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Psychological Effects

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# **Effects of Nocturnal Aircraft Noise**

## **Volume 4**

### **Psychological Effects**

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# **Effects of Nocturnal Aircraft Noise: Psychological Effects**

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# PART 1: NOISE ANNOYANCE

## 1.1 Introduction

The annoyance by unwanted and disturbing sound is the central psychological variable in noise effects research. It is considered as the most important psychological noise effect. Many social-psychological studies have shown that especially the “public” noise sources - i.e., street, railway and air traffic - lead to the annoyance of large parts of the population [Guski 1987, 2001a, 2001b; Guski et al. 1999; Kryter 1985; Ortscheid & Wende 2002a, 2002b; Rohrmann et al. 1978].

In principle, it is assumed that the term “annoyance” concerns a psychological circumstance, which cannot be demonstrated as pathogenic, yet presents a potentially negative factor for the physical, mental and social well-being of an individual and consequently is ranked below the threshold of direct health impairment [Kastka 2001a; WHO 1947]. Whether a long-term annoyance has negative hygienic effects is still unclear at this time. It is merely known that an adaptation or habituation to chronic noise exposure with regard to the annoyance reaction does not take place [e.g. Rohrman 1974]; in long-term studies the annoyance actually increased during the course of time [e.g. Weinstein 1982].

The feeling of annoyance mainly results from the disturbance of communication, rest, relaxation, and sleep, which are also referred to as *primary reactions* in the meaning of acute reactions, which coincide closely with noise impact. Noise-induced, primary sleep disorders include, for example, changes in the natural sleep cycle (e.g., awakening, delayed falling asleep, noticeable deep-sleep changes in the EEG, body movements). The disturbance of nocturnal sleep is one of the most common reasons for noise complaints [Guski 1987, 1991]. Since annoyance follows primary noise effects with a certain temporal delay, it belongs to the so-called *secondary*

*reactions*. Among these are also the perceived sleep quality and the sleep quantity, the individual degree of fatigue, changes of the mood, as well as the mental and psycho-motoric performances in the morning following a night of noise exposure. The analysis focuses on the description of noise-induced secondary disturbances, in which emphasis is on the noise annoyance.

## **1.2 Theoretical principles: definitions, models and scaling methods of noise annoyance**

### 1.2.1 Definitions of noise annoyance

Although annoyance is affirmed as one of the main noise effects in many cases and has been studied all the time, up to now, only little consent exists concerning the exact meaning of the term “noise annoyance”. The definitions, as well as the inquiry methods, vary considerably within the respective studies. Koelega [1987] introduces, for example, some definitions that can be found in the international context of noise effects research. His summary shows that annoyance contains both the conscious perception, as well as the negative assessment of a noise-induced disturbance of an intended activity. Activities such as communication, relaxation and recuperation are considered as especially sensitive to disturbances. Predominant affects are discomfort, irritation, discontent, and also anxiety and fear. Perception and thinking are dominated by experiences of the loss of personal autonomy and competence (e.g., helplessness and the limitation of autonomy of decision, since an intended activity was constrained and this disturbance cannot, or only at considerable effort, be counteracted), threat (e.g., hazard of health and life), as well as necessitation (e.g., inducement of relocation) [Guski 1987, 1999; Guski et al. 1999; Hellbrück & Fischer 1999; Schick 1997]. In an intercultural study concerning the meaning of the con-

tent of the term “noise annoyance”, Guski et al. [1999], using the method of semantic differential, show country-specific differences with respect to its connotative meaning. Apparently, in the German-speaking part the term “annoyance” is semantically closest to the concept of disturbance<sup>1</sup>, while in Japan emotional components, such as irritation, are emphasized. Taken together, noise annoyance represents a complex concept integrating behavioural and evaluative components [Guski & Schick 2004]. Koelega points out [1987], most researchers do not explicitly distinguish between these components, especially with respect to emotional and cognitive aspects of annoyance.

## 1.2.2 Models of noise annoyance

According to the different definitions of the term “noise annoyance”, there are different models that describe the relationship between acoustic exposure and resulting annoyance. These will be shortly outlined in the following:

### 1.2.2.1 *The psycho-physical approach*

According to the psycho-physical model, sounds (regardless of their meaning) are unspecific “additional stimuli”, which, depending on their level, lead to a more or less strong arousal-reaction (i.e., an increased psycho-physical activation) in the central nervous system. The ascending reticular activating system plays a neurologically important role. In the approach based on the *Yerkes-Dodson-law* [Yerkes & Dodson 1908], also referred to as the *arousal theory*, medium arousal levels lead to performance enhancement, while lower and higher levels lead to increased excitation and, therefore, to less effective actions. According to this explanation-model,

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<sup>1</sup>According to Kastka [2001a], a “disturbance” is understood as an immediate reaction to a preceding noise exposure, which interrupts an intended course of action, such as the process of communication, or negates an intended aim, e.g., sleeping through the night.

noise can cause the disturbance of activities (communication, recuperation, sleep), which usually leads to annoyance. This approach was criticized, on the one hand because acoustic characteristics (primarily the sound level) are given too much importance with regard to physiological reactions, and, on the other hand, because cognitive factors, as well as personal and situational moderators, are disregarded, hence, neither individual differences in noise annoyance, nor annoyance differences between noise sources with the same acoustic exposure can be explained [Düker 1963; Hall et al. 1983; Lazarus 1966].

#### 1.2.2.2 *The stress-theoretical approach*

The time following the psycho-physical approach was dominated by various approaches, which can be summarized under the concept of "stress". Contrary to its everyday use, the term "stress" is applicable as *stressor*, *reaction* and also as *transaction*.

