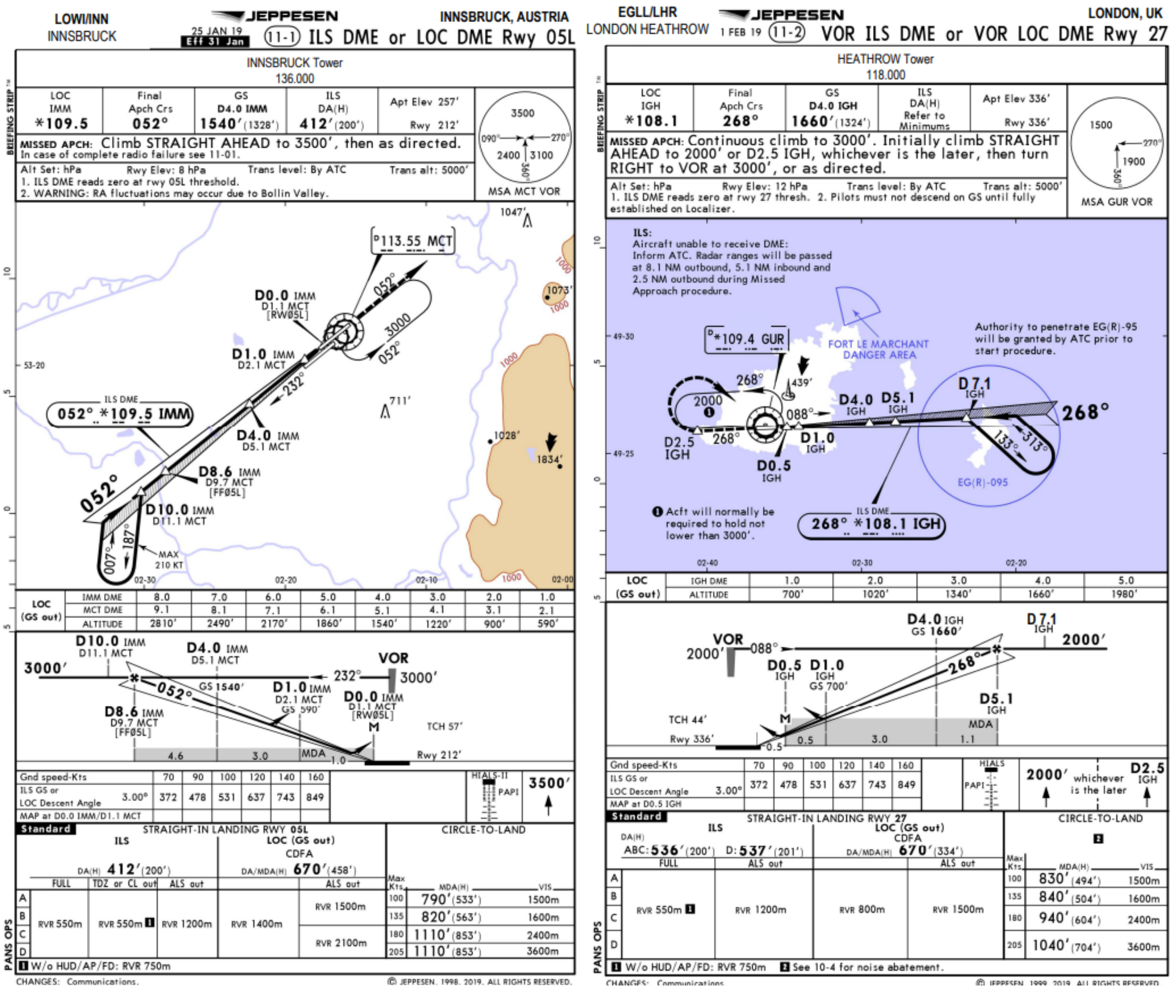

Figure 3. Approach charts provided to the participants

Copies of the charts used for the experiment are shown in Figure 3. The required profile consisted of 1 holding pattern over a Very-High Frequency Omnidirectional Range (VOR) and an ILS approach commencing after a procedure turn at some distance from the runway.

The participants were provided with respective approach charts 3 minutes before the beginning of the flight for the purposes of briefing. The time limitation was planned to create certain time pressure.

Then the participants were placed at a location 2 minutes away from the VOR beacon that would require a specific type of entry to the holding pattern, the correctness of which was checked by the observer for further evaluation. Subsequently, they were cleared for one holding over the VOR before commencing the initial approach. Close to the point of completing the final approach, a loud sound was introduced to assess the startle response of the subjects (reaction time), as they were instructed to press a button when hearing it.

The heart rate recording lasted from the beginning of the flight until very end, right before the startle response assessment.

3.2.3. Time between flights

After completing flight 1, each subject had 10 minutes before the examiner would enter the room. The activity during this period is the only phase of the experiment that differs between the groups.

For Group A, it was rest in their seat. Group A members were not allowed to use their phones and were asked to stay in silence. Their heart rate during the last 5 minutes was recorded.

Group B were using this time to practice a relaxation technique. They were provided with a simple video of a ball rising and descending between 2 borders. Every movement up or down took 5 seconds. The subjects were asked to inhale along all the time the ball was moving up and to exhale while it was falling. This approach was chosen to maintain a breathing frequency of 6 times a minute, which, according to the discussion in the state of the art review, appears to trigger SNS suppression and PNS activation. The full session was 10 minutes long, while the last 5 minutes were used for heart rate data collection. Similarly, to the baseline recording, the duration of 5 minutes was set due to the measurement technique requirements. In addition, the 5-minute period before the measurement enabled the participants to experience the potential effects of relaxation.

3.2.4. Flight 2 – Examination flight

Following the 10-minute period after Flight 1, the examiner entered the room. They introduced the exam criteria which matched the legal requirements for the issue of an instrument rating.

Before providing the participant with the examination approach chart, they asked the subject to rate their subjective expectation of performance for the flight, using a scale from 1 (very bad) to 5 (very good).

Similarly to Flight 1, the participants were given 3 minutes to brief the approach for Flight 2. Flight 2 was intended to expose the subjects to stress similar to that experienced by students attending their real check rides. The second of the 2 flight profiles was nearly identical to Flight 1, which can be clearly seen in Figure 3. The participants again started at a point 2 minutes from the VOR and, following one holding pattern, had to perform a full ILS approach. Similarly to Flight 1, the participants' startle response was tested during the final approach. Flight 2 was also subject to heart rate recording.

To further make the conditions nearly identical, the two flights took place under the same weather settings (overcast clouds with a base at 300 ft above ground with no wind or turbulence) and mass and balance conditions. Any differences between the profiles are largely cosmetic, such as altitudes or type of terrain (one approach path lies over the water and the other one – over land), and therefore are not expected to influence the results while appearing different to the participants.

Both approaches were flown independently by the participants and any air traffic control instructions were provided only for purposes of maintaining the examination environment, such as issuing a landing clearance.

3.2.5. Post-flight activities

The subjects were evaluated by the examiner and requested again to subjectively assess their actual performance on the scale from 1 to 5. To support further subjective data collection and personal data processing, they were given a questionnaire of 5 questions, which is described in the chapter of "Data collection and processing".

3.3. Equipment

The equipment selected for the experiment was chosen based on the experimental setup and the practical examination environment.

The physical part of the simulator included a yoke, rudder pedals, and a throttle quadrant. It enabled the participants to control the airplane flight path and perform basic operations with avionics, such as adjustments of the course selector, heading bug, and navigation frequencies, together with the control of flaps. The virtual cockpit panel was displayed on a 2-dimensional screen to allow the participants to freely use their physical chart and kneeboard. This arrangement is shown in Figure 4 below.

The selected software was X-Plane 11 (Laminar Research Ltd., Columbia, South Carolina, USA). The airplane flown was Cessna 172 equipped with the Garmin G1000 (Garmin Ltd., Olathe, Kansas, U.S.) glass cockpit. It is important to note that all the participants had experience with similar types of Garmin-produced avionics.

Heart rate measurements were performed with the FlexiGuard mobile telemetry system, and specifically its electrocardiogram (ECG) unit (Czech Technical University in Prague, Prague, Czech Republic) [54]. A participant wearing the ECG equipment is shown in figure 5.

Figure 4. Simulator arrangement

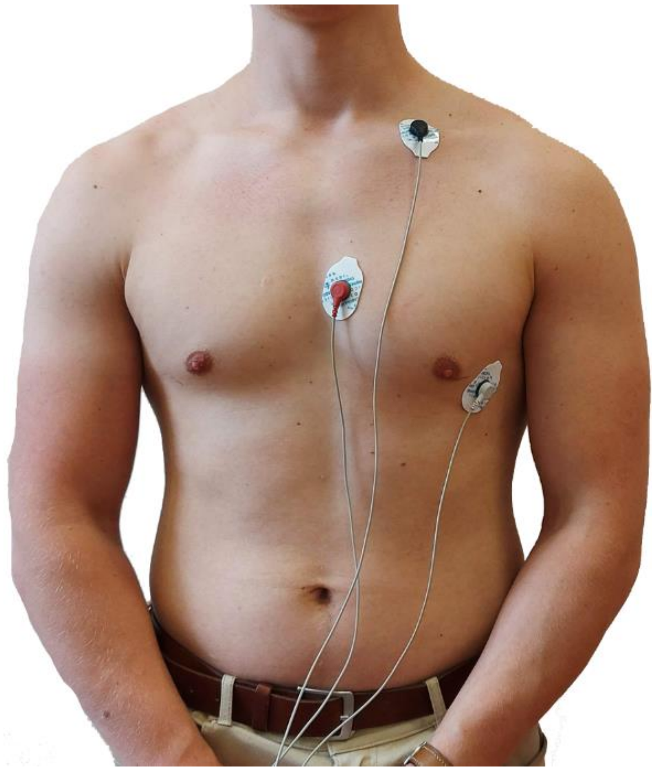

Figure 5. A participant wearing ECG measurement equipment

3.4. Data Collection and Processing

The aforementioned experimental setup enables 3 types of data collection. Firstly, the collection of flight data throughout the profile was performed for the purposes of piloting performance assessment. Secondly, heart activity data was recorded through ECG to objectively assess the psychophysiological state of the participants. Finally, a questionnaire was provided for collection of subjective data and personal information as additional support for objective data gathering. The collected data is available upon request to the author.

3.4.1. Piloting performance data

Each pilot was required to maintain the airplane within the given 3-dimensional profile and their piloting performance was judged based on deviations from it. The profiles were divided to 4 separate phases for the purposes of such data collection. These phases with their respective parameters monitored are given in Table 1.

The beginning and the end of each flight phase were manually recorded by the observer by means of time stamps. The resulting data samples were analyzed by 4 approaches: root-mean-square error, variance, maximum deviation, and the number of deviations beyond the exam requirements. The processing of these data was performed using MATLAB software (MATLAB R2022a, MathWorks, Inc., Natick, MA, USA).

Table 1. Phases of flight data collection

Phase description	Monitored parameters	Required value
Holding entry and holding	Altitude	Flight 1: 3000 ft Flight 2: 2000 ft
Outbound leg from VOR	Altitude	Flight 1: 3000 ft Flight 2: 2000 ft
	CDI deviation	0° for both flights
Procedure turn	Altitude	Flight 1: 3000 ft Flight 2: 2000 ft
Final approach	CDI deviation (both vertical and horizontal)	0° for both flights
	Speed	80 kt for both flights

In terms of root-mean-square error and variance, they were chosen to assess both the accuracy and the precision. This method was practically proven useful. Researches note, for example, that even though the pilot can have great performance shown based on average deviation, the approach can still be flown inadequately if small deviations are overcorrected along the whole sector [44].

With regards to maximum deviations and the number of deviations from the exam criteria, they were observed to additionally support the measures described above. In addition, it might be useful for describing the pilot's awareness of their flight and the examination requirements. The examination criteria was chosen according to Commission Regulation (EU) No 1178/2011, Annex I (Part-FCL). These requirements are: ± 100 feet for altitude, ± 5 kt for speed, and staying within half-scale deflection of the CDI (Course Deviation Indicator) both vertically and horizontally.

In addition to piloting performance, another 3 items were checked: the correct selection of holding entry, the number of radiotelephony mistakes, and the time of response following a startle. The first two were recorded manually, while the last one was collected by counting time from the appearance of a loud sound until the pilot pressed a button. In terms of radiotelephony mistakes, they were counted as a number of missed messages and incorrect readbacks.

3.4.2. Heart rate data

Heart rate data were recorded during the flights and during the periods of rest to assess the psychophysiological state of the subjects. It was recorded in the form of the full ECG curve, which was later processed to identify separate heart contractions. It was performed using the Pan-Tompkins algorithm adapted for MATLAB [55]. Further processing was done through the use of MATLAB according to the HRV parameters described later in this chapter.

The method of HRV measurement was selected based on its effectiveness in assessing stress. For example, a study comparing a number of various measures (electroencephalogram, electromyogram, eye activity, body posture, speech, skin temperature, and heart rate) concluded that heart activity is one of the most credible ways of assessing stress [56]. The same study notes that such objective measurements offer better integrity when compared to subjective measures since such body activity is not consciously controlled. These findings are consistent with results of previous research. For example, a study by Czech Technical University in Prague in 2017 confirmed that HRV measurements are the most reliable tool to assess stress and explained it by the direct connection of heart activity and ANS [57].

The HRV stress assessment is based on the natural arrhythmia of the human heart. Since the heart rate regulation is directly connected to the ANS, any activation of SNS or PNS as a part of stress response will have an impact on its behavior. Normally, SNS activation will lead to a more constant heart rate and reduced arrythmia, while the opposite holds for PNS. Therefore, the lower is the level of arrythmia, the higher is the level of stress experienced [58].

In terms of HRV data processing, 3 approaches were chosen: the mean of RR intervals (mRR), standard deviation of NN intervals (SDNN), and root mean square of successive RR interval differences (RMSSD) – all in the time domain.

The mRR index is basically the inverse of mean heart rate – an RR interval is the time between two consecutive heart contractions. Even though it is not exactly an HRV metric, it still can be used when comparing the psychophysiological states between two or more recordings. For the same subject, the higher is the level of stress, the higher is their rate, and the lower is their mRR [58].

The SDNN index is practically the most basic measure of the variability of the heart rate. A high value of standard deviation represents a calmer subject, while a low SDNN indicates a greater level of stress. The NN part of the index means that only normal beats are taken into account while abnormal ones are ignored. However, for simplicity, it can be assumed to be the same as RR intervals. It is actively influenced by both SNS and PNS [59].

The RMSSD index focuses on beat-to-beat heart rate variability, taking into account the differences in consecutive RR intervals. It is one of the most used HRV measures and is correlated with PNS activity [59].

It is important to note that even though HRV analysis in the frequency domain has its own value and importance, it could not be used for the present setup because of the effects of slow breathing on the frequency of respiratory sinus arrythmia. Decreasing the breathing rate decreases the rate of such arrhythmia and shifts it to a different frequency band, causing incorrect results that correspond to the breathing cycle and not the ANS activation. Meanwhile, the time-based HRV measures were proven to not change significantly with breathing [60].

Different HRV indices require varying minimum recording durations to be credible. Even though ultra-short SDNN recordings, for instance, can last several dozen seconds, the golden standard of short-term HRV is 5 minutes, as used in the present research [59].

3.4.3. Post-flight questionnaire

After the examination flight, the subjects were asked to fill out a questionnaire consisting of 3 sections: personal information, general questions, and stressor ranking. In the section of general questions, the participants were offered to rate the following statements using a 5-point scale (from “strongly agree” to “strongly disagree”): “exams make me stressed” and “stress during exams improves my performance”. Participants from Group B were also offered to rate the statement: “the breathing relaxation technique helped me reduce anxiety”. The last sections asked the participants to rank the following stressors in terms of their significance: written exams, aircraft availability, flight course load, check rides and practical tests, and financial load. The questionnaire data would be used to determine subjective attitudes of the participants.

In addition, the questionnaire contained a section filled by the observer, indicating the performance self-assessment of the participants before and after the check ride. This part of data collection was performed for the purposes of identifying the self-perception and its tendencies caused by the check ride.

3.5. Data Analysis

In order to address the selected goals, similarly to data collection and processing, the statistical data analysis was performed in 3 areas: investigation of piloting performance tendencies focused on the simulator recordings, determination of psychophysiological state variation based on the HRV, and examination of the personal attitude, together with possible correlations it creates.

3.5.1. Flying performance analysis

For the purpose of this thesis, the total performance was of interest as each individual parameter's deviation value is not representative of the overall pilot's ability for a given flight leg. That is why a method of standardization had to be applied before any conclusions can be made. The so-called "Z-score" method was selected to enable different flight parameters such as altitude, speed, and CDI deviation, to be combined into a single value.

For Z-score determination, every participant's value for a given measure and parameter (e.g. a root-mean-square error for altitude) was expressed as the number of standard deviations from the group subjects' mean value [61]. Mathematically, this process can be explained with the formula below:

$$Z = \frac{X - \mu}{\sigma}$$

Where X is the given value, μ is the sample average, and σ is the sample standard deviation. Then all the z-scores for a given participant for a given measure for a given flight leg were summed and averaged, resulting in a single performance value for the given segment. This process was repeated 3 times to calculate the per-leg overall performance in terms of root-mean-square error, variance, and maximum deviations. The only measure that did not require the application of z-score is the number of deviations beyond the exam criteria since it is a standardized value.

The resulting per-participant per-leg values of performance were combined in a single table that was subjected to repeated-measures Analysis of Variance (ANOVA) with 2 grouping variables considered both together and separately: the experimental group (Group A and Group B) and the examination outcome (pass or fail) [61]. However, ANOVA has several requirements to the data that had to be met: normal distribution of the values and data sphericity. There were several cases where the data was not normally distributed, as confirmed with the Shapiro–Wilk test [62]. Despite the issue, ANOVA still remains the most suitable tool for the task and robust enough to accept some abnormalities, as proven by the researchers [63]. Similarly, data sphericity was not confirmed with the Mauchly's test, requiring the Greenhouse–Geisser correction to be applied to the final values [64].

Where necessary, further comparisons were performed within the data by means of the Tukey's and Wilcoxon's tests [61].

3.5.2. Analysis of HRV

For the analysis of HRV data, similar techniques were used as repeated-measures ANOVA was required to verify the grouping influence. It used the same grouping variables, however, here Z-score was not required since the measurement data was used as it was and did not require standardization. Therefore, ANOVA was repeated 3 times – once for every HRV index (mRR, SDNN, RMSSD). Similar irregularities of normality and sphericity like those with flight data were observed and treated in the same manner.

In addition, paired groups of measurements were compared through the Wilcoxon's and Tukey's tests where necessary.

3.5.3. Other forms of data analysis

As a supplement to the aforementioned analysis of piloting performance, additional factors such as the number of radiotelephony errors, evolution of the self-assessment, and the correct selection of holding entry were investigated with the use of ANOVA, keeping the grouping variables listed in the previous paragraphs.

The questionnaire was analyzed with the basic statistics by calculating the means and standard deviations of the indicated answers.

Chapter 4 – Results

The results obtained through data processing and statistical analysis detailed above are described in the following chapter. Similarly, the outcomes will be provided according to the 3 areas of interest: flying performance, HRV indices, and other remaining investigated variables. In addition to the numerical values, box plots will be provided for visualization and easier interpretation. The decoding is as follows: the red horizontal line is the median value, the blue rectangle contains the values between the bottom 25% and the top 75%, the black zone contains the participants within the 1.5 times the interquartile range, and lastly, the red crosses are outliers.

4.1. Flying performance results

4.1.1. Performance based on z-score calculation

Statistical analysis of the total piloting performance calculated using z-score through repeated-measures ANOVA returned no statistically significant results in terms of the factor of group for 3 branches of performance (accuracy, precision, and maximum deviations). The respective results are $F(7, 98) = 0.43$, $p = 0.78$ in terms of root-mean-square errors, $F(7, 98) = 0.55$, $p = 0.69$ for variance, and $F(7, 98) = 0.59$, $p = 0.68$ for maximum deviations.

For further investigation, Tukey's test was applied to compare specific flight legs to verify if no changes existed through the experiment between the behavior of two groups. Similarly, this test showed no statistically significant difference between how the groups' performance changed during the flights. The general results can be observed in Figure 6.

However, some overall findings can be noticed. For instance, when comparing all of the flight legs, it was found that a statistically significant difference exists for participants among various maneuvers. This tendency is the most visible with maximum deviations – the ANOVA returned $F(7, 98) = 2.92$, $p = 0.025$. In other words, the majority of participants reacted to every new flight leg in a similar way, generally improving over time. This tendency is the most visible for the paired comparison of leg 3 for flights 1 and 2. In addition, it was confirmed that the students who were subjectively failed by the examiner objectively performed worse with statistical significance compared to their colleagues who passed. The Tukey's test returned $p = 0.001$, $p = 0.0005$, and $p = 0.0002$ for accuracy, precision, and maximum deviations. However, even though their results were worse, the tendencies in their flying were the same as for all the subjects – ANOVA returned no statistically significant results for the interaction between the leg and the factor of passing or failing.

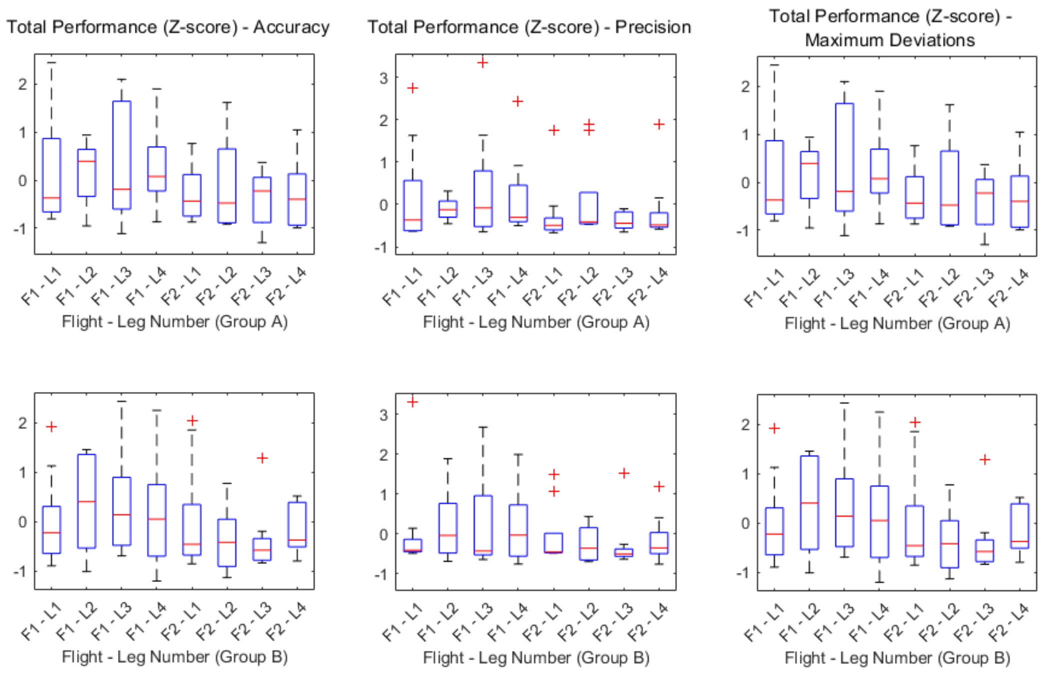

Figure 6. Overall comparison of total performance depending on the group

4.1.2. Performance based on the number of deviations beyond exam criteria

Similarly to the results obtained by the analysis of z-score performance, when applying ANOVA to the data given as the number of deviations beyond examination criteria, it is evident that a statistically significant variation of performance throughout the experiment exists for the majority of participants ($F(7, 98) = 18.767$, $p = 1 \times 10^{-15}$). In other words, the legs with relatively larger or smaller deviations were the same for most subjects. The same applies to the ANOVA testing of the relationship between general changes in performance and if the subject passed the exam ($F(7, 98) = 2.66$, $p = 0.04$).

However, unlike the previous z-score assessment, the investigation of the number of deviations beyond examination criteria gave certain results indicating a potential difference in behavior between the control and treatment groups. For instance, the output of ANOVA considering the group as a factor is $F(7, 98) = 1.93$, $p = 0.11$, which cannot be taken as statistically significant, however, represents a possible tendency. The respective plot of the performance based on deviations from the required standard is given in Figure 7.

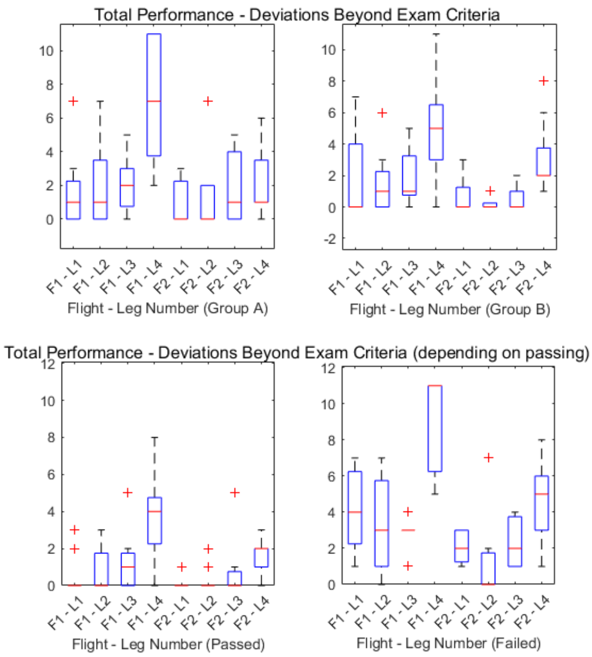

Figure 7. Comparison of the exam violations based on the group and the factor of passing

These results are also supported by the Tukey's test. Most significantly, one can observe the approach segment – leg 4. The control group demonstrated a statistically significant ($p = 0.009$) improvement in performance between the first and second flights X, while the treatment group nearly did not change ($p = 0.84$). However, these results were not repeated during any other of the maneuvers.

4.2.HRV Results

4.2.1. mRR

Statistical analysis of the ECG data in terms of mRR gave statistically significant results on the application of ANOVA. The respective results are $F(3, 42) = 13.25$, $p = 0.0003$ when considering all measurements and all participants together. Taking into account the factor of group, the test returned $F(3, 42) = 0.36$, $p = 0.78$, which is not statistically significant. However, there are statistically significant outcomes between the students who passed and who failed – $F(3, 42) = 6.6$, $p = 0.008$.

When applying the Tukey's test, statistically significant results were obtained between measurements 2 and 4 (in other words, flights 1 and 2) for both groups – the mRR decreased in both cases ($p = 0.04$ and $p = 0.003$ respectively). The same applies to the Wilcoxon's test of these values.

A similar tendency can be observed between the students who passed and who failed where a statistically significant difference exists between the flights, as confirmed by the Tukey's test ($p = 0.02$ and $p = 0.005$ respectively) as well as by the Wilcoxon's test. mRR results are summarized in Figure 8.

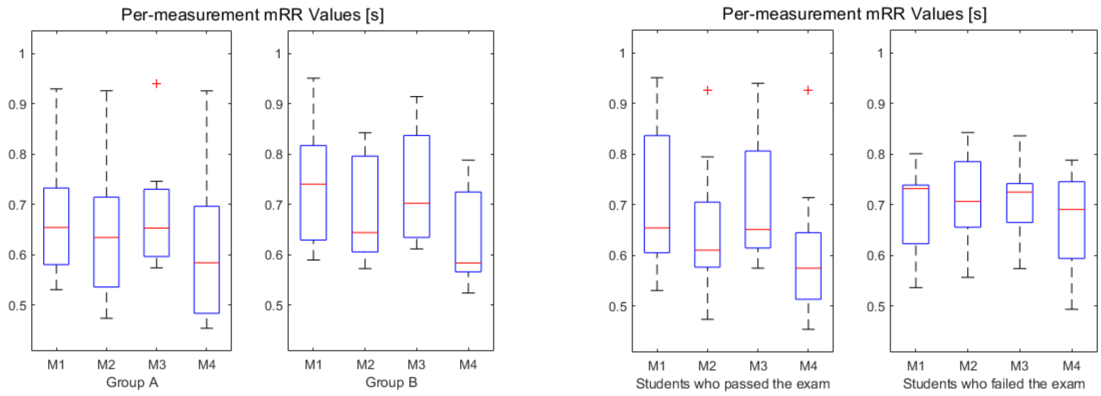

Figure 8. mRR between the groups and students who passed or failed

4.2.2. SDNN

ANOVA of SDNN values shows statistically significant results in almost every aspect. As for variations among the measurements when considering all the participants, the results are as follows: $F(3, 42) = 33.7$, $p = 6.7 \times 10^{-11}$. When taking into account the group as a factor, the outcome obtained is $F(3, 42) = 10.9$, $p = 2.7 \times 10^{-5}$. Lastly, the factor of passing the exam is close to statistical significance and is worth noting – $F(3, 42) = 2.7$, $p = 0.06$.

As for paired comparison between the baseline measurement and the relaxation period, only the treatment group had a statistically significant increase of the SDNN value – $p = 3.2 \times 10^{-5}$, as shown by the Tukey's test as well as by Wilcoxon's test ($p = 0.0035$). However, with regards to the comparison of measurements 2 and 4, no significant results were obtained for either group.

Interestingly, in terms of students who passed or who failed, for Tukey's test, only the unsuccessful students showed a statistically significant difference between measurements 1 and 3 with an increase in SDNN ($p = 0.0003$). However, these results were not confirmed by Wilcoxon's test, which shows near-significant results in both cases ($p = 0.047$ and $p = 0.053$ for students who failed and who passed respectively). These results are provided in Figure 9.

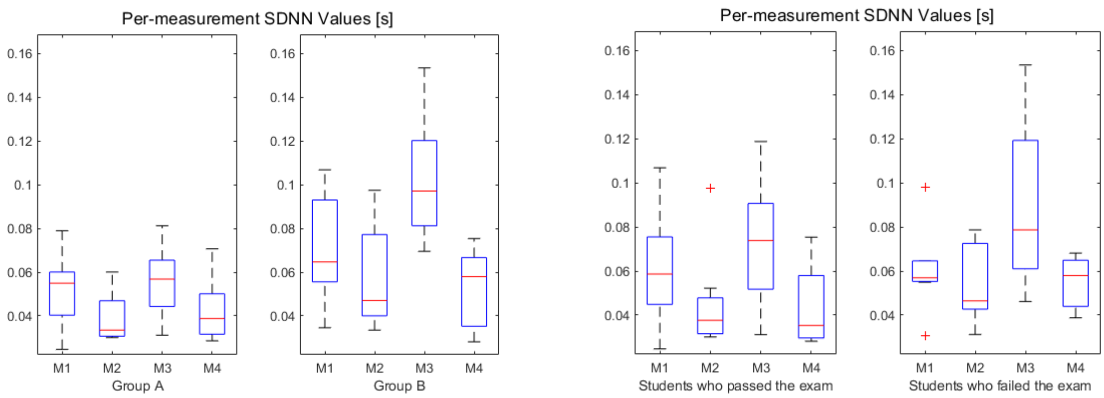

Figure 9. SDNN between the groups and students who passed or failed

4.2.3. RMSSD

For the general ANOVA, similarly to SDNN, statistical significance was determined in every aspect. For variation among the measurements, the test returned $F(3, 42) = 45.8$, $p = 1 \times 10^{-12}$, when considering all the participants. A very low p-value was obtained also when comparing the tendencies in the two groups – $F(3, 42) = 14.6$, $p = 2 \times 10^{-6}$ – as well as between the students who passed or failed – $F(3, 42) = 3.6$, $p = 0.02$.

Looking into the tendency between measurements 1 and 3, only the treatment group shows a statistically significant difference with an increase of RMSSD, as shown by Tukey's and Wilcoxon's tests ($p = 5 \times 10^{-5}$ and $p = 0.02$).

The results comparing the RMSSD of students who failed and who passed were statistically significant for both Tukey's and Wilcoxon's tests, however, showed the opposite tendencies. For instance, Tukey's test indicated a statistically significant increase in RMSSD between measurements 1 and 3 for students who failed ($p = 0.001$) and no such change for successful students, while Wilcoxon's test returned statistically significant increase for students who passed ($p = 0.03$) and no certain tendency for unsuccessful students. The results of this subchapter are illustrated by Figure 10.

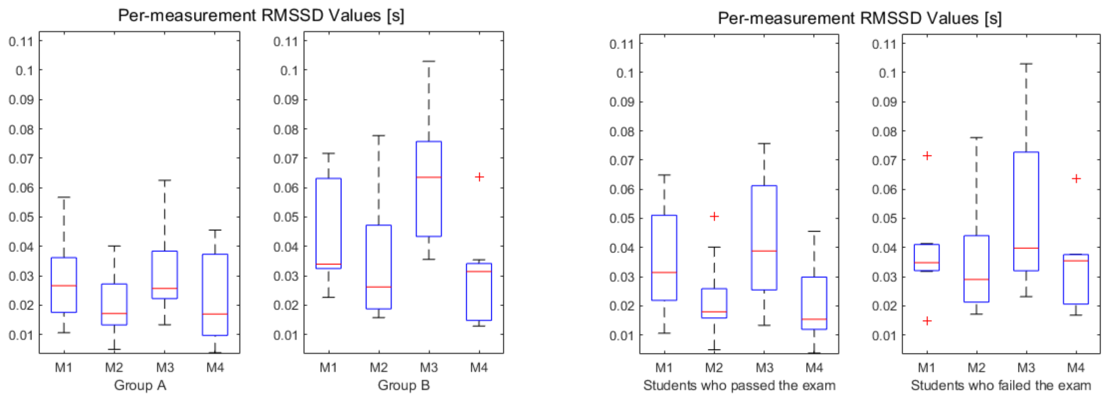

Figure 10. RMSSD between the groups and students who passed or failed

4.3. Results of other forms of data analysis

4.3.1. Subjective questionnaire

With regards to the attitudes of the participants to stress and its influence during exams, overall, 3 subjects (17%) strongly agreed that exams are a stressor for them, 11 participants (61%) rather agreed, while only 3 (17%) students rather disagreed, and 1 (5%) participant was neutral.

At the same time, 8 (45%) students agreed that stress improves their exam performance, 6 subjects (33%) disagreed, 1 (5%) subject strongly disagreed, and another 3 (17%) remained neutral.

When asked if the breathing relaxation technique helped them reduce exam anxiety, 2 (22%) of treatment group participants strongly agreed, 5 (56%) subjects generally agreed, 1 (11%) generally disagreed, and 1 (11%) remained neutral.

4.3.2. Stressor ranking

Within the subjective stressor ranking, the factor of check rides and practical tests was ranked as #1 concern for the majority of students. Other results of this stressor ranking are provided in Table 2.

Table 2. The ranking of stressors by the participants

Rank	Stressor Type	Mean Score
1	Check rides and practical tests	4.0
2	Financial load	3.44
3	Written examinations	3.28
4	Flight course load	2.67
5	Aircraft availability	2.44

4.3.3. Other factors

Among other recorded and processed factors, it was noticed that the participants who failed the examination tended to overestimate their performance before with statistical significance ($F(1, 14) = 8.7$, $p = 0.01$).

With regards to the recorded duration of startle response, no correlation was detected depending on the group, flight, or the factor of passing. The remaining collected data such as radiotelephony mistakes, flying experience, or holding entry selection gave no statistically significant results when combined with other factors. The factor of holding a license and the correlation between the past check ride experience and the stress in the experimental exam could not be determined due to the small sample size of non-license-holders (3 out of 18).

Lastly, out of the 7 students who failed their exam, 4 were coming from the control group and 3 – from the treatment group.

Chapter 5 – Discussion

It was important for the purposes of study to randomly distribute the participants between the two groups in terms of every aspect, including their age, flight hours, and experience. However, as it can be noticed in the participants description within the experimental setup, some misalignments existed in certain regards. For instance, Group B had 10 additional hours of flying experience compared to Group A. Despite these differences, as the results confirm, it was not a factor in this experiment. It is shown by the processed data of the parts that were identical for both groups (for instance, almost all flying tasks) where no statistically significant difference existed based on the group. Also, additional support is given by the failure rate, which is similar between the two groups (4 and 3 students failing in groups A and B). Therefore, it can be concluded that the participants and their distribution are acceptable for the present setup.

From the piloting performance standpoint, it is visible that the majority of the participants performed better in their exam than during the trial flight. This factor is opposed to the fact given in the state of the art, where normally performance decreases during exams due to anxiety [2; 3]. This tendency is unsurprising because of the influence of other factors like familiarization with the simulator and experiencing a similar profile twice. However, the goal for this experiment was to verify if a greater improvement occurs for one of the groups.

The only parameter where a statistically significant difference can be observed between the groups is the number of exam criteria violations recorded during ILS approaches of the trial and examination flights. In this case, only the control group showed statistical significance by considerably improving their performance. However, since this tendency was observed only for one leg and only one method of piloting performance evaluation, combined with the small sample size, it cannot be proven to be a result of presence or absence of relaxation practice. This fact together with every other aspect (reaction time, number of radiotelephony mistakes, incorrect holding entry selections, etc.) showing no statistical significance in terms of differences of piloting performance between the two groups makes it possible to conclude that the selected breathing technique did not affect the pilot’s ability in either way for the given experimental setup.

However, the part of piloting performance comparison that returned statistically significant results in practically every measure and test was the assessment of the students who passed against the students who failed. This confirms the examiner's evaluation in objective manner and enables the use of these categories for further analysis.

In contrast to the limited findings in terms of piloting performance, the ECG measurements offer room for more conclusions. Firstly, it is visible that all the participants, no matter the group or their exam result, acted in a similar manner. During the baseline measurements and the break/relaxation period, a lower level of stress was experienced, as shown by higher mRR SDNN, and RMSSD values. In the meantime, the values for the measurements taken during the flights, showed the opposite tendency and decreased, indicating a higher level of anxiety. In addition, some tendency given by the mRR results suggests that the examination flight was more stressful than the trial flight. However, this finding was not verified by SDNN and RMSSD analysis and, therefore, is recommended for further investigation.

While the tendency in HRV was similar for all the participants, the strength of those changes was a factor that showed statistically significant difference between the groups. When observing the data between the baseline recording (measurement 1) and relaxation session (measurement 3) for Group B, the results are outstanding. Both SDNN and RMSSD indices indicate a significant increase in HRV corresponding to PNS activation. It is very different than Group A where no statistically significant changes took place between the two recordings in any of the HRV indices. It confirms the results of studies given in the state of the art and verifies the effectivity of the chosen technique in achieving relaxation within short time and on first practice without prior experience.

However, the effect of relaxation did not last long and did not significantly affect the psychophysiological state of the participants during the examination flight following the practice. This is shown by the absence of statistically significant differences between measurements 2 and 4 (the trial and examination flights) for both groups in terms of SDNN and RMSSD values.

It is important to note that the only conclusion that can be made from the available data so far is the short-term efficiency of the selected relaxation technique in terms of improving the psychophysiological state of the participants. Since its effects did not last into the examination flight, it does not imply that any relaxation cannot improve the flight performance. It is still possible that there exists some other form of relaxation that either has longer effects or can be practiced during the flight, positively affecting the pilot's ability to handle the examination anxiety.

The importance of developing such a technique is supported by the attitudes of the majority of pilot students who report that practical exams are the most stressful events in their studies and professional training. In addition, given the fraction of students who highly believe in the efficiency of relaxation technique to reduce their exam anxiety and see such stress as a factor impairing their performance, it can be expected that they will be interested in a possible solution.

Even though based on the present information, it is not possible to suggest a relaxation solution for examination situations, the results confirm the importance of flying practice as shown by the significant improvement of flying performance between the trial and the examination flight. It proves the significance of familiarity of the students pilots with the equipment used and the profiles flown.

With regards to the overall attitudes of the participants, it can be noted that they were found similar to previous studies. Beside the stress from check rides, the students reported financial concerns as their number two and, in some cases, number one priority. In addition, the majority of students still believe that stress improves their performance. It indicates that general attitudes of pilot students have not changed in 7 years since the last available survey.

While not being the primary target of this research, some additional observations can be made based on the participants' division into ones who passed and ones who failed. The examination of their HRV data in terms of SDNN and RMSSD revealed that students who failed had a possible tendency to relax to a greater extent when comparing measurements 1 and 3. This can be explained by their overestimation of own abilities as shown by the self-assessment survey before and after the examination and could have led to their low arousal. However, complete interpretation of these data is limited due to the small sample size of the students who failed and certain irregularities in the observed values and test results. Therefore, these assumptions should be taken as potential points of interest for further research done in this scope rather than as statements.

Conclusion

This thesis aimed to verify the possibility of using a known breathing short-term relaxation technique in the flight deck environment to reduce stress in general and to specifically address exam anxiety and hence improve the performance of student pilots during check rides. It included a detailed review of the available literature covering the physiological mechanisms of stress and its unique impact on examination, aviation industry, and specifically combination of these two. Based on the revealed limitations of the state of the art, a suitable experimental setup was developed. Firstly, an appropriate relaxation technique was found which both was easy to implement and required short practice. Then a suitable experiment was performed around an existing university practical examination, involving 18 participants split into equal control and treatment groups. The setup consisted of baseline measurements of heart activity followed by a trial flight, then a treatment period of the treatment group, and a final exam flight. The students' HRV data was collected throughout the experiment as a measure of the psychophysiological state, together with flight data used to assess their piloting performance. Based on the statistical analysis, the selected research questions can be answered as follows. In terms of question 1, the effects on psychophysiological state, it can be concluded that practice of the chosen relaxation technique gives a substantial decrease in the level of stress, however, it is evident that its effects are limited to the time of the practice and do not have a long-lasting influence. All in all, $H0_1$ was rejected. With regards to question 2, the effects of relaxation on piloting performance, it is evident that no significant change was observed. Nevertheless, it is impossible to determine if such results are related to the ineffectiveness of relaxation for improving performance or the limited influence time of the selected breathing technique. Regardless, $H0_2$ could not be rejected. While it can be concluded that the investigated method of relaxation is not effective for flight performance improvement, based on the experimental results, it can be stated that students' familiarity with equipment and profiles contributes to the pilot's ability.

This thesis and its findings have certain limitations. The primary challenge when investigating stress during practical exam is to induce the same amount of stress when compared to a real check ride. Despite extensive efforts, it is believed that the present experimental setup was not able to fully simulate a real aviation exam situation and, therefore, might have been less stressful. The burden of a university exam is not comparable to the anxiety students may feel in their check rides where their future is determined. Also, the duration of the experimental exam which lasted 30 minutes does not create the same load as a 1.5-hour examination flight. In addition, the complexity and the responsibility of flying a real aircraft does not match the relatively limited requirements from the simulator and flight profiles in use. Another issue introduced by the simulator was the factor of familiarization of students between the flights, resulting in an increased performance during the exam. Finally, the relatively small sample size decreases the number of factors that could be investigated and limits the full applicability of the conclusions to the general population.

Despite its limitations, it is important to note that this research was first-of-a-kind investigation for the influence of short-term relaxation on piloting performance. While its scope was focused on the issue of stress during examination, the resulting findings can be applied to the issue of stressful flight in general. Indeed, it was not able to offer a final working solution for the issue, however, it has definitely offered an interesting insight into the area of examination stress and relaxation and will serve as a guide for future researchers of the issue.

Exam anxiety and stress in flight remains significant and with no doubt will be in the focus of future studies. Based on the experience of this thesis, certain points of interest for such research can be identified. Firstly, future studies may find it interesting to focus on developing and verifying a new relaxation technique that would fit specifically the flight deck environment and be effective under such conditions. Alternatively, a way of implementing the present coping technique during the flight can be tested – for instance, its practice can be based on aural hints instead of a video. Furthermore, a larger sample size would allow future researchers to get more definite results and even test additional variables such as the effects of holding a license, age, flight experience, etc. In addition, using different profiles for the trial and examination parts can be applied to address the issue of familiarization. Finally, future studies can split the short-term HRV recordings into numerous ultra-short-term recordings in order to investigate the evolution of the level of stress and the period of relaxation effectiveness. The experience of the present thesis, combined with a great potential for further research, make this topic an exciting item to watch for in the future.

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