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ASSOCIATION BETWEEN SHORT-TERM ANNOYANCE AND SEVERAL PHYSIOLOGICAL PARAMETERS DURING DIFFERENT AMOUNTS OF NOCTURNAL AIRCRAFT NOISE EXPOSURE

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Abstract

Annoyance is the most prevalent community response to environmental noise. Observational and experimental lab studies have shown that exposure to environmental noise leads to annoyance, sleep disturbance, daytime sleepiness, increased heart rate and increased blood pressure. However, previous literature is preliminary based on controlled settings or experimental design, raising the question of the generalizability and applicability in daily life scenarios. This study aimed to investigate two main research questions. First, what is the relationship between short-term annoyance and different amounts of nocturnal aircraft noise exposure in daily life? Second, what is the relationship between physiological parameters, including heart rate, number of awakenings, sleep efficiency, sleep duration and different amounts of nocturnal aircraft noise exposure in daily life? This study also aimed to explore the suitability of non-invasive commercially available activity trackers to measure physiological metrics in a scientific way. During this field study, participants were wearing Fitbit Charge 3 activity trackers recording heart rate and different sleep-derived metrics (e.g. deep sleep duration, sleep efficiency and awakenings). The used activity trackers were readily available, non-intrusive, relatively cheap and easy to use by the participants. Simultaneously, a logbook was used by the participants to track the subjective perception and situational context of air traffic noise exposure. The noise levels corresponding to the exposure of air traffic of each participant were calculated based on the location of the participant and the corresponding radar track using an aircraft noise monitoring system.

We hypothesize that a higher amount of exposure to aircraft noise in real life will be associated with increased annoyance, increased rest heartrate, higher number of awakenings, decreased sleep efficiency and decreased deep sleep duration.

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Preliminary results on the interactions between aircraft noise exposure, perceived annoyance and physiological metrics suggest increased nocturnal aircraft noise exposure seems to negatively affect sleep efficiency and deep sleep duration.

Keywords: Aviation, aircraft noise, short-term annoyance, heart rate, deep sleep, sleep efficiency, awakenings, actigraphy.

INTRODUCTION

Air transport comes with many economic and societal benefits for the world, but unfortunately it also comes with negative effects, such as health impacts of aircraft noise near airports. Although aircraft have become more silent due to technological development and noise mitigation technologies, the increase in air traffic movements caused that the total amount of sound that is produced by aircraft will continue to increase in the coming years [1]. Several observational and experimental studies have shown that exposure to environmental noise leads to annoyance, sleep disturbance, daytime sleepiness and increased occurrences of high blood pressure and heart rate [2]. The noise annoyance can result from noise interfering with daily activities, feelings, thoughts, sleep or rest. Annoyance is the most prevalent community response to environmental noise and can be accompanied by negative feelings such as anger, displeasure, exhaustion and stress related symptoms [3] [4]. People do not have to be awake to react to environmental noise either, human beings perceive, evaluate and react to environmental sounds, even while asleep [5]. A sufficient length of sleep is required for daytime performance, quality of life and health, which is why sleep disturbance is thought of the most deleterious non-auditory effect of environmental noise exposure [6] [7]. Sleep disturbance has short-term and long-term effects on the human body. Short-term effects of noise-induced sleep disturbance include impaired mood, subjectively and objectively increased daytime sleepiness and impaired cognitive performance [8] [9]. These previous studies made use of EEG's for measuring the sleep-derived metrics, where the measurements were performed in laboratory-like settings. EEG measurements are known to be precise but there are also limitations such as limited representatively to daily life, complex execution, expensive and time consuming for both the participant and researcher conducting the experiment. To the author's knowledge, the deployment of commercially available activity trackers has not been applied in a comparable setting before in previous studies concerning noise impact. Several studies have compared varying commercially available activity trackers against industry standard measuring devices (e.g. Polysomnography) and found that the activity trackers did not differ much from the control [10] [11] [12] [13] [14]. However, these studies did not use the model-specific activity tracker used in this study so the overall measuring accuracy is not entirely confirmed.

The current study tries to be closer to daily life, less intrusive to the participants, and use less expensive equipment than previous studies. It is therefore easier applicable to a broader public, and has the benefit that more participants can be approached in the same amount of time and with significantly fewer resources then the EEG studies. The current study aimed to investigate the relationship between short-term annoyance and exposure of aircraft noise. Second, the relationship between four physiological parameters and the exposure of aircraft noise at night in a daily life environment was investigated.