In the stimulus-orientated application of the term "stress", the concept serves as specification of manifold physical, chemical and psycho-social environmental influences that affect the human organism (physiologically and psychologically) and to which it has to adapt [Baum et al. 1982; Cohen 1978; Evans & Cohen 1987; Lepore & Evans 1996]. In the stress-taxonomy by Cambell [1983], environmental noises are typical "ambient stressors", i.e., chronic, relatively stable and difficult to change conditions of the physical environment. These ambient stressors are often background conditions, which are initially disregarded, yet, in certain situations may impair health and performance. Among these are noise conditions such as the chronic exposure to aircraft noise [Lepore & Evans 1996]. *Physiological approaches* (stress as reaction), as well as *psychological approaches* (stress as transaction) exist for the description of the ambient stressor effects, which, according to Baum et al. [1982] should be seen as complementary rather than exclusive.

In order to explain physiological effects of ambient stressors from a medical perspective, Selye [1957, 1974, 1991], a pioneer of stress research, defined the *General Adaptation Syndrome*, which consists of a sequentially unspecific "stress" reaction to environmental demands (the stressors) in the form of alarm and resistance processes, which can lead to exhaustion of the organism. Selye's stress model is based on findings by Cannon [1932], who interpreted stress as a (rehabilitative) reaction to disturbances of the homeostatic equilibrium of an organism by external environmental conditions. By today's standards, these reactions are physiologically justified in two neuro-humoral control circuits (hypothalamus-adrenal medulla-system, hypothalamus-pituitary-adrenal cortex-system) and serve the regeneration of the original homeostatic equilibrium of the organism. Henry & Stephens [1977] expanded this physiological approach by making the psychological effectiveness of a stimulus dependent on genetic or acquired-by-learning coping strategies.

From the psychological point of view, stress is neither stimulus nor reaction, but rather the result of an individually perceived consideration between environmental demands (stressors) and one's own abilities and alternatives of coping with these demands. As higher the demands are relatively to one's own capabilities, as higher the state of disequilibrium in a person and, therefore, as higher the resulting stress. According to the so-called *transactional stress model*, primary importance is given to the cognitive contention between man and environment (transaction), while the physical aspects of load are seen as less important [Lazarus 1966, 1990, 1991; Lazarus & Cohen 1977; Lazarus & Folkman 1984]. In this context, noise is seen as more annoying, as less a person rates the possibility of coping with the unwanted sounds, respectively the negative consequences following it (e.g., disturbance of activities) [Guski & Schick 2004]. The relative powerlessness of the affected persons against the noise source (or their low control-competence), is seen as an essential aspect of the annoyance effect [de Jong 1990; Evans 1982; Glass & Singer 1972; Gunn 1987; Stallen 1999].

This model is favoured, particularly by the high variance explanation, which is achieved by the consideration of inter-individually diverse coping strategies. Stallen [1999, 2000] expanded the psychological stress concept by social components. He assumes that the degree of perceived disturbance, the different (social) attitudes towards the noise source, the individually perceived threat, and the coping and control alternatives, as well as the confidence in the persons responsible for causing noise (i.e., source authorities), are essential moderators of noise annoyance.

#### 1.2.2.3 *The rational choice theory*

According to Fidell [1987; Fidell et al. 1988; Green & Fidell 1991], a noise annoyance judgement is the result of a more or less *rational choice process*. This choice (i.e., the annoyance judgement) is influenced by the actual acoustic exposure, experiences or conveyed information about former acoustic exposures, the sensitivity towards external disturbances of one's behaviour, as well as the cost-benefit considerations regarding the reached decision (e.g., disadvantages and advantages following a certain noise annoyance judgement). This model explicitly refers to the *annoyance judgement*, not to the annoyance experience. The influence of emotional aspects and further non-acoustic moderators is not taken into account.

#### 1.2.2.4 *The cognitive approach*

The cognitive model of noise annoyance by Höger et al. [2001] supposes that affected persons establish a *cognitive representation of the noise situation* by means of the acoustic exposure, as well as psychological, situational and social frameworks. The mental representation contains rational assessments, experiences, emotional components, stress experiences, and attitudes. Affected persons refer to this cognitive representation of their own noise situation when submitting annoyance and disturbance judgements

and when complaining. Annoyance and disturbance judgements, as well as complaints, are related; however, the causal direction has not yet been specified.

### **1.3 Scaling methods of noise annoyance**

In the past, annoyance of the population has been measured in various ways. Guski [1997] has partly discussed the methodological differences. Frequently, global annoyance ratings, in which a summarized assessment is given retrospectively for a certain period of time, were given by means of *rating scales with different answering formats* (graphic or verbal categories) with a different number of scale categories, which makes a comparison of the studies difficult [Guski & Schick 2004]. For instance, 3-point verbal scales are found in Anderson et al. [1983], 4-point scales in Fields & Walker [1982] and Aasvang & Engdahl [1999], 5-point scales in Finke et al. [1980], Fidell & Teffeteller [1981], as well as in the "Deutsche Forschungsgemeinschaft" [1974], 7-point answering scales are found in Kastka et al. [1995] and 9-point scales in Hall et al. [1981], as well as in Aasvang & Engdahl [1999]. The so-called "noise barometer" to estimate the noise annoyance on an 11-point "annoyance thermometer", has been applied very often [Oliva 1998; Winneke & Liu 1995]. However, it is assumed that this scale is over-differentiated and not equidistant. Miedema & Vos [1998, 1999] tried transforming the different answering scales into one unified format. To achieve an international standardisation of annoyance-measurement, Felscher-Suhr et al. [2000] recommend the application of a noise annoyance scale with five verbal answering categories, which allows a differentiated ascertainