The Effect of Susceptibility to Sleep Deprivation on 6df Docking Performance: An Experimental Study

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Psychologie
Faculteit der Sociale Wetenschappen

March 5, 2022

The Effect of Susceptibility to Sleep Deprivation on 6df Docking Performance: An Experimental Study

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Abstract

Operations in space are anything but restful for astronauts, as there are both physical and psychological stressors. One known stressor is the lack of sufficient sleep in space which can drastically impact astronauts' performance. Successful docking is highly important during space missions since small mistakes can lead to disastrous consequences. The docking process can be trained with the 6df task, a simulation in which six degrees of freedom must be controlled. This experimental study aimed to investigate the effect of susceptibility to sleep deprivation (SSD) on 6df docking performance impairment due to sleep deprivation (SD). A total of 62 participants (28 female; 18-39 years, M_{age} = 24.84; SD_{age} = 4.69) completed a balanced-repeated-measures-cross-over-total-SD design. Test variables were calculated by subjects' performance differences between "well-rested-" and "SD measurements". The dependent variable docking performance impairment due to SD was operationalised by 6df outcomes ("top-level achieved" and "mean docking accuracy"). SSD was defined as 1/reaction time (RT) from the Psychomotor Vigilance Test. A background analysis showed that participants' RT slows significantly when SD ($p < .001$). Multinomial regressions ("top-level achieved") showed no significant relations between SSD and docking performance impairment, whereas multiple regressions ("mean docking accuracy") showed significant relations ($p < .001$). Post-hoc analysis showed that testing order is noteworthy because participants assessed in the order "well-rested-" followed by "SD measurements" have lower docking performance impairment due to SD than the group with reversed order. Further, a posthoc analysis showed when participants split in "least SSD" and "most SSD", the effect of SSD on 6df docking performance impairment due to SD was affected by testing order. The importance of testing order suggests the presence of a learning effect, meaning that docking performance impairment due to SD could be reduced by exhaustive training in well-rested conditions. In conclusion, this study can help construct guidelines for determining whether an individual can still perform the operationally relevant task safely under SD. This could also be interesting for other professions such as submarines, pilots, and surgeons, in which six degrees of freedom have to be controlled under SD.

Keywords: Docking Performance; 6df; Sleep Deprivation; Susceptibility; PVT

Layman's Abstract

Space flights are anything but restful for astronauts, as there are both physical and psychological stressors. One known stressor is the lack of sufficient sleep in space, and it can have a drastic impact on astronauts' performance. A task in which astronauts are not allowed to make mistakes is when docking with a space capsule to a space station (like the International Space Station). Already small mistakes can lead to disastrous consequences, such as high economic losses or the failure of an entire mission. The docking process can be trained with a simulation named the "6df task". An essential part of the task is to become familiar with the six degrees of freedom that are present in space. Unlike here on earth, objects can move along three axes (forward-backwards, left-right, up-down) and rotate around them in space.

This study aimed to assess the effects of sleepiness on docking performance. It is assumed that people who are more impaired by sleep deprivation will also show more docking performance impairment due to sleep deprivation than people who are not as impaired by sleep deprivation.

The results of this study indicate that this is the case. Furthermore, the results of this study suggest that docking impairment due to sleep deprivation may improve with repeated training in the task under well-rested conditions. Finally, the subjects were divided into two groups regarding their susceptibility to sleep deprivation, "high-" and "low susceptibility to sleep deprivation". Only when considering participants' testing order a group difference was found. Reasons for no direct group differences could be that the grouping- and determining processes for a person's susceptibility to sleep deprivation are not optimal yet.

In conclusion, this study can help construct guidelines for determining whether an individual can still perform the operationally relevant task safely under the effect of sleep deprivation. This could also be interesting for other professions such as submarines, pilots, and surgeons, in which six degrees of freedom have to be controlled under SD.

Acknowledgement

To my external supervisor Dr. Christian Mühl, for his long and patient support. I want to thank him for his versatile and instructive help. Especially, I want to thank him for making my dream of writing my master's thesis in space psychology possible and for providing me with the unique experiences that came along with it.

To my second external supervisor, Sarah Madeleine Piechowski,
was always available for advice and assistance regarding expertise on my master thesis.

To my supervisor from Leiden University Dr. Esther Habers, who was very empathetic, and showed great understanding of my illness-related time out. I would also like to thank her for the knowledge she gave me and for sharpening my critical thinking.

To my roommate Anne, who helped me find a way through the labyrinth of coding full of intricated paths.

To my grandparents Regine, Friedel, Ingeborg, and Peter, who always had an ear for me and gave blank checks for trips and other costly matters regarding my thesis work.

To my parents Regine and Andreas, who supported me with much love and stood by me in times of need.

To AR Sahasransu, Dominik, Leonhard, and all others who helped me in any way to shape this thesis.

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Introduction

Nearly 120 years ago, on December 17, 1903, the first aeroplane-controlled flight was demonstrated by the Wright brothers. In the three years following the moon landing, 11 other humans have been on the Moon, and 12 others have flown around it. Interplanetary landings have not been possible since then. Nevertheless, space traffic has not stood still for a moment; on the contrary, it has increased rapidly. For instance, the International Space Station (ISS) has been permanently inhabited since November 2, 2000, and simultaneously provides docking ports for eight spaceships (Garcia, 2021). This space frontier has provided unique opportunities for zero gravity research, noiseless exploration of cosmos, etc., and experiments that would otherwise be impossible to carry out on earth. Once in space, there are many tasks that astronauts have to perform under the most difficult conditions. These include restorations on the ISS and satellites or space telescopes such as the Hubble (Communication, 2018; Foust, 2015; Garner, 2020; Jones, 2010). In addition, objects in space are manoeuvred, such as robotic arms on the ISS or the control of drones for observations outside the ISS or planetary exploration (Hassanalian et al., 2018; Hu et al., 2021).

Space missions are anything but restful for the human body, as there are both physical and psychological stress factors. The article by Morphew (2020) gives an overview of the stressing factors and mentions, among others, microgravity, high work pressure, isolation, confinement, and an altered circadian rhythm. All these stressors, in turn, influence the health and well-being of the astronauts and thus also their performance (Morphew, 2020). A critical safety issue during spaceflight is how to adapt to the space environment while maintaining operational performance. In studies, the strained environment is often called isolated, confined, and extreme environment (ICE).

This study will investigate one of the ICE factors, namely, the effect of sleep deprivation (SD) (SD also used for sleep-deprived in this thesis) on one’s docking performance, which is an operationally relevant ability. Based on the current literature, the impact of SD on humans on the ground and in space will be discussed; then, a test on how to measure docking performance will be introduced. Finally, the introduction is concluded with a background analysis and two hypotheses built on the discussed literature.

Impact of Sleep Deprivation on Humans

Prolonged SD causes people to become increasingly sleepy. As a result, people tend to make more mistakes and have more accidents (Harrison & Horne, 2000; Lee & Kim, 2018). However, before discussing the consequences of sleepiness, the term sleepiness needs to be defined more precisely. For this purpose, it is worthwhile to refer to the paper by Shen et al. (2006). A clear definition of sleepiness is hard to formulate, so the researchers explain and mention its essential differences from fatigue. Accordingly, sleepiness is "[...] one’s tendency to fall asleep, also referred to as sleep propensity" (Shen et al., 2006, p. 64). Furthermore, the term is multidimensional, can have many underlying causes, and is best explained with an operational definition. Sleepiness concerns an impairment in the normal arousal mechanism and the inability to stay awake, even in situations where alertness is required (i.e., during a docking operation). On the other hand, fatigue is a state of exhaustion and diminished capacity for physical and mental work (i.e., not having the energy to accomplish a task). Fatigue cannot directly be compensated by rest (Peters, 2020). Summarised, people with sleepiness will fall asleep if given the opportunity, whereas fatigued people might stay awake.

Many studies have revealed the dangers of sleepiness here on earth. A meta-analysis by Uehli et al. (2014) found that workers with sleep problems are 1.62 times more likely to be injured at work than those without sleep problems, and 13% of work accidents are due to sleep problems. The prospective cohort study by Gottlieb et al. (2018) showed that after a night of six or fewer hours of sleep, the chance of a crash risk increases by 33%, compared to sleeping seven or eight hours per night. A study by Czeisler et al. (2016) found that drivers who had slept less than two hours in the last 24 hours cannot drive safely. Also worth mentioning is the research by Tefft (2018) in which more than 7000 motor vehicle drivers were intensively monitored over two years. Accordingly, for people who slept 6-7 hours in the last 24 hours, the chance of a traffic accident increases by a factor of 1.3, if they slept 5-6 hours by 1.9, if they slept 4-5 hours by 4.3, and if they slept less than four hours by 11.5. It should be noted that the increase is not linear but exponential, meaning, that with every hour of sleep lost, the chance of an accident increases strongly. These accident rates were compared with drivers who slept at least seven hours in the last 24 hours.

In addition to road traffic, similar statistics are reported for accidents involving sleepiness in maritime (Jepsen et al., 2015) and aviation (Jackson & Earl, 2006). A variety of disasters in human history are also associated with a lack of sleep. These include several nuclear power plant disasters, such as the Chernobyl disaster in 1986 (Harrison & Horne, 2000), the crash of Air India Express Flight 812 in 2010 (Walker, 2010), and the grounding of the oil tanker Exxon Valdez. The latter is considered the worst environmental oil spill in US history (Palinkas, 2009). Besides the accidents here on earth, there have been noteworthy accidents in the short history of space travel. In 1997, a cargo shuttle collided with the Russian Mir space station during a manual docking process (Ellis, 2000; Sawyer, 1997). Another accident known as the Space Shuttle Challenger disaster occurred in 1986, whereby seven astronauts lost their lives (Rogers et al., 1986). These accidents are likely caused by human errors related to sleepiness, including making wrong decisions and avoidable mistakes (Ellis, 2000; Hickman, 2011). The examples above show that SD profoundly impacts human safety and performance. To better understand the effect of SD on humans, a closer look will be made between SD and cognitive mechanisms.

Several studies have seen cognitive performance deficits due to SD, including reduced sustained attention, working memory deficit, reduced physiological latency to sleep, slower and more inaccurate decision making, and psychomotor and cognitive slowing (Banks & Dinges, 2007; Goel et al., 2009; Kaliyaperumal et al., 2017; Watson et al., 2015). Impairments in these brain areas, in turn, can have a profound impact on human performance. Among these, sustained attention is an ability strongly disabled by SD and can be assessed with the Psychomotor Vigilance Test (PVT) (Dinges & Powell, 1985;

Hudson et al., 2020). The PVT is seen as the gold standard to detect the effects of SD (Ferris et al., 2021). Subjects must react as quickly and accurately to a visual stimulus displayed at random inter-stimulus intervals on a computer screen that provides response time (RT) feedback in milliseconds (ms). According to Watson et al. (2015), vigilant attention, (incorrectly) is used interchangeably with sustained attention[1], is sensitive to less than seven hours of sleep. Also, the study notes that sustained attention deficits increase sharply with prolonged SD, which was also found earlier by Pilcher et al. (2007). Interestingly, performance deficits to SD vary greatly between individuals but are stable within the individual (Hudson et al., 2020; Rupp et al., 2012). So, while some people suffer greatly from the effects of SD, others show considerable neurobehavioral resistance to SD (Van Dongen et al., 2004). St. Hilaire et al. (2013) found that vulnerable and resilient people to SD are distinguishable based on PVT performance from well-rested conditions, later confirmed by Patanaik et al. (2015). Subsequently, sensitivity to total SD could be determined using PVT performance with a 77-82% accuracy. Another study found that individuals susceptible to SD tend to have slower PVT RT in the well-rested state (Chua, Yeo, Lee, Tan, Lau, Cai, et al., 2014). It should be noted that there are meaningful differences in performance between subjects in the well-rested state (Gunzelmann et al., 2009). The study by Chua, Yeo, Lee, Tan, Lau, Tan, et al. (2014) demonstrates that while SD, the between-subject differences on PVT performance are stable. This was measured in two sessions of 26 hours of total SD. Much of the variance in SD effects are due to differences in baseline performance between subjects. Thus, a way to determine subjects' sensitivity to SD with PVT performance would be to choose the difference score (delta) between the well-rested condition and the SD condition; therefore, between-subject variation can be considered.

How Being in Space Impacts Sleep

Sleep deprivation is frequent among astronauts on space missions (Barger, Flynn-Evans, et al., 2014), which results in higher sleepiness among astronauts (Lo et al., 2016). For an adult to be well-rested, the National Sleep Foundation (NSF) recommends seven to nine hours of sleep based on a study by Eugene and Masiak (2015) (Pacheco, 2021). A similar time of eight hours is suggested in the NASA regulations (Lueder, 2015). However, several studies (Barger, Wright, et al., 2014; Dijk et al., 2003; Flynn-Evans et al., 2016; Pandi-Perumal & Gonfalone, 2016) reveal that the average sleep time of astronauts in space is around six hours per night, one hour less than here on earth (Pandi-Perumal & Gonfalone, 2016; Wu et al., 2018), which is no longer in line with the NSF standards. On some nights, astronauts sleep as little

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[1] According to Van Schie and colleagues vigilance is "the capability to be aware of potential relevant, unpredictable changes in one's environment, including a quantitative dimension, a sufficient level of alertness, and a temporal dimension." (p. 180). Further, they state that vigilance is difficult to measure and often confused with sustained attention. Sustained attention adds to this capability a direction, cognitive control, and that the attention is consciously controlled for a specific time. Sustained attention might thus relay more on top-down control, while vigilance is more based on the bottom-up mechanism in the brain. Also, one could cautiously argue that vigilant attention is a capability whereas sustained attention is more like an ability. A detailed differentiation of the two terms would go beyond the scope of this Master's thesis and can be found in the paper by Van Schie and colleagues (2021). Finally, from these findings, it can be deducted that the PVT might more correctly be called a psychomotor sustained attention test.

as 3.8 hours (Dijk et al., 2003), and in extreme cases, they only sleep 1.88 ± 0.40 hours (Barger, Flynn-Evans, et al., 2014). There are two reasons for this lack of sleep, the first being that astronauts are under high work stress, and their presence may be required around the clock, i.e. when a docking operation has to be carried out. This can lead to a misalignment of the circadian rhythm, which in turn causes sleep disturbances (Williams, 2016). The second reason is that the sleep conditions in space are in no way comparable to those here on earth. Disturbing factors that can reduce sleep quality, such as weightlessness, non-24hr light-dark cycles, loud engine noises, and more, are summarised in the paper by Basner and Dinges (2014). NASA has been using countermeasures to mitigate these problems, yet sleep problems persist (Allen, 2018; Mallis & DeRoshia, 2005). Another attempt to ameliorate sleep problems in space and consequential sleepiness is by taking medication. A study shows that three out of four astronauts take sleep-promoting drugs during space missions (Barger, Flynn-Evans, et al., 2014).

In summary, it can be said that sleep quality in space cannot be easily improved; sleepiness remains a problem on missions to this day. Therefore, it is even more important to find out what exactly the influence of SD has on the individual tasks of the astronauts. And how the deficits due to SD can possibly be compensated.

Docking in Space

An essential task for astronauts during a space mission is to dock manually with a space capsule (SC) to a space station (SS). Small mistakes during such operations can lead to disastrous consequences. For example, an error during the docking process can cause components to bend or even explode. This damage not only results in enormous economic losses but can even lead to the death of the crew. Johannes et al. (2017) developed a simulation to train the spacecraft docking manoeuvre, whereby a pilot has to dock with an SC to an SS. This operationally relevant task is named “6df”, the acronym for six degrees of freedom. Wu et al. (2018) suggest that SD could significantly impair docking operations, but a distinction should be made between high complexity tasks and tasks of lower complexity. Interestingly, their previous study showed that high complexity tasks and manual operations are less affected by SD than low complexity tasks and two-way judgment (Zhang et al., 2015). The study concluded that SD might have a complex impact on the docking success rate and that the attention network might have a meaningful role. Basner et al. (2020) found correlations between the 6df and 10 cognitive tests. Of all the 10 cognitive tests, RT on the Digit-Symbol-Substitution Task (DSST) correlated most strongly with 6df performance. The DSST is a speed test that demands complex scanning, visual tracking, and working memory and might rely on the same brain areas as the 6df. The importance of RT for docking success was also emphasised by Wu et al. (2018) and Strangman et al. (2005). The latter based their results on fMRI imaging while performing the SpaceDock task, similar to the 6df. During the SpaceDock task, activation was found in brain areas representing the following cognitive functions: cognitive planning, simulation of complex motion, working and episodic memory processing, cognitive control, and spatial attention (Strangman et al., 2005). These brain areas are also areas impaired by SD (Watson et al., 2015). Based on these studies, there is a high probability that people's cognitive impairment by SD, has a profound impact on docking success. In turn, one's impairment due to SD, results, among others, from someone's susceptibility to SD. Interestingly, one study finds contradictory results, namely that SD subjects showed no decrease in task performance; in fact, their performance even improved (Wong et al., 2020). This was examined by measuring subjects' performance on a Robotics On-Board Trainer-r during SD. Like the 6df, controlling the six degrees of freedom is also critical for the Robotics On-Board Trainer-r. Based on this study, it can be said that SD enables a person to maintain performance. It remains unclear how SD exactly affects 6df performance. To get a deeper understanding, a background analysis (0) and two hypotheses (1 & 2) were made. For the background analysis, PVT performance was assessed, as it is seen as the gold standard for detecting effects of SD. From the literature above, it can be argued that susceptibility to SD is relevant for docking success. Subsequently, it can be assumed that susceptibility to SD correlates positively with 6df docking performance impairment due to SD. A susceptibility to SD score was calculated for each subject obtained from its PVT performance. Participants were then divided into two groups most and least susceptible to SD. Following hypothesis were posed:

0) Participants have higher PVT performance scores[2] when well-rested than when SD.
1) Subjects higher in susceptibility to SD[3] have higher docking performance impairment[4] due to SD.
2) The group most susceptible to SD[5] shows worse docking performance impairment[6] due to SD than the group least susceptible to SD.

[2] The background analysis was performed on the absolute PVT performance values (reaction time).

[3] The susceptibility to SD score was derived from PVT performance (reaction time). To assess susceptibility to SD, a delta score was calculated from the difference between the sleep-deprived measure minus the well-rested measure. The analysis was done with the delta scores.

[4] The docking performance score was derived from the 6df performance (once by mean docking accuracy, and once by top-level). Delta scores were again calculated and used for the analysis.

[5] The susceptibility to SD delta scores from hypothesis 1 were used for this. With the median split method, participants were divided into two groups: "most susceptible to SD" and "least susceptible to SD".

[6] Docking performance was defined in the same way as in hypothesis 1.

Methods

Participants

A total of 66 healthy adults were recruited. After removing participants with incomplete data, N = 62 participants (28 female, aged 18-39 years, M_{age} = 24.84, SD_{age} = 4.69) had valid data including 856 6df trials and 124 PVT trials. Four subjects were excluded from the analyses due to technical issues during data collection (e.g. broken controller).

Participants were recruited for the study via the DLR institute's database, university job boards, and corresponding internet portals. A written explanation of the study was given. A general questionnaire followed an initial selection. The selection criteria were that participants had to be aged between 18 and 40 years; their gender was irrelevant. They had to be German-speaking, have a good sleep-wake rhythm and health suitability, and have a BMI < 30. Further, they should not be smokers or drug consumers, should not have any visual or hearing problems, should not be pregnant, and should not be taking any medication that has a proven influence on the experiment. Suitable subjects were invited to the DLR for further information about the study and had to sign the informed consent. During the visit, different questionnaires were taken for further exclusion criteria regarding mental health. These assessment questionnaires consisted of STOP-Bang and ESS (for sleep problems), FPI (personality traits), and BDI (tendency to depression). An extra visit was planned for a medical examination conducted by a doctor, who performed eye tests, and a blood and urine analysis to check for the exclusion criteria mentioned above. During that visit, participants were also introduced to the PVT. The subjects received an expense allowance for the study.

Design

This study was part of the Inter-Team-Collaboration project, which explored the impact of sleepiness (induced by SD) on cognitive abilities (e.g. sustained attention, vigilance, problem-solving, communication) used in team collaborations. The experiment was based on participants assessed in teams in a controlled laboratory setting at the DLR in Cologne. Each team consisted of three participants. These teams were randomly assigned into two different experimental groups, group 1 and group 2. Group 1 first had a sleep-deprived measurement (SDM) followed by the well-rested measurement (WRM), whereas group 2 had their measurements reversed (WRM -> SDM). A balanced repeated measures cross-over SD design (SDM -> WRM or WRM -> SDM) was used for this study. The study received approval from the ethical commission North Rhine Medical Association (Ärztekammer Nordrhein) and followed the guidelines of the Declaration of Helsinki as amended in October 2013.

Procedure

The experiment lasted for five consecutive days and four nights. Day 1 proceeded the same for both groups. The participants arrived in the morning. After a safety briefing, they had a training session (1200 – 1900 h) to become familiar with all experimental tasks. Both groups then got a full eight-hour sleep opportunity (2300 – 0700 h) to ensure they were well-rested. On Day 2, both groups spent the day with relaxing activities such as watching TV and reading. Then came the first group difference. Group 2 slept another night of eight hours (Day 2 to Day 3). Group 1 was kept awake for a minimum of 27-hours straight, going without sleep for a whole night. On Day 3, between 0600 and 1000 h, SDM for group 1 on the PVT and 6df were examined. After that, they were allowed to rest for several hours (1000 – 1400 h). On day 3, group 2 had their WRM between 1100 and 1500 h. In the afternoon, both groups engaged in relaxing activities. Then both groups slept again for eight hours. On Day 4, both groups spent the day with relaxing activities. Group 1 slept another night of eight hours (Day 4 to Day 5). Group 2, this time, was kept awake for a minimum of 27-hours straight, going without sleep for a whole night. On Day 5, between 0600 and 1000 h, SDM on the PVT and 6df were examined. After that, they were allowed to rest for several hours (1000 – 1400 h). On Day 5, group 1 had their WRM from 1000 to 1400 h. There was a debriefing for both groups in the afternoon, whereafter the experiment was concluded, and they were allowed to leave the institute. All participants completed both conditions, and an investigator was always present to supervise the subjects.

Measures

One week before the study, participants were required to adhere to a sleep-wake schedule that indicated an 8-hour nocturnal sleep (2300 – 0700 h). It was not allowed to consume caffeine during this week and the study. Verification was done by comparing wrist-worn actimetry output with the subjects' diary entries. This was intended for circadian concordance and minimising variation in cognitive performance due to individual differences in a daily rhythm.

During the study, participants stayed in the "Simulation Facility for Occupational Medicine Research" and the sound laboratory at the DLR during the entire experiment. The two locations were connected through a tunnel, so they did not have to leave the building, and light conditions could be controlled. The participants were exposed to standardised light conditions below 100 lux during the experiment. The Simulation Facility for Occupational Medicine Research is a research facility that contains a kitchen, bedrooms, a living room, a research room, and other useful spaces. The sound laboratory is soundproof and provided with artificial light. Here, the participants were examined on the PVT and 6df. The tests were administered on a 23,8 inch full HD monitor ('VN248H', AsusTek Computer Inc., Taipei, Republic of China (Taiwan)). All subjects were seated at a 70 cm distance from the monitor. Data were collected between October 28 2019, and March 13 2020.

6df Docking Task

The 6df is a docking simulation performed on a computer screen developed by Johannes et al. (2017). With this task, the basic principles of abstractly controlling any object with six degrees of freedom can be trained. During the task, the subject is presented with a screen (see Figure 1). The screen shows the perspective of an astronaut sitting in the cockpit of an SC. In the distance, there is an SS to which the subject must either dock or align, depending on the flight level. Fixed in the centre of the screen is a yellow cross called the "visor"–which helps to navigate better in space. In addition, there is a red and a black cross on the SS. When the red cross disappears behind the black one, the orientation towards the station is perfect. Furthermore, the screen displays the current speed (m/s), distance (m) to the SS, and remaining flight time. An additional window on the screen shows the current approach speed–comparable to a speedometer. Speed violations are signalled by a change in colour from green to red on the speedometer and the current speed (red means that the SC moves too fast). The subject moves the SC by manipulating two hand-controlled joysticks, the left one for translation (forward-backwards, left-right, up-down) movements and the right one for orientation (pitch, roll, and yaw) movements (see Figure 2). Unlike most vehicles on earth which have two degrees of freedom, in space, the SC has six degrees of freedom. The SC can be moved along three orthogonal axes and spin around each of them. Especially, roll, pitch, and up-down are uncommon movements for humans and are only found in particular situations on earth, such as controlling a robot arm, flying objects or navigating a submarine. Consequently, these uncommon movements can cause dizziness and motion sickness (Johannes et al., 2019). The 6df software was developed by SpaceBit GmbH (Eberswalde, Germany). The hand controllers are based on the technology of the Russian Soyuz capsule controllers and were produced by Koralewski Industrie-Elektronik oHG (Hambühren Germany).

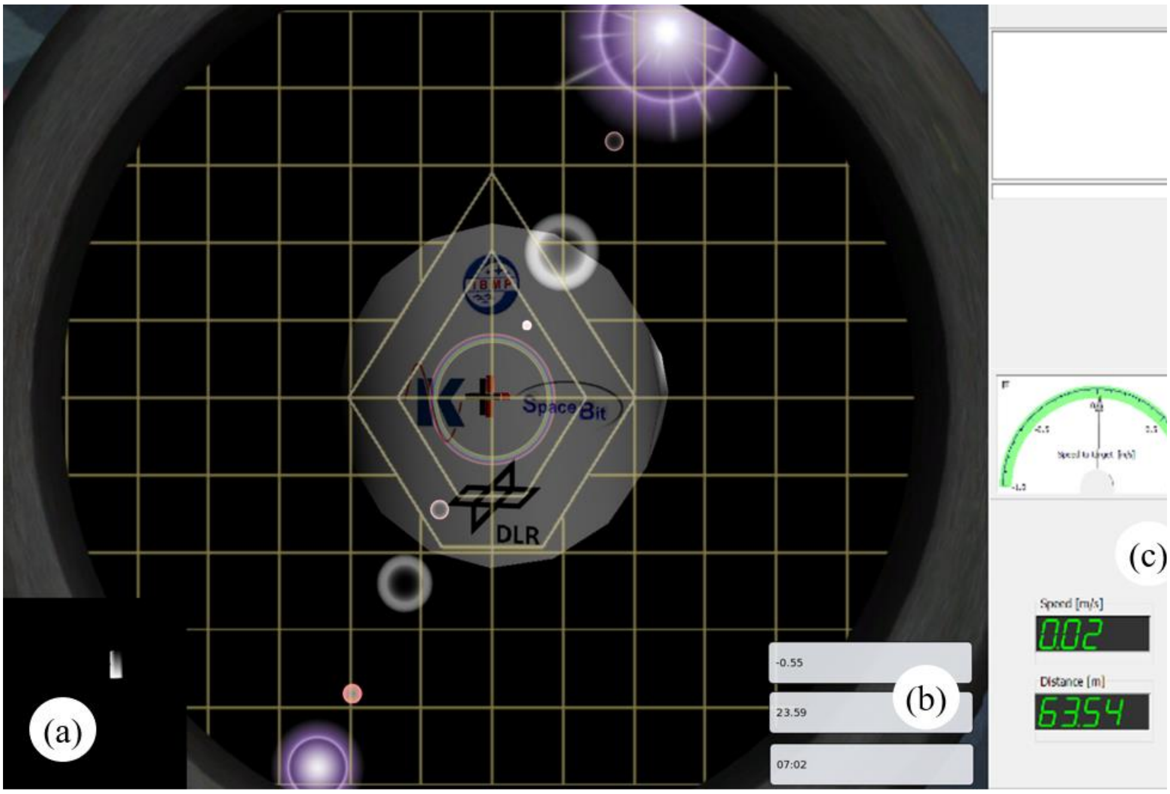
A diagnostic variant of the 6df was chosen for this study to measure the subjects' performance using the six degrees of freedom training. Moreover, this shortened version has fewer flight levels and a total task time. There are five levels for this 6df. Level one is the easiest, and level five is the most difficult. For levels 1-3, the subject must align to the SS in the distance. At levels 4 and 5, the subject must dock with the SS. Each subject starts at level three and depending on the docking performance, the subject then has to repeat the level, advances to a higher level or drops to a lower level. The docking performance is determined by the docking- and alignment accuracy and is reflected by a score between 0-1.00 (1.00 is the highest accuracy achieved during a flight). If the docking accuracy is < 0.85, the subject will be assigned to an easier level for the next flight. The subject must repeat the flight level with a docking accuracy between 0.85 and 0.95. If the docking accuracy is > 0.95, a task is considered complete, and the subject will be assigned to a higher level on the next flight. After each task, the results (i.e. task performance parameters) are shown (see Figure 3). It should be noted that flight levels cannot be skipped. Not even through particularly bad or good performance. If a subject does not complete a level within 10 minutes, the flight performance will be assessed to assign the next level. The entire 6df flight simulation ends after 35 minutes or if the participant completes the fifth level with a docking accuracy of > 0.95 before the time is up.

Subjects' performance on the 6df was assessed in two ways: the highest task level completed (level 1–5) and the mean docking accuracy (0–1.00) of the entire 6df flight simulation. A delta value per subject was calculated for both performance variables by subtracting the subjects' 6df performance during WRM from the SDM. In this regard, lower delta scores mean more impairment in docking performance due to SD. Finally, all possible values for the ordinal variable delta highest task level were -1, 0, and 1. The variable was named "delta top-level". The "delta mean docking accuracy" ranged from

-41.51 to 46.16. The variable was named "delta mean accuracy". Delta variables were chosen because they correct for between-subject variation.

Figure 1

Screenshot of the 6df docking simulation during a task flight



Note. The view from the space capsule to the space station. Perfect docking is achieved when the red cross disappears behind the black one and the permitted approach speed is respected. (a) This is the flight map. (b) Speed, distance, and remaining flight time are displayed here. (c) Speed and distance towards the space station are depicted again.

Figure 2

The six degrees of freedom in space

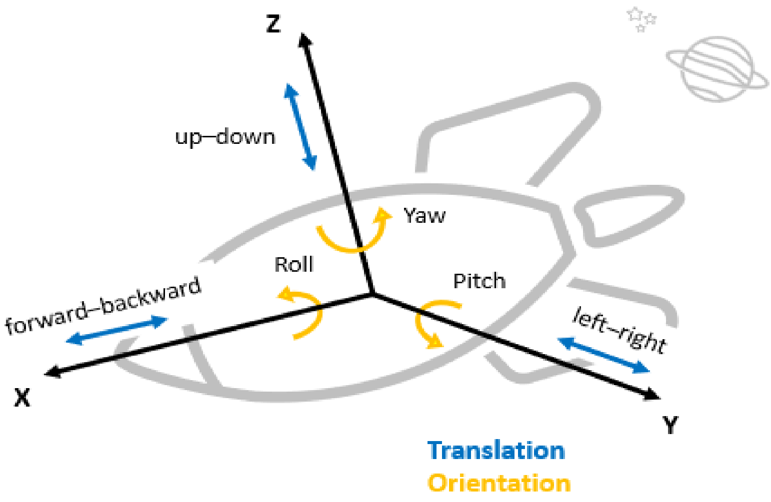
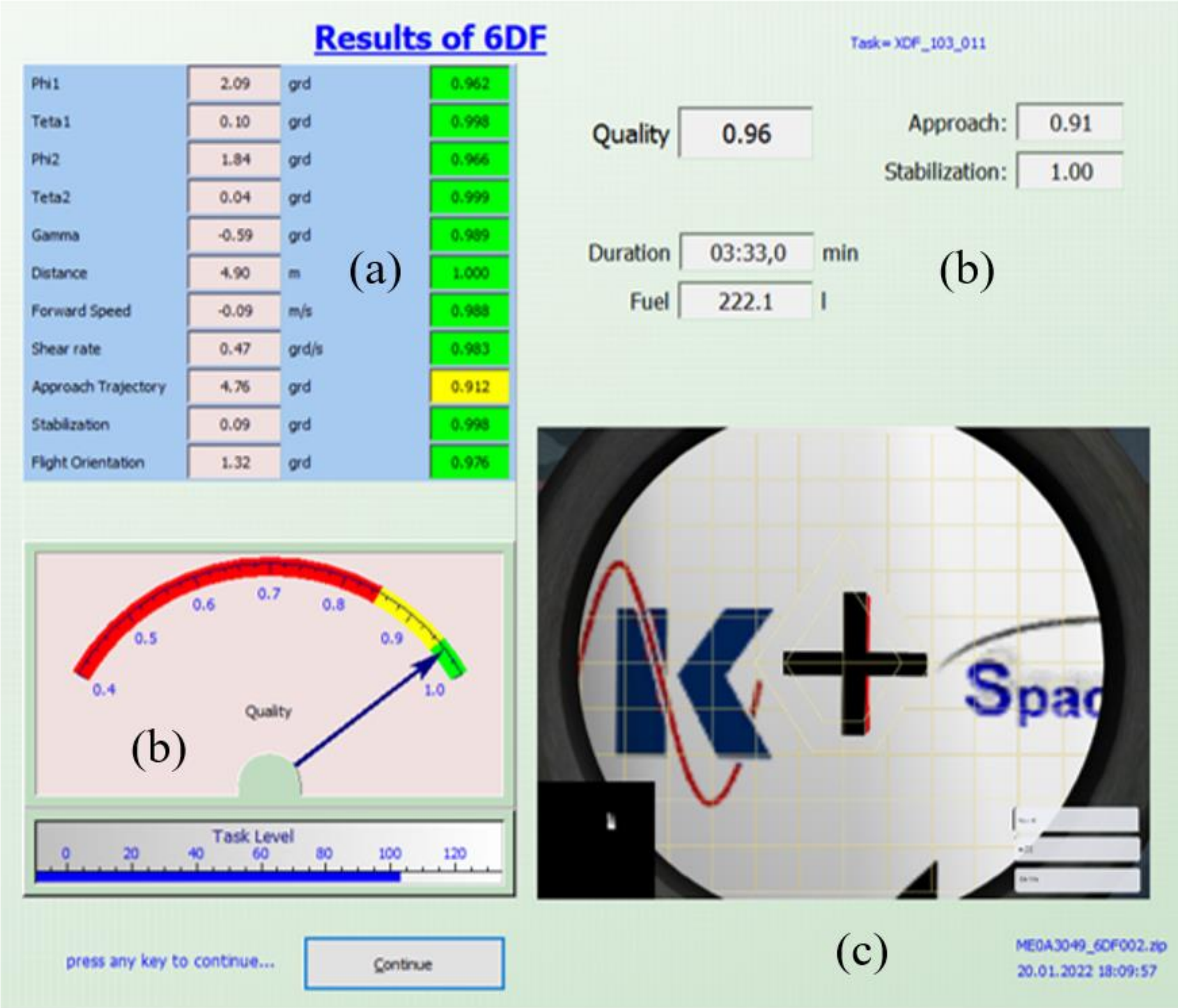


Figure 3

Screenshot of the result page of a performed 6df docking flight



Note. This figure displays the feedback after a finished level. In (a) parameters for the docking flight are listed with their degree of accuracy (0 to 1.00). In (b) the docking accuracy (Quality) is shown. If the needle is in the red area, then an easier level will be assigned. If it is in yellow, the level will be repeated and if it is green, a higher level will be assigned. Below (b) the current level is depicted. In (c) a screenshot of the docking moment is shown.

Psychomotor Vigilance Test

A test commonly used to measure sleepiness is the Psychomotor Vigilance Test (PVT) (Basner & Dinges, 2011; Basner et al., 2011; Basner et al., 2020; Dorrian et al., 2004; Lim & Dinges, 2008). It was developed in 1985 by Dinges and Powell (1985) and is now considered the gold standard for measuring the effects of SD; it is easy to use and requires little training (Evans et al., 2019; Lopez et al., 2012)[7]. Since its creation, the test has reliably shown that performance declines with reduced sleep (Basner &

[7] Since its invention, several versions of the PVT have appeared. Today, there are versions like the 3- (PVT-B), 5-, and 10-min PVT (Ferris et al., 2021) but also other versions such as the PC-PVT (Reifman et al., 2018), and m-PVT (Evans et al., 2019). All have in common that they aim to assess sustained attention.

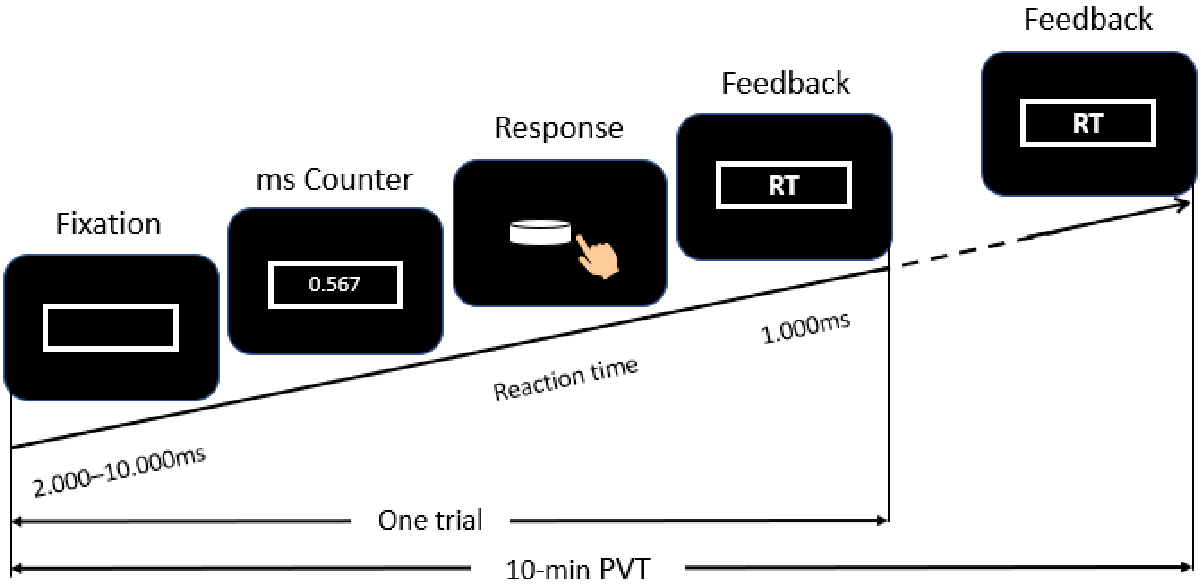
Dinges, 2011; Pilcher et al., 2007; Russo et al., 2015). In comparison to other cognitive tests, the PVT prevents compensatory stimulation and is hardly influenced by aptitude- and learning effects (inter-individual- and intra-subject-variability), i.e. PVT performance does not improve as a function of repeated use, and it has a high sensitivity for both acute and chronic SD (Basner & Dinges, 2011). Furthermore, the paper explains that mean 1/RT (used as an outcome variable for sleepiness in this study) has the second-largest effect size (1.93, 95% CI 1.55 - 2.65) for total SD. The test shows an overall slowing of PVT RT due to SD and is reliable for intra-class correlations for mean RT above 0.8, which can be seen as an almost perfect correlation (Dorrian et al., 2004). Lastly, it should be noted that the PVT has high ecological validity (Dinges, 1995). Thus, sustained attention, as measured with the PVT, is required for learning, safe driving, etcetera. When transferring this idea to the docking task, it could be that signals are missed due to slow RT, which can then cause a docking accident.

The 10-min PVT was chosen for this study (see Figure 4). The test was performed on a computer and measures a person's RT to visual stimuli. The subject sits in front of a black screen and a keyboard during the task. On the screen, visual cues are presented at pseudo-random intervals (between two and 10 seconds), in the form of a millisecond counter (Lim & Dinges, 2008). After each cue presentation, the subject must press the response button as quickly as possible to elicit feedback. This deletes the cue and starts the next trial. Responses without a millisecond counter displayed on the screen should be avoided by the subjects and are counted as false starts or commission errors. Only responses greater than 100 ms were considered valid RT. Outcome variables of the 10-min PVT that provide information about the subject's performance include reaction time (RT), lapses (RTs > 500 ms), commission errors, and false start data (Evans et al., 2019).

This study took the subject's average RT (in ms) per session (WRM and SDM) to operationalise PVT performance. Reaction times were transformed into response speed (1/RT) (i.e. reciprocal reaction time) by mean log(1/RT)*1000, as was done in several studies before to normalise the distribution of raw data (Basner & Dinges, 2011; Evans et al., 2019; Wong et al., 2020). The variable was multiplied by 1000 to get the response speed based on seconds (range 1.64; 5.08). A higher response speed score aligned with better PVT performance. Raw response speed scores were used for the background analysis, whereas delta response speed scores were calculated for testing the two hypotheses. Delta response speed scores were obtained as follows. For hypothesis 1, participants' response speed scores from WRM were subtracted from the associated SDM response speed scores. This new variable, "delta speed", ranged between -2.06 and 0.18. Lower delta speed values represented a more pronounced slowing after SDM relative to WRM and, therefore, stand for a greater impairment due to SD. Finally, the variable delta speed was named "susceptibility to SD". The same susceptibility to SD scores (i.e. delta speed scores) scores were used for hypothesis 2. The scores were median-split into two groups, i.e. the continuous variable was transformed into two categorical outcomes. The two groups were named "least susceptible to SD" and "most susceptible to SD". Before splitting the data, the susceptibility to SD scores were grouped by the variable testing order. Grouping subjects by testing order beforehand resulted in the group least susceptible to SD containing both upper halves from rested-sleepy and sleepy-rested regarding subjects' susceptibility to SD scores, whereas the group most susceptible contained both lower halves of rested-sleepy and sleepy-rested regarding susceptibility to SD scores. A similar procedure was done in another study on PVT lapses (Patanaik et al., 2015). The new dichotomous variable was named "group susceptibility to SD".

Figure 4

Timeline of the 10-min Psychomotor Vigilance Test (PVT)



Statistical Analysis

The background analysis was performed using IBM SPSS Statistics, Version 26, whereas all other statistical analyses were performed using R-studio, Version 1.4.1717, for Windows. Q-q plots and other graphs were used to inspect the variables and check the assumptions visually. Hence, other correlations except for the linear correlation could be excluded. The variable testing order was added as a counterbalance to the two hypotheses and the background analysis. Thus order effects could be taken into account to increase the study's internal validity. Testing order had two categories: rested-sleepy for participants who had first WRM followed by SDM, and sleepy-rested for participants who had first SDM followed by WRM. An overview of all variables for this study is given in Table 1. For the background analysis, the variables reaction speed (as dependent variable), sleep deprivation (as independent within variable) and testing order (as independent between variable) were assessed with a two-way mixed ANOVA. Multiple regressions were used for hypotheses 1 and 2 whenever "delta mean accuracy" was the dependent variable. Multinomial regressions were used whenever "delta top-level" was the dependent variable. Furthermore, susceptibility to SD and testing order were the independent variables for hypothesis 1. Group susceptibility to SD and testing order were the independent variables for hypothesis 2. Since each model contained two independent variables (fixed effects), adjusted R^2 was reported to measure the effect size (goodness-of-fit). Values of $p < .05$ were set as the significance level.

Table 1

Overview of the Seven Variables for this Thesis

	Variable	Level of measurement	Computation of the variable	Outcome[1]
PVT	Response speed[2]	Continuous	Derived from PVT RT	1.64 to 5.08
	Susceptibility to SD[3]	Continuous	= delta speed (derived from response speed) = SDM (response speed) – WRM (response speed)	-2.06 to 0.18
	Group susceptibility to SD	Ordinal	Derived from susceptibility to SD: 1. Susceptibility to SD values grouped by testing order 2. Median split on rested-sleepy and sleepy-rested	least susceptible to SD; most susceptible to SD
6df	Delta mean accuracy[4]	Continuous	= SDM (mean docking accuracy) – WRM (mean docking accuracy)	-41.51 to 46.16
	Delta top-level[4]	Ordinal	= SDM (highest level achieved) – WRM (highest level achieved)	-1, 0, and 1
Other	Testing order	Ordinal	Rested-sleepy = well-rested followed by sleep-deprived measures; Sleepy-rested = Sleep-deprived followed by well-rested measures	Rested-sleepy; Sleepy-rested
	Sleep deprivation	Ordinal		SDM; WRM

Note. PVT = psychomotor vigilance test, 6df = docking simulation task, RT = Reaction time, WRM = well-rested measurement, SDM = sleep-deprived measurement, SD = Sleep-deprivation

[1] For continuous variables the range was given; whereas for ordinal variables all possible outcomes.

[2] Higher scores mean better PVT performance.

[3] Lower values result in higher PVT performance impairment by SD.

[4] Lower values result in higher 6df performance impairment by SD.

Results

Background analysis

A two-way mixed ANOVA was performed to evaluate the effect of SD and testing order on PVT reaction speed. There was a statistically significant main effect of SD ($F(1,50) = 102.79$, $p < .001$, $\eta_p^2 = .63$) meaning that reaction speed on the PVT was significantly faster during WRM ($M = 3.90$, $SE = .06$, 95% CI [3.49, 3.71]) than during SDM ($M = 3.36$, $SE = .08$, 95% CI [3.20, 3.52]) (see Figure 5). There was also a significant main effect for testing order ($F(1,60) = 6.29$, $p = .015$, $\eta_p^2 = .98$), meaning that participants with the testing order rested-sleepy ($M = 3.79$, $SE = .06$, 95% CI [3.64, 3.94]) responded significantly faster than participants with sleepy-rested ($M = 3.48$, $SE = .08$, 95% CI [3.33, 3.63]). The interaction effect between SD and testing order was non-significant, so the effect of SD was not different between the testing order conditions.

Figure 5

Testing Order and Day as Predictors of PVT Reaction Speed

Note. Boxplots represent the distribution of the variable reaction speed. They consist of the median, two hinges, two whiskers (±1.5 * IQR from the hinge), and all fours outliers (star-shaped) of the data.

Hypothesis 1a

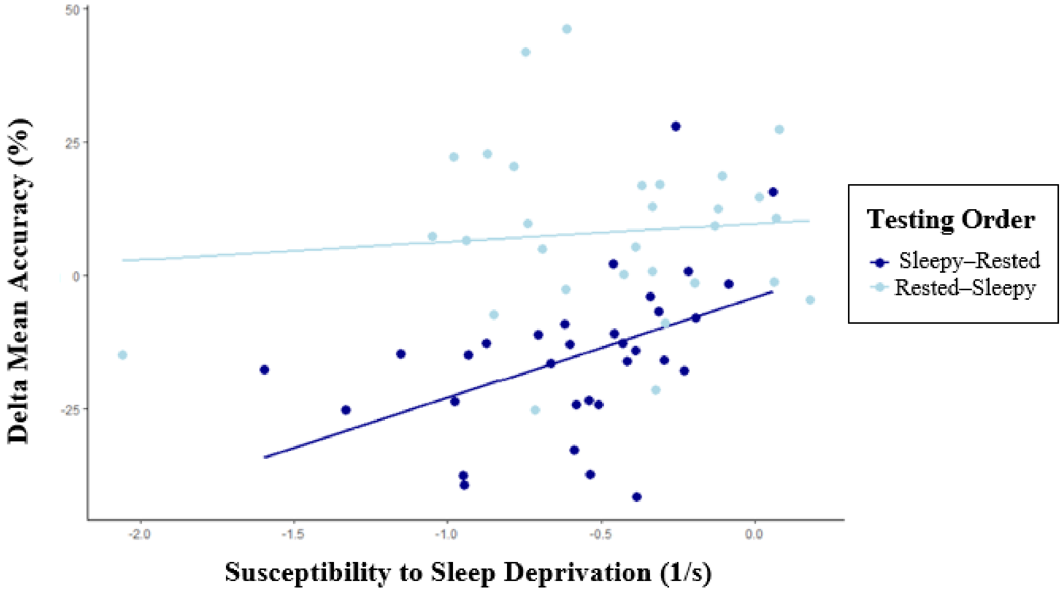
Multinomial logistic regression was performed to create a model of the relationship between the two predictors, “susceptibility to SD” and “testing order”, and the predicted variable “delta top-level” (-1, 0, and 1). Susceptibility to SD and testing order were no significant predictors for delta top-levels -1 vs 0 and -1 vs 1.

Hypothesis 1b

Multiple regression was used to predict “delta mean accuracy” based on “susceptibility to SD” and “testing order”. A significant regression equation was found ($F(3,58) = 14.61$, $p < .001$), with an adjusted $R^2 = .40$ (see Figure 6). Both predictors “susceptibility to SD” (β = 18.81, t (58) = 2.56, p = .013) and “testing order” (β = 13.77, t(58) = 2.15, p = .036) showed significant main effects. For susceptibility to SD, more negative susceptibility to SD values correlate positively with more negative 6df performance values. For testing order, the group “rested-sleepy” had significantly less docking performance impairment due to SD than the group “sleepy-rested” ($p < .05$). No significant interaction effect was found. Participants’ predicted “delta mean accuracy” was equal to -4.18 + 18.81 (susceptibility to SD) + 13.77 (testing order). Participants’ “delta mean accuracy” increased by 18.81 accuracy units for each “susceptibility to SD” unit, and the testing order group “rested-sleepy” was 13.77 “delta mean accuracy” units higher than the “sleepy-rested” group.

Figure 6

Susceptibility to SD and Testing Order as Predictors of 6df Task Performance Impairment Due to Sleep Deprivation



Note. Each point represents an individual’s score. The two lines represent the linear fit of the two “testing order” groups. Higher “delta mean accuracy” scores represent participants with lower docking performance impairment due to SD. Higher “susceptibility to SD” scores represent participants with lower susecptiblity to SD

Hypothesis 2a

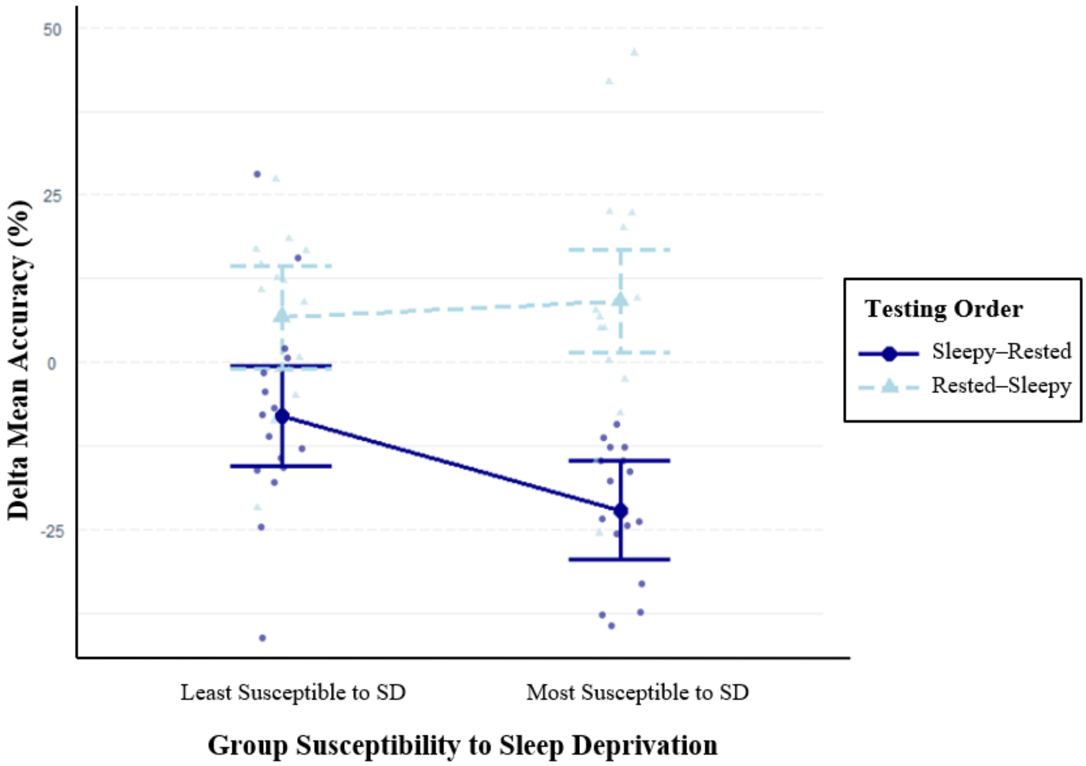
Multinomial logistic regression was performed to create a model of the relationship between the predictor variables “group susceptibility to SD” (dichotomous), “testing order” and the predicted variable “delta top-level” (-1, 0, and 1). The “group susceptibility to SD” and “testing order” were no significant predictors for delta top-level -1 vs 0 and -1 vs 1.

Hypothesis 2b

Multiple regression was used to test if “group susceptibility to SD” (dichotomous) and “testing order” (dichotomous) significantly predicted participants’ “delta mean accuracy” (see Figure 7). A significant regression equation was found ($F(3,58) = 14.89$, $p < .001$), with an adjusted $R^2 = .41$. “Group susceptibility to SD” (β = -14.11, t (58) = -2.69, p = .0092) and “testing order” (β = 14.79, t (58) = 2.78, p = .00742) showed both significant main effects. In addition, a significant interaction effect (susceptibility*order) was found (β = 16.43, t (58) = 2.18, p = .0334). Participants’ predicted “delta mean accuracy” was equal to -8.01 + 14.11 (group susceptibility to SD) + 14.79 (testing order) + 16.43 (group susceptibility to SD*testing order). A Tukey post hoc test gave the following results with a 95% CI. The groups “least-“ and “most susceptible to SD” did not differ significantly (p = 0.107). The testing order “sleepy-rested” had significantly more docking performance impairment due to SD than the group “rested-sleepy” ($p < .05$). The significant interaction between “group susceptibility to SD*testing order” indicated that the relationship between group susceptibility to SD and delta mean accuracy depended on testing order (see Figure 7). The group most susceptible to SD with testing order “sleepy-rested” had more docking performance impairment due to SD compared to all other groups ($p < .05$). The group “least susceptible to SD” with testing order “sleepy-rested” had higher “docking performance impairment due to SD” than both subgroups with testing order “rested-sleepy” ($p < .05$).

Figure 7

Group Susceptibility to Sleep Deprivation and Testing Order as Predictors of 6df Task Performance Impairment Due to Sleep Deprivation



Note. The figure depicts 6df performance impairment (delta mean accuracy) by "group susceptibility to SD" accounted for "testing order". Each dot represents an individual's performance change. More positive "delta mean accuracy scores" mean a lower docking performance impairment due to SD. Error bars represent a 95% confidence interval.

Discussion

This study assessed the impact of the subject’s susceptibility to SD on 6df docking performance impairment due to SD. The susceptibility to SD scores were defined as the subject’s change in PVT performance due to SD. The PVT is considered the gold standard for measuring the effects of SD. Docking performance impairment due to SD was obtained from the subjects’ change in 6df performance after SD; performance was operationalised once by “delta mean accuracy” and by “delta top-level”. The 6df is a simulation analogue to the docking procedure which Russian Mir astronauts perform. With a background analysis, it was assessed if participants’ PVT performance drops when SD. Further, subjects’ susceptibility to SD and their docking performance impairment due to SD was assessed. It was hypothesised that subjects higher in susceptibility to SD have higher docking performance impairment due to SD. Participants were divided into two groups “most-“ and “least susceptible to SD”. The groups were obtained by applying the median split method on the susceptibility to SD scores from hypothesis 1. It was hypothesised that the group “most susceptible to SD” shows worse 6df docking performance impairment due to SD than the group “least susceptible to SD”. Additionally, posthoc analyses were done for further inspections of the results.

Regarding the background analysis, results show that SD has a meaningful effect on PVT performance, i.e. subjects’ performance dops significantly after SD. Additionally, the predictor testing order plays a significant role, which shows that subjects in the testing order “rested-sleepy” have significantly better PVT performance than subjects with the order “sleepy-rested”, when grouping wake and sleep conditions. Since there was no interaction effect, “testing order” did not influence the link between PVT performance and the effects of SD. With repeated use of the task, there might have been improvement with each trial, as the participant learns how to perform the task more successfully, and a learning effect may be present (Mosheiov, 2001). However, the results do not suggest a learning effect and are in line with the literature (Basner et al., 2018; Dinges et al., 1997). Accordingly, repetition of the PVT (a relatively simple task) should have no meaningful effect on one's respective performance because the test is robust for aptitude and learning effects.

The two hypotheses were first tested with “delta top-level” as an indicator for 6df docking performance impairment due to SD. For both hypotheses, however, no significant effects were found. An explanation for these results could be that the 3-level variable “delta top-level” (-1 if worse after SD, 0 if the same, and 1 if better after SD) does not contain enough information to display noticeable differences compared to the continuous variable “delta mean accuracy”. Hence, further studies could test whether “delta top-level” with more than 3 levels is sensitive enough to show significant differences, and if so, how many levels have to be included?

The first hypothesis was confirmed using multiple regression to show that people with a higher susceptibility to SD have higher docking performance impairment due to SD. In the regression, both predictors, “susceptibility to SD” and “testing order” had significant main effects on docking performance. For susceptibility to SD, being more susceptible to SD correlated positively with docking performance impairment due to SD. This is in line with the previously discussed study from Wu et al. (2018), who reasserts that total SD worsens operational performance in space. However, the study also mentions that more complex tasks are less affected by SD because subjects are less likely to fall asleep than when performing a simple task. This raises the question of how complex the 6df task is and whether an even more complex version would result in lower or higher performance impairment due to SD.

Since susceptibility to SD was a significant predictor for docking performance impairment due to SD, the idea of creating a susceptibility to SD index, which could become part of an assessment of astronauts, is raised. This would follow up on St. Hilaire et al. (2013), who used a pattern recognition algorithm to determine the most reliable factors for susceptibility to SD in a single session and found promising results. Other than what was done in this thesis, the study suggests basing the index on single sessions where the subjects are well-rested. They also found that adding more factors can make performance impairment predictions based on susceptibility to SD even better. An index would be useful for astronauts (and other professions where six degrees of freedom are controlled under SD) to assess whether they show significant performance drops due to SD, which can have life-threatening outcomes in space. It should be noted that this study only focuses on performance changes and not how well subjects actually perform. Further studies should therefore also investigate the latter. A first attempt to classify subjects is discussed further in hypothesis 2.

Several studies have found that total SD causes deficits in cognitive functions such as attention, working memory, long-term memory, and decision-making (Gattoni et al., 2021; Goel et al., 2009; Kaliyaperumal et al., 2017). The importance of these cognitive functions for the 6df docking operation can be inferred from the studies by Basner et al. (2020) and Strangman et al. (2005). The former study found correlations between a cognitive test battery and the 6df. From the cognitive test battery, RT on the DSST correlates most strongly with 6df performance. This again emphasises RT as an important factor for docking performance. Interestingly, the study found no meaningful correlation between the PVT (simple RT test) and the 6df. Two conclusions can be drawn from this. First, docking performance cannot be determined solely by someone's PVT RT; other underlying cognitive factors might play a role. Second, PVT RT may only correlate with 6df performance under the influence of SD because simple PVT RT then shows more variance (Chua, Yeo, Lee, Tan, Lau, Tan, et al., 2014). As the results of this thesis show a relation between the two tasks, including SD.

Unfortunately, the literature regarding operational tasks in spaceflight is still scarce and more precise correlations between 6df and cognitive domains such as long-term memory can hardly be made. However, testing order was significant for hypothesis 1, and thus a relationship might exist between docking performance and long-term memory. Long-term memory is divided into explicit memory and implicit memory. The focus is on implicit memory, which includes procedural memory. Procedural memory involves bodily movement and learning how to use objects in the environment, such as the

6df's joysticks (Cherry, 2021). Regarding the predictor testing order, the group "rested-sleepy" had lower docking performance impairment than "sleepy-rested". As mentioned above, people learn better when well-rested compared to when SD (Chee & Chuah, 2008; Curcio et al., 2006; Kurinec et al., 2021). Thus, the group that performed the task first in the WRM "learned" more, i.e. bound information better to the contexts (Kurinec et al., 2021), and could apply this in the following SDM condition. In other words, the learning effect was higher in the "rested-sleepy" group. Thus the learning effect could explain the significant testing order effect. An earlier paper also found indications of a (still unresolved) learning curve regarding a decrease in docking performance after a night of SD (Strangman et al., 2005). This leads to the compelling question of whether "sufficient" 6df training can compensate SD deficits to the extent that a safe docking manoeuvre is possible? With sufficient training, the task could be internalised so that brain areas responsible for controlling the joystick require little cognitive capacity. Further research could be done on how many training sessions are needed to reduce impairment due to SD on the task to meaning level. Once again, it should be noted that this study only focuses on performance changes and not on subjects' actual performance. Further studies should therefore also investigate the latter. Interestingly, Wong et al. (2020) found no decrease but rather an increase in operational performance under SD. However, the study did not have a control group, and the sample size was only nine people; therefore, training effects could not be accounted for, which may have modulated effects of SD impairment. Nonetheless, the study's results elicit the idea that participants' docking performance could be improved while training the task under SD. In line with this idea is a single case study that has found that ultra-endurance athletes improved their endurance while SD (Gattoni et al., 2021). Further research could investigate whether docking performance can be improved while astronauts are SD. This would directly address today's problem of SD in space research in such a way astronauts in space can still improve docking performance while SD.

The second hypothesis was confirmed using multiple regression to show that subjects "most susceptible to SD" show worse docking performance impairment due to SD than subjects "least susceptible to SD". The regression's variables "group susceptibility to SD" and "testing order" were significant predictors for docking performance impairment due to SD, as was the interaction effect. In the presence of an interaction effect, main effects are usually negligible. However, interactions do not make the main effects meaningless in some cases. A posthoc analysis was done for further inspection of the data.

Regarding the predictor "group susceptibility to SD", the group "least susceptible to SD" did not differ from the group "most susceptible to SD" in docking performance impairment due to SD, when the variable "testing order" was not considered. Thus, predicting docking performance impairment due to SD based on the two groups is not directly possible. Referring to the paper by St. Hilaire et al. (2013), the following explanations can be found. It could be that just two groups are not sensitive enough to detect differences in docking performance impairment due to SD. For example, the aforementioned study created three groups for susceptibility to SD, low impairment, moderate impairment, and severe impairment. Another reason would be that the variable susceptibility to SD might not be sensitive enough due to how it was operationalised in this thesis. To better determine “susceptibility to SD” using PVT outcomes, additional information (such as sex, time of day, length of time awake) would play an important role (St. Hilaire et al., 2013). Further studies could find a method to make the variable “susceptibility to SD” more sensitive. Additionally, research could assess the number of groups “susceptibility to SD” should consist of for better differentiation in performance. As in hypothesis 1, testing order again correlated significantly, and the interpretation of its meaning remains the same. Namely, subjects in the order “rested-sleepy” had significantly lower 6df performance impairment due to SD than the group with the order “sleepy-rested”. Again, this indicates the presence of a learning effect.

Regarding the interaction of the two predictors, the group “most susceptible to SD” with testing order “sleepy-rested” showed significantly higher docking performance impairments due to SD compared to all other groups (see Figure 7). The group “least susceptible to SD” with testing order “sleepy-rested” showed more impairment in docking performance due to SD than the two groups “least susceptible to SD” and “most susceptible to SD” with testing order “rested-sleepy”. It can be concluded that testing order significantly affects the relation between docking performance impairment due to SD and group susceptibility to SD. Furthermore, it should be noted that the ordinal data (group susceptibility to SD and test order) are difficult to interpret because multiple explanations for the interaction are possible. Simplifying the data into two groups (“least-“ and “most susceptible to SD”) may also have a smaller or larger effect than the sum of the individual effects. The interaction could simply be an unintended result of ordinal scale measurement (Mitchell & Jolley, 2016).

The following study’s limitations should be considered when applying the findings. This is a ground-based study by which participants are not exposed to any other spaceflight stressors such as confinement, isolation, microgravity, and high workload, listed by Morphew (2020). Also, one should ask whether the results of 6df on a 2D screen can simply be transferred to a 3D environment because the perception of one’s position could be hindered. However, a study by Piechowski et al. (2020) found that just a slightly faster learning performance was found when comparing 3D technology with 2D screens, and no advantages for performance over a longer period were found. Further, it should be noted that the participants were all students, and the results are not easily transferable to other populations due to the selection criteria. The students were completely unfamiliar with the 6df task before the experiment and familiarised themselves with the task for the first time under SD. This excludes the role of expertise or automaticity in task performance, which may impact behaviour in the context of SD. In other words, the students went into the experiment completely naive, while on the other hand, astronauts would have already performed many docking training sessions under difficult circumstances. It remains unclear whether and how ICE factors multiply in this task. It is open to question how far astronauts’ performance differs from students’. More precise conclusions can be drawn with further studies in ICE environments and more experienced docking subjects.

Besides the limitations, also some particular strengths of this study can be pointed out. This study gives the first answers to the relation between the operationally relevant 6df docking task and the ICE factor SD. As space travel increases and the effects of SD on the human body are still difficult to tackle, it is even more important to know which tasks are strongly affected. Individuals who can not safely perform this specific task due to SD impairment can then be identified. Because of the experimental setup, a direct relation between the effects of SD and the 6df task in which six degrees of freedom must be controlled is possible. This increases the external validity of this study. With some caution, the results of this study can be translated to other tasks such as navigating submarine boats and aircrafts, and controlling surgical equipment, in which six degrees of freedom have to be controlled (quite often under SD). Because of the high standards and specific selection criteria, the results can be more easily applied to high-performance groups such as astronauts, submarines, pilots, and surgeons. Another strength is the cross-over design. Since performance was assessed twice in the same subjects, inter-subject variability is eliminated, i.e., study participants serve as their own control. This also means that fewer subjects were needed for the study, which is consistent with the principle in medical research to use resources wisely.

In conclusion, this was a novel study to demonstrate the effect of subjects' susceptibility to SD on their 6df docking performance impairment due to SD. A background analysis shows that subjects have a noticeable slowing of RT after a night of SD, compared to when they were well-rested. These findings are in line with the literature. The hypotheses show that subjects' susceptibility to SD has a meaningful impact on their 6df docking performance impairment due to SD, as does the testing order. This means that higher susceptibility to SD results in higher performance impairment. The significance of the testing order indicates the presence of a learning effect. It remains unresolved to what extent the impairment effects diminish with exhaustive training of the task. Furthermore, 6df performance impairment due to SD only differs significantly between the groups "least-" and "most susceptible" when taking "testing order" into account. Docking performance impairment due to SD was most severe for the group "most susceptible to SD" with the testing order "sleepy-rested". Finally, this study gives a better understanding of the impact of SD on an operational task in which six degrees of freedom have to be controlled. The results can help to construct scientifically based guidelines for determining whether an individual can still perform tasks safely under SD.

Abbreviations

ICE = isolated, confined, extreme environment

NSF = National Sleep Foundation

PVT = Psychomotor Vigilance Test, to measure susceptibility to sleep deprivation

RT = reaction time

SC = space capsule

SD = sleep deprivation; sleep-deprived

SDM = sleep-deprived measures

SS = space station

WRM = well-rested measures

6df = 6df docking simulation task, to measure docking performance due to sleep deprivation

Bibliography

Allen, C. (2018). International Space Station Acoustics - A Status Report. *INTER-NOISE and NOISE-CON Congress and Conference Proceedings*, *258*(6), 1319-1334. https://www.ingentaconnect.com/content/ince/incecp/2018/00000258/00000006/art00033

Banks, S., & Dinges, D. F. (2007). Behavioral and Physiological Consequences of Sleep Restriction. *Journal of Clinical Sleep Medicine*, *3*(5), 519-528.

Barger, L., Flynn-Evans, E., Kubey, A., Walsh, L., Ronda, J., Wand, W., Wright, K., & Czeisler, C. (2014). Prevalence of Sleep Deficiency and Use of Hypnotic Drugs in Astronauts Before, During, and After Spaceflight: An Observational Study. *The Lancet Neurology*, *13*(9), 904-912. https://doi.org/10.1016/S1474-4422(14)70122-X

Barger, L., Wright, K., Burke, T., Chinoy, E., Ronda, J., Lockley, S., & Czeisler, C. (2014). Sleep and Cognitive Function of Crewmembers and Mission Controllers Working 24-h Shifts During a Simulated 105-day Spaceflight Mission. *Acta Astronautica*, *93*, 230-242. https://doi.org/10.1016/j.actaastro.2013.07.002

Basner, M., & Dinges, D. F. (2011). Maximising Sensitivity of the Psychomotor Vigilance Test (PVT) to Sleep Loss. *Sleep*, *34*(5), 581-591. https://doi.org/10.1093/sleep/34.5.581

Basner, M., & Dinges, D. F. (2014). Lost in Space: Sleep. *The Lancet Neurology*, *13*(9), 860-862. https://doi.org/10.1016/S1474-4422(14)70176-0

Basner, M., Hermosillo, E., Nasrini, J., McGuire, S., Saxena, S., Moore, T. M., Gur, R. C., & Dinges, D. F. (2018). Repeated Administration Effects on Psychomotor Vigilance Test Performance. *Sleep*, *41*(1). https://doi.org/10.1093/sleep/zsx187

Basner, M., Mollicone, D., & Dinges, D. F. (2011). Validity and Sensitivity of a Brief Psychomotor Vigilance Test (PVT-B) to Total and Partial Sleep Deprivation. *Acta Astronautica*, *69*(11-12), 949-959. https://doi.org/10.1016/j.actaastro.2011.07.015

Basner, M., Moore, T. M., Hermosillo, E., Nasrini, J., Dinges, D. F., Gur, R. C., & Johannes, B. (2020). Cognition Test Battery Performance is Associated With Simulated 6df Spacecraft Docking Performance. *Aerospace Medicine and Human Performance*, *91*(11), 861-867. https://doi.org/10.3357/AMHP.5602.2020

Chee, M. W., & Chuah, L. Y. (2008). Functional Neuroimaging Insights Into How Sleep and Sleep Deprivation Affect Memory and Cognition. *Current opinion in neurology*, *21*(4), 417-423.

Cherry, K. (2021). *What is Long-Term Memory*. Verywell Mind. Retrieved Janaury 28 from https://www.verywellmind.com/what-is-long-term-memory-2795347

Chua, E. C.-P., Yeo, S.-C., Lee, I. T.-G., Tan, L.-C., Lau, P., Cai, S., Zhang, X., Puvanendran, K., & Gooley, J. J. (2014). Sustained Attention Performance during Sleep Deprivation Associates with Instability in Behavior and Physiologic Measures at Baseline. *Sleep*, *37*(1), 27-39. https://doi.org/10.5665/sleep.3302

Chua, E. C.-P., Yeo, S.-C., Lee, I. T.-G., Tan, L.-C., Lau, P., Tan, S. S., Ho Mien, I., & Gooley, J. J. (2014). Individual Differences in Physiologic Measures are Stable Across Repeated Xxposures to Total Sleep Deprivation. *Physiological Reports*, *2*(9), e12129. https://doi.org/10.14814/phy2.12129

Communication, D. o. (2018). *Hubble Repair Man Jeffrey A. Hoffman*. Retrieved 11. August from https://www.tudelft.nl/evenementen/2018/lr/hubble-repair-man-jeffrey-a-hoffman

Curcio, G., Ferrara, M., & Degennaro, L. (2006). Sleep loss, learning capacity and academic performance. *Sleep Medicine Reviews*, *10*(5), 323-337. https://doi.org/10.1016/j.smrv.2005.11.001

Czeisler, C. A., Wickwire, E. M., Barger, L. K., Dement, W. C., Gamble, K., Hartenbaum, N., Ohayon, M. M., Pelayo, R., Phillips, B., Strohl, K., Tefft, B., Rajaratnam, S. M. W., Malhotra, R., Whiton, K., & Hirshkowitz, M. (2016). Sleep-Deprived Motor Vehicle Operators are Unfit to Drive: a Multidisciplinary Expert Consensus Statement on Drowsy Driving. *Sleep Health*, *2*(2), 94-99. https://doi.org/10.1016/j.sleh.2016.04.003

Dijk, D.-J., Neri, D. E., Wyatt, J. K., Ronda, J. M., Riel, E., Cecco, A. R.-D., Hughes, R. J., & Czeisler, C. A. (2003). Sleep, Circadian Rhythms, and Performance During Space Shuttle Missions. https://ntrs.nasa.gov/citations/20030068197

Dinges, D. F. (1995). An Overview of Sleepiness and Accidents. *Journal of Sleep Research*, *4*, 4-14. https://doi.org/10.1111/j.1365-2869.1995.tb00220.x

Dinges, D. F., Pack, F., Williams, K., Gillen, K. A., Powell, J. W., Ott, G. E., Aptowicz, C., & Pack, A. I. (1997). Cumulative Sleepiness, Mood Disturbance, and Psychomotor Vigilance Performance Decrements During a Week of Sleep Restricted to 4–5 Hours per Night. *Sleep*, *20*(4), 267-277.

Dinges, D. F., & Powell, J. W. (1985). Microcomputer Analyses of Performance on a Portable, Simple Visual RT Task During Sustained Operations. *Behavior Research Methods, Instruments, & Computers*, *17*(6), 652-655. https://doi.org/10.3758/bf03200977

Dorrian, J., Rogers, N. L., & Dinges, D. F. (2004). *Psychomotor Vigilance Performance: Neurocognitive Assay Sensitive to Sleep Loss*. CRC Press.

Ellis, S. R. (2000). Collision in Space. *Ergonomics in Design: The Quarterly of Human Factors Applications*, *8*(1), 4-9. https://doi.org/10.1177/106480460000800102

Eugene, A. R., & Masiak, J. (2015). The Neuroprotective Aspects of Sleep. *MEDtube science*, *3*(1), 35.

Evans, M. S., Harborne, D., & Smith, A. P. (2019). Developing an Objective Indicator of Fatigue: An Alternative Mobile Version of the Psychomotor Vigilance Task (m-PVT). In (pp. 49-71). Springer International Publishing. https://doi.org/10.1007/978-3-030-14273-5_4

Ferris, M., Bowles, K.-A., Bray, M., Bosley, E., Rajaratnam, S. M. W., & Wolkow, A. P. (2021). The Impact of Shift Work Schedules on PVT Performance in Naturalistic Settings: A Systematic Review. *International Archives of Occupational and Environmental Health*. https://doi.org/10.1007/s00420-021-01668-0

Flynn-Evans, E. E., Barger, L. K., Kubey, A. A., Sullivan, J. P., & Czeisler, C. A. (2016). Circadian Misalignment Affects Sleep and Medication Use Before and During Spaceflight. *npj microgravity*, *2*(1), 15019. https://doi.org/10.1038/npjmgrav.2015.19

Foust, J. (2015). *Astronauts Repair Space Station Sattelite Deployer*. Retrieved October 22 from https://spacenews.com/astronauts-repair-space-station-satellite-deployer/

Garcia, M. (2021). *International Space Station Facts and Figures*. NASA. Retrieved July 12 from https://www.nasa.gov/feature/facts-and-figures

Garner, R. (2020, 18.12.2020). *Astronauts, Robots and the History of Fixing and Building Things in Space*. Retrieved 11.08.2021 from https://www.nasa.gov/feature/goddard/2020/astronauts-robots-and-the-history-of-fixing-and-building-things-in-space

Gattoni, C., Girardi, M., O'Neill, B. V., & Marcora, S. M. (2021). Sleep Deprivation Training to Reduce the Negative Effects of Sleep Loss on Endurance Performance: A Single Case Study. *International Journal of Sports Physiology and Performance*, *1*(aop), 1-5. https://doi.org/10.1123/ijspp.2021-0230

Goel, N., Rao, H., Durmer, J., & Dinges, D. (2009). Neurocognitive Consequences of Sleep Deprivation. *Seminars in Neurology*, *29*(04), 320-339. https://doi.org/10.1055/s-0029-1237117

Gottlieb, D. J., Ellenbogen, J. M., Bianchi, M. T., & Czeisler, C. A. (2018). Sleep Deficiency and Motor Vehicle Crash Risk in the General Population: A Prospective Cohort Study. *BMC Medicine*, *16*(1). https://doi.org/10.1186/s12916-018-1025-7

Gunzelmann, G., Moore, L. R., Gluck, K. A., Van Dongen, H. P. A., & Dinges, D. F. (2009). Examining Sources of Individual Variation in Sustained Attention. *Cognitive Science Society*, 608-613.

Harrison, Y., & Horne, J. A. (2000). The Impact of Sleep Deprivation on Decision Making: A Review. *J Exp Psychol Appl*, *6*(3), 236-249. https://doi.org/10.1037//1076-898x.6.3.236

Hassanalian, M., Rice, D., & Abdelkefi, A. (2018). Evolution of Space Drones for Planetary Exploration: A Review. *Progress in Aerospace Sciences*, *97*, 61-105. https://doi.org/10.1016/j.paerosci.2018.01.003

Hickman, L. (2011). *The Hidden Dangers of Sleep Deprivation*. Retrieved July 28 2021 from https://www.theguardian.com/lifeandstyle/2011/feb/09/dangers-sleep-deprivation

Hu, B., Yan, L., Han, L., & Yu, H. (2021). Coordinated Compliance Control of Dual-Arm Robot Astronaut for Payload Operation. *International Journal of Advanced Robotic Systems*, *18*(3), 172988142110128. https://doi.org/10.1177/17298814211012850

Hudson, A. N., Van Dongen, H. P. A., & Honn, K. A. (2020). Sleep Deprivation, Vigilant Attention, and Brain Function: A Review. *Neuropsychopharmacology*, *45*(1), 21-30. https://doi.org/10.1038/s41386-019-0432-6

Jackson, C. A., & Earl, L. (2006). Prevalence of Fatigue Among Commercial Pilots. *Occupational Medicine*, *56*(4), 263-268. https://doi.org/10.1093/occmed/kql021

Jepsen, J. R., Zhao, Z., & Van Leeuwen, W. M. A. (2015). Seafarer Fatigue: A Review of Risk Factors, Consequences for Seafarers' Health and Safety and Options for Mitigation. *International Maritime Health*, *66*(2), 106-117. https://doi.org/10.5603/imh.2015.0024

Johannes, B., Bronnikov, S., Bubeev, Y., Arz, M., Piechowski, S., & Rittweger, J. (2019). Individual Learning Curves in Manual Control of Six Degrees of Freedom [Research article]. *International Journal of Applied Psychology*, *9*(2), 47-51. https://doi.org/10.5923/j.ijap.20190902.01

Johannes, B., Bronnikov, S., Bubeev, Y., Dudukin, A., Hoermann, H.-J., Frett, T., Rittweger, J., & Gaillard, A. (2017). A Tool to Facilitate Learning in a Complex Manual Control Task. *International Journal of Applied Psychology*, *7*(4), 79-85. https://doi.org/10.5923/j.ijap.20170704.01

Jones, P. M. (2010). Human Performance in Space. *Reviews of Human Factors and Ergonomics*, *6*(1), 172-197. https://doi.org/10.1518/155723410x12849346788787

Kaliyaperumal, D., Elango, Y., Alagesan, M., & Santhanakrishanan, I. (2017). Effects of Sleep Deprivation on the Cognitive Performance of Nurses Working in Shift. *J Clin Diagn Res.*, *11*(8). https://doi.org/10.7860/JCDR/2017/26029.10324

Kurinec, C. A., Whitney, P., Hinson, J. M., Hansen, D. A., & Van Dongen, H. P. A. (2021). Sleep Deprivation Impairs Binding of Information with its Context. *Sleep*, *44*(8). https://doi.org/10.1093/sleep/zsab113

Lee, S., & Kim, J. K. (2018). Factors Contributing to the Risk of Airline Pilot Fatigue. *Journal of Air Transport Management*, *67*, 197-207. https://doi.org/10.1016/j.jairtraman.2017.12.009

Lim, J., & Dinges, D. F. (2008). Sleep Deprivation and Vigilant Attention. *Annals of the New York Academy of Sciences*, *1129*(1), 305-322. https://doi.org/10.1196/annals.1417.002

Lo, J. C., Ong, J. L., Leong, R. L. F., Gooley, J. J., & Chee, M. W. L. (2016). Cognitive Performance, Sleepiness, and Mood in Partially Sleep Deprived Adolescents: The Need for Sleep Study. *Sleep*, *39*(3), 687-698. https://doi.org/10.5665/sleep.5552

Lopez, N., Previc, F. H., Fischer, J., Heitz, R. P., & Engle, R. W. (2012). Effects of Sleep Deprivation on Cognitive Performance by United States Air Force Pilots. *Journal of Applied Research in Memory and Cognition*, *1*(1), 27-33. https://doi.org/10.1016/j.jarmac.2011.10.002

Lueder, K. L. (2015). *ISS Crew Transportation and Services Requirements Document*. https://ntrs.nasa.gov/citations/20150010757

Mallis, M. M., & DeRoshia, C. W. (2005). Circadian Rhythms, Sleep, and Performance in Space. *Aviation, space, and environmental medicine*, *76*(6), 94-107.

Mitchell, M., & Jolley, J. (2016). *Web Appendix For Research Design Explained Interpreting Ordinal and Disordinal Interactions*. https://www.jolley-mitchell.com/Appendix/WebAppOrdinalInteraction/WebAppOrdinalInteractions.htm#_ftn1

Morphew, E. (2020). Psychological and Human Factors in Long Duration Spaceflight. *McGill Journal of Medicine*, *6*(1). https://doi.org/10.26443/mjm.v6i1.555

Mosheiov, G. (2001). Scheduling Problems With a Learning Effect. *European Journal of Operational Research*, *132*(3), 687-693. https://doi.org/10.1016/S0377-2217(00)00175-2

Pacheco, D. (2021, December 9 2021). *Why Do We Need Sleep?* https://www.sleepfoundation.org/how-sleep-works/why-do-we-need-sleep

Palinkas, L. (2009). The Exxon Valdez oil spill. *Mental Health and Disasters*, 454-472. https://doi.org/10.1017/CBO9780511730030.027

Pandi-Perumal, S. R., & Gonfalone, A. A. (2016). Sleep in space as a New Medical Frontier: The Challenge of Preserving Normal Sleep in the Abnormal Environment of Space Missions. *Sleep Sci*, *9*(1), 1-4. https://doi.org/10.1016/j.slsci.2016.01.003

Patanaik, A., Kwoh, C. K., Chua, E. C. P., Gooley, J. J., & Chee, M. W. L. (2015). Classifying Vulnerability to Sleep Deprivation Using Baseline Measures of Psychomotor Vigilance. *Sleep*, *38*(5), 723-734. https://doi.org/10.5665/sleep.4664

Peters, B. (2020, March 21 2020). *Difference Between Sleepiness and Fatigue*. Verywell Health. https://www.verywellhealth.com/sleepiness-fatigue-difference-3973906

Piechowski, S., Pustowalow, W., Arz, M., Rittweger, J., Mulder, E., Wolf, O. T., Johannes, B., & Jordan, J. (2020). Virtual Reality as Training Aid for Manual Spacecraft Docking. *Acta Astronautica*, *177*, 731-736. https://doi.org/10.1016/j.actaastro.2020.08.017

Pilcher, J. J., Band, D., Odle-Dusseau, H. N., & Muth, E. R. (2007). Human Performance Under Sustained Operations and Acute Sleep Deprivation Conditions: Toward a Model of Controlled Attention. *Aviation, space, and environmental medicine*, *78*(5), 15-24.

Rogers, W., Armstrong, N., Acheson, D., Covert, E., Feynman, R., Hotz, R., Kutyna, D., Ride, S., Rummel, R., & Sutter, J. (1986). Report of the Presidential Commission on the Space Shuttle Challenger Accident, Volume 1.

Rupp, T. L., Wesensten, N. J., & Balkin, T. J. (2012). Trait-Like Vulnerability to Total and Partial Sleep Loss. *Sleep*, *35*(8), 1163-1172. https://doi.org/10.5665/sleep.2010

Russo, M., Mahon, K., & Burdick, K. E. (2015). Measuring Cognitive Function in MDD: Emerging Assessment Tools. *Depression and Anxiety*, *32*(4), 262-269. https://doi.org/10.1002/da.22297

Sawyer, K. (1997). Docking Crash Cripples MIR Space Station. *Washington Post*. https://www.washingtonpost.com/archive/politics/1997/06/26/docking-crash-cripples-mir-space-station/f31a6d1c-612e-47cb-8e6e-6f4ca084f172/

Shen, J., Barbera, J., & Shapiro, C. M. (2006). Distinguishing Sleepiness and Fatigue: Focus on Definition and Measurement. *Sleep Medicine Reviews*, *10*(1), 63-76. https://doi.org/10.1016/j.smrv.2005.05.004

St. Hilaire, M. A., Sullivan, J. P., Anderson, C., Cohen, D. A., Barger, L. K., Lockley, S. W., & Klerman, E. B. (2013). Classifying Performance Impairment in Response to Sleep Loss Using Pattern Recognition Algorithms on Single Session Testing. *Accident Analysis & Prevention*, *50*, 992-1002. https://doi.org/10.1016/j.aap.2012.08.003

Strangman, G., Thompson, J. H., Strauss, M. M., Marshburn, T. H., & Sutton, J. P. (2005). Functional Brain Imaging of a Complex Navigation Task Following One Night of Total Sleep Deprivation: A Preliminary Study. *Journal of Sleep Research*, *14*(4), 369-375. https://doi.org/10.1111/j.1365-2869.2005.00488.x

Tefft, B. C. (2018). Acute Sleep Deprivation and Culpable Motor Vehicle Crash Involvement. *Sleep*, *41*(10). https://doi.org/10.1093/sleep/zsy144

Uehli, K., Mehta, A. J., Miedinger, D., Hug, K., Schindler, C., Holsboer-Trachsler, E., Leuppi, J. D., & Künzli, N. (2014). Sleep Problems and Work Injuries: A Systematic Review and Meta-Analysis. *Sleep Medicine Reviews*, *18*(1), 61-73. https://doi.org/10.1016/j.smrv.2013.01.004

Van Dongen, H., Maislin, G., & Dinges, D. F. (2004). Dealing With Inter-Individual Differences in the Temporal Dynamics of Fatigue and Performance: Importance and Techniques. *Aviation, space, and environmental medicine*, *75*(3), A147-A154.

Walker, P. (2010). *Pilot Was Snoring Before Air India crash*. Retrieved June 26 from https://www.theguardian.com/world/2010/nov/17/sleepy-pilot-blamed-air-india-crash

Watson, N. F., Badr, M. S., Belenky, G., Bliwise, D. L., Buxton, O. M., Buysse, D., Dinges, D. F., Gangwisch, J., Grandner, M. A., Kushida, C., Malhotra, R. K., Martin, J. L., Patel, S. R., Quan, S. F., Tasali, E., Twery, M., Croft, J. B., Maher, E., Barrett, J. A., Thomas, S. M., & Heald, J. L. (2015). Joint Consensus Statement of the American Academy of Sleep Medicine and Sleep Research Society on the Recommended Amount of Sleep for a Healthy Adult: Methodology and Discussion. *Sleep*, *38*(8), 1161-1183. https://doi.org/10.5665/sleep.4886

Williams, K. (2016). *NASA Research Reveals Biological Clock Misalignment Effects on Sleep for Astronauts*. Retrieved August 10 from https://www.nasa.gov/feature/ames/nasa-research-reveals-biological-clock-misalignment-effects-on-sleep-for-astronauts

Wong, L., Pradhan, S., Karasinski, J., Hu, C., Strangman, G., Ivkovic, V., Arsintescu, L., & Flynn-Evans, E. (2020). Performance on the Robotics On-Board Trainer (ROBoT-r) Spaceflight Simulation During Acute Sleep Deprivation. *Frontiers in Neuroscience*, *14*, 1-9. https://doi.org/10.3389/fnins.2020.00697

Wu, B., Wang, Y., Wu, X., Liu, D., Xu, D., & Wang, F. (2018). On-Orbit Sleep Problems of Astronauts and Countermeasures. *Military Medical Research*, *5*(1). https://doi.org/10.1186/s40779-018-0165-6

Zhang, Y., Li, Z., Liu, X., Liu, F., Jing, X., & Wu, B. (2015). Simulated Spaceflight Operations under Sleep Deprivation and Confinement. *Aerospace Medicine and Human Performance*, *86*(10), 865-874. https://doi.org/10.3357/amhp.4175.2015

Inspirational Quotes

“It’s easy to sleep floating around — it’s very comfortable. But you have to be careful that you don’t float into somebody or something!”

James Irwin, American Astronaut

*“In any field, it’s a plus if you view criticism as potentially helpful advice rather than as a personal attack.”**

Chris Hadfield, Canadian Astronaut

*An inspiring thought that I internalised during my time at university and which will guide me on my further path in life.