Additionally, we aimed to explore whether commercially available activity tracker can be used to measure physiological data in a scientific way. This is an explorative study which is partially designed to understand the use of activity trackers in a scientific way.

We hypothesize that higher amounts of exposure to aircraft noise in real life will be associated with:

- Increased short-term annoyance
- Increased rest heartrate
- Higher number of awakenings
- Decreased sleep efficiency
- Decreased deep sleep duration

METHODOLOGY

The population of this study is assumed to be a reasonable representation of adult residents surrounding international airports in The Netherlands. Ultimately, 35 people participated in this study (mean age range = 41-50, 20 female, 1 unknown). The participants were recruited within NLR or circles of acquaintances of NLR members. The data collection period started on the 8th of August and lasted until the 30th of August 2019. The logbooks were designed to be filled in for 10 consecutive days. All participants confirmed that they have normal hearing. The participants were given information regarding the use of personal data and consent. They were also given a package containing data collection tools and corresponding instructions how to use these tools:

- Logbook
- Fitbit Charge 3 (including extra band and charging cable)

There are three instrumentation components in this study: Logbooks, Fitbit Charge 3 activity trackers and FANOMOS. The next three paragraphs will explain these components in detail.

Logbooks

The design of the logbooks has multiple parts and originates from several sources. Logbook parts relevant to the results from this study are mentioned in the paper.

Location

The calculations for the noise levels of overflying aircraft required the participant's locations. The postal codes of the participants were used to estimate the locations of the participants when they were in the residence.

Aircraft Noise Annoyance Assessment

The majority of the logbook content consists of an assessment of short-term aircraft noise annoyance. This entails the personal assessment of acute noise annoyance when the participant heard an aircraft. The variables for the short-term noise annoyance assessment include:

- Noise annoyance scale
- Time of noise annoyance occurrence
- The location of the participants during the noise annoyance occurrence
- Situation of noise annoyance occurrence
- Notes

The scale ranges from 0 (not at all) to 10 (extremely) [15] [16]. The situations the participants could be in during the noise annoyance assessment originate from a different paper [17]. When assessing the noise annoyance, the participants could fill in the location and situation of when the noise annoyance assessment was made. The following locations could be filled in, "at home" or "other". When answering "other", the participants could fill in the postal code or place name and description. The participants could fill in the noise annoyance assessment four times per day. The situations the participants could be in were given:

- During communication, when using the phone
- When staying and/or recovering outdoors
- When listening to the radio and watching TV
- When falling asleep
- When reading and concentrating
- During the night

- When having visitors at home
- When awakening
- Other…

When answering "Other…" in the situation section, the participants wrote down their own interpretation of the situation they were in. The participants filled in the noise annoyance assessment and were given a short description of the variables to ensure that no misinterpretations were present during the assessment:

- Time: please use local times when filling in
- Aircraft Noise Annoyance Scale: the level of annoyance you currently experience due to aircraft noise

All data that was written down by the participants in the logbooks was used in the analysis.

Fitbit Charge 3 activity trackers

The activity trackers used in this study are manufactured by Fitbit Inc. and the data acquisition is provided by Fitabase owned by Small Steps Labs LLC (SSL). The Fitbit Charge 3 activity trackers were used for a number of reasons, one of which is their ability to measure rest heartrate. The activity trackers acted as watches, which showed the time and date. The activity trackers connected with the participant's mobile phone which acted as a databank, which then sent the information to SSL. This way, the researchers could gather the data from the activity trackers. Another big factor was the relatively high cost-effectiveness. This allows a lot of people to participate in the study at a relatively low cost. The activity trackers were used to measure rest heart rate, the number of awakenings during the night, sleep efficiency and deep sleep duration. Sleep efficiency corresponds to the efficient time of sleep including light and deep sleep overall. Deep sleep duration measures only the phase of deep sleep.

FANOMOS

FANOMOS (Flight track and Aircraft Noise Monitoring System) is developed by the NLR. All data presented in FANOMOS is provided by the air traffic control of the Netherlands (LVNL). This program was used to calculate the peak noise levels of every aircraft in dB(A). The calculation model used for determining the peak noise levels works with the instructions set by the Nederlands Reken Model (Dutch Calculation Model). From now on, peak noise levels in dB(A) will be referred as LAmax. Because of FANOMOS calculation limitations, the LAmax's are calculated for levels outside the participant's residences. The information contained in the FANOMOS dataset consists of:

- A unique ID for each LAmax for easy indexing
- LAmax
- Date
- Time

Depending on the locations, several studies used night time background noise levels between 20 dB(A) and 50 dB(A) [18] [19] [20] [21]. Because of this, the nocturnal LAmax threshold was set at 35 dB(A). The period in which "night time" is defined is between 22:30 and 06:00 the next day. This period coincides with the LVNL regulations regarding night time runway use. The area in which the LAmax's were calculated differs between participants. The postal codes of the participants, together with the other locations the participants mentioned in the logbooks, acted as coordinate markers. All possible LAmax's were calculated for the markers as long as the LAmax's were above 35 dB(A). No outliers were identified in both the Fitbit and logbook datasets.

Analysis plan

Until now noise level is the dominant noise exposure metric for calculating the relationship between noise and annoyance [22]. Recent research suggests a link between the number of aircraft noise related events above a threshold (NATs) and annoyance. It was found that NAT was a significant predictor for the harmful effects of aircraft noise exposure [22]. Within the current study the relationship between noise annoyance and physiological measures was investigated using the number of fly-overs.

The number of nocturnal flights in all comparisons has been put through a natural log function to provide a normal distribution. The logarithmic transformation was also applied to the rest heartrate and the number of awakenings. The five metrics mentioned in the hypothesis are subjected to separate regression analysis models, performed using IBM SPSS 20.

RESULTS

The degrees of freedom, F-value and p-value are given resulting from the tests with rest heartrate, awakenings, sleep efficiency, deep sleep duration and short-term annoyance. Since the variable "In fly-overs" was used to perform several regression analysis a Bonferroni correction was required to correct for type 1 error (concluding that a difference is significant when in fact it is not). This means that the p-value was compared with a p-value of 0.05 / 5 = 0.01. Scatter plots with corresponding regression lines are generated in Python 3.7 using the Matplotlib and Seaborn packages.

Short-term noise annoyance

There was a statistically significant relationship between the average noise annoyance scale scores and the (ln) number of nocturnal fly-overs of the past night as determined by a regression analysis model ($F(1,239)= 8.172$, $p=.005$, $R^2=.033$). The regression line in Fig. 1 shows that as the (ln) number of nocturnal fly-overs increases, the average short-term noise annoyance decreases.

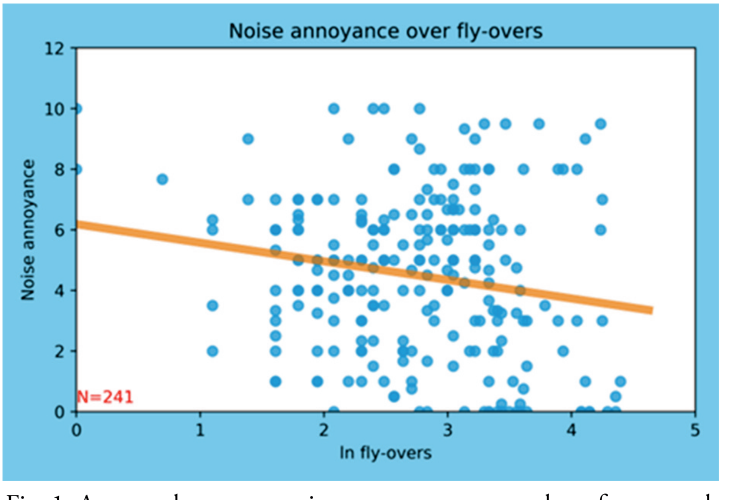

Fig. 1. Average short-term noise annoyance per number of nocturnal flights above 35 dB(A).

Rest heartrate

There was no statistically significant relationship between the rest heartrate and the number of nocturnal fly-overs as determined by a regression analysis model ($F(1,298)=3.172$, $p=.076$, $R^2=.011$). The regression line in Fig. 2 shows that as the (ln) number of nocturnal fly-overs increases, the (ln) rest heartrate increases. This is not statistically significant as indicated by the regression analysis model.

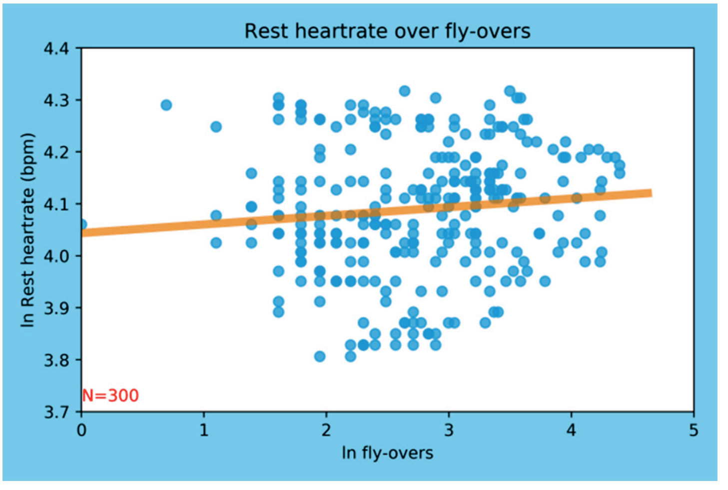

Fig. 2. Rest heartrate per number of nocturnal flights above 35 dB(A).

Number of awakenings

There was no statistically significant relationship between the (ln) number of awakenings and the (ln) number of nocturnal fly-overs as determined by a regression analysis model ($F(1,281)= 2.161$, $p=.143$, $R^2=.008$), (see Fig. 3).

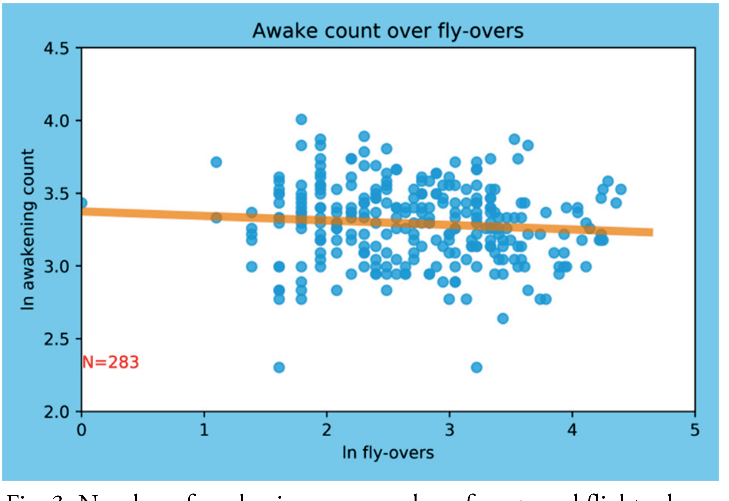

Fig. 3. Number of awakenings per number of nocturnal flights above 35 dB(A).

Sleep efficiency

There was a statistically significant relationship between the sleep efficiency and the number of nocturnal fly-overs as determined by a regression analysis model ($F(1,301)=6.927$, $p=.009$, $R^2=.022$). The regression line in Fig. 4 shows that as the (ln) number of nocturnal fly-overs increases, the sleep efficiency decreases.

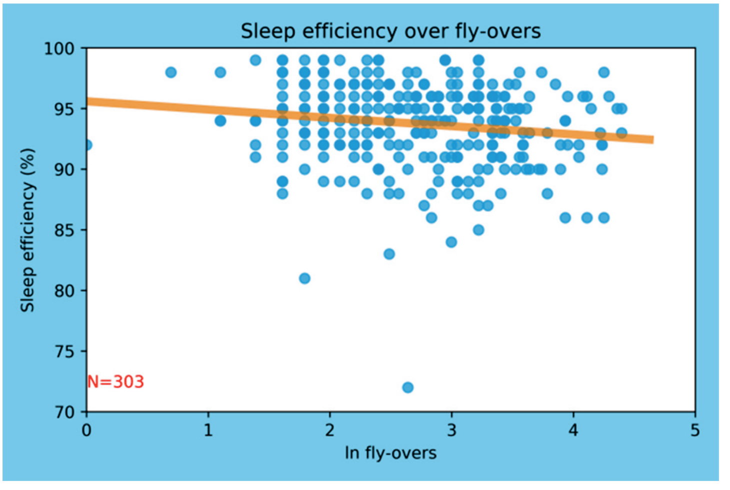

Fig. 4. Sleep efficiency per number of nocturnal flights above 35 dB(A).

Deep sleep duration

There was a statistically significant relationship between the deep sleep duration and the number of nocturnal fly-overs as determined by a regression analysis model ($F(1,281)= 9.093$, $p=.003$, $R^2=.031$). The regression line in Fig. 5 shows that as the (ln) number of nocturnal fly-overs increases, the deep sleep duration decreases.

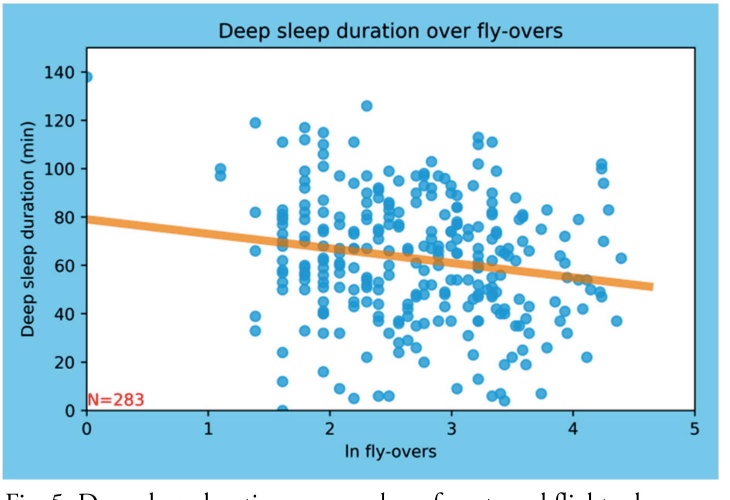

Fig. 5. Deep sleep duration per number of nocturnal flights above 35 dB(A).

DISCUSSION

Within this study, we examined how the subjective and physiological measurements differ across different number of nocturnal aircraft noise events. We hypothesized that higher amounts of exposure to aircraft noise in terms of number of events in real life will be associated with:

- Increased short-term annoyance
- Increased rest heartrate
- Higher number of awakenings
- Decreased sleep efficiency
- Decreased deep sleep duration

The three parameters that have statistically significant relationships with the number of nocturnal fly-overs are short-term noise annoyance sleep efficiency and deep sleep duration.

When short-term noise annoyance is directly compared with the number of nocturnal fly-overs, the resulting relationship looks counter intuitive. Fig. 5 suggests that an increase in nocturnal fly-overs causes the participants to have a lower average noise short-term annoyance score the following day. Recent research suggests that annoyance to aircraft noise increases with increasing intermittency of the noise situation. Continuous sound situations, such as noise from frequently used highways, are less annoying than noise situations with distinct pass-by events [23]. As in this study noise exposure is operationalized by the number of fly-overs and not by noise levels this might explain the results with regard to the impact on annoyance.

The relationship with the rest heartrate and the number of nocturnal fly-overs was calculated to be statistically insignificant ($p>0.01$). Why this relationship shows such a low significance may be because of low effect size and pure statistical power due to low sample size or because of the way the activity tracker measures rest heartrate. Rest heartrate is measured during sleep, but when for instance the tracker is not tight enough around the wrist during the night, the rest heartrate is measured during the day. This causes the rest heartrate to be increased, which might influence the results due different measurement methods. It is currently not possible to tell which occurrence of high rest heartrate was due to improper measurement (e.g. not tight enough around the wrist) or actual high rest heartrate. Based on the current result ($p=0.076$) there is no indication that there is a relationship between heartrate and flyovers.

The number of awakenings has no statistically significant relationship with the number of nocturnal fly-overs ($p=0.143$). The reason may be again because of low effect size and pure statistical power caused by low sample size or because the trackers have a high tendency to report false positives regarding awakenings.

The physiological measures of rest heart rate and the number of awakenings in relationships the amount of fly-overs could have low statistical significance due to the measuring methods used by the activity tracker. The possible causes are hard to confirm as Fitbit does not make the underlying data processing algorithms publicly accessible.

The results from this study suggest that there is a link between nocturnal fly-overs and decreased sleep efficiency ($p=0.009$). This result indicates that an increase in the number of nocturnal fly-overs has a direct negative effect on the sleep efficiency of people. This finding also supports the results from previous research suggesting that increased aircraft noise exposure decreases the sleep quality of humans [2]. We find that an increase in the number of nocturnal fly-overs can cause the deep sleep duration to be decreased ($p=0.003$). This result suggests that increased nocturnal aircraft noise exposure decreases the sleep duration in humans. Possible consequences are that a decreased deep sleep duration can cause decreased blood pressure dipping, causing higher overall nocturnal blood pressure, increased hypertension and lowered mental toughness in people [24] [25] [26].

It seems that the Fitbit activity trackers might not be equally sensitive to all physiological measures tested within this study. It is perhaps more complex to measure reliable data for rest heartrate or the number of awakenings while the activity trackers seem to be more sensitive to measure metrics such as sleep efficiency and deep sleep duration. However, within scientific research full understanding of data processing is required to draw reliable conclusions. The not fully transparent data processing algorithms within Fitbit might be a reason to question the suitability of those activity trackers for scientific research. Further research using commercially available activity trackers and perhaps additional comparisons with EEG measures are required to reliably confirm the suitability for scientific research. However, the usage of commercially available activity trackers might have potential for scientific research due to cost efficiency and longer periods of data collection. The participants of the current study reported positive experiences wearing the Fitbit activity trackers, such as intuitive and simple usage in daily life.
The importance of this study is emphasized by the social and economic implications resulting from the increased annoyance and decreased sleep efficiency and deep sleep duration [3], as productivity and time is lost during working hours as a result of poor sleep quality [27].

CONCLUSION

The results from this study indicate that there is evidence of increased nocturnal aircraft noise exposure negatively effecting sleep efficiency and deep sleep duration. The suitability of commercially available activity trackers used to measure physiological parameters such heart rate, number of awakenings, sleep efficiency and deep sleep duration cannot be entirely confirmed. For studies where there is a need for a larger number of participants, or where measurements must be done resembling daily life routine of participants, the set-up of this study might be preferred over laboratory (sleep) studies. Further research has to be conducted on the relationships between rest heartrate, number of awakenings, short-term noise annoyance and increased nocturnal aircraft noise exposure.

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ZWIĄZEK MIĘDZY KRÓTKOTRWAŁYM ZNUŻENIEM A KILKOMA PARAMETRAMI FIZJOLOGICZNYMI PODCZAS RÓŻNEJ LICZBY NARAŻEŃ NA HAŁAS EMITOWANY PRZEZ SAMOLOTY NOCĄ

Abstrakt

Znużenie jest najbardziej rozpowszechnioną reakcją społeczności na hałas w środowisku. Obserwacyjne i eksperymentalne badania laboratoryjne wykazały, że ekspozycja na hałas środowiskowy prowadzi do irytacji, zaburzeń snu, senności w ciągu dnia, podwyższonego tętna i podniesionego ciśnienia krwi. Jednakże, wcześniejsza literatura opiera się wstępnie na ustawieniach kontrolowanych lub projektach eksperymentalnych, podnosząc kwestię uogólnienia i możliwości zastosowania w scenariuszach życia codziennego. To studium miało na celu zbadanie dwóch głównych kwestii badawczych. Po pierwsze, jaka jest zależność między krótkotrwałym znużeniem a różnymi liczbami nocnego hałasu emitowanego przez samoloty w życiu codziennym? Po drugie, jaka jest zależność między parametrami fizjologicznymi, w tym tętnem, liczbą przebudzeń, efektywnością snu, czasem trwania snu a różną ilością narażenia na hałas emitowany przez nocne samoloty w życiu codziennym? Badanie to miało również na celu zbadanie przydatności nieinwazyjnych, dostępnych na rynku urządzeń śledzących aktywność, do naukowego pomiaru parametrów fizjologicznych. Podczas tego badania terenowego uczestnicy nosili urządzenia śledzące aktywność Fitbit Charge 3, rejestrujące tętno i różne wskaźniki fizjologiczne (np. czas trwania głębokiego snu, efektywność snu i przebudzenia). Użyte rejestratory aktywności były łatwo dostępne, nieinwazyjne, stosunkowo tanie i łatwe w użyciu przez uczestników. Jednocześnie uczestnicy korzystali z dziennika rejestrującego w celu śledzenia subiektywnego postrzegania i kontekstu sytuacyjnego narażenia na hałas wytwarzany przez ruch lotniczy. Poziomy hałasu odpowiadające narażeniu na ruch lotniczy każdego z uczestników zostały obliczone na podstawie lokalizacji uczestnika i odpowiadającego mu toru radarowego z wykorzystaniem systemu monitorowania hałasu lotniczego.

Zakładamy, że większe narażenie na hałas emitowany przez samoloty w warunkach rzeczywistych będzie wiązało się ze zwiększonym znużeniem, zwiększonym tętnem spoczynkowym, większą liczbą przebudzeń, zmniejszoną efektywnością snu i zmniejszonym czasem trwania głębokiego snu.

Wstępne wyniki dotyczące interakcji między narażeniem na hałas emitowany przez samoloty, postrzeganym znużeniem i parametrami fizjologicznymi sugerują, że zwiększona nocna ekspozycja na hałas emitowany przez samoloty wydaje się negatywnie wpływać na efektywność snu i czas trwania głębokiego snu.

Słowa kluczowe: Lotnictwo, hałas emitowany przez samoloty, krótkotrwałe znużenie, tętno, głęboki sen, efektywność snu, przebudzenia, aktygrafia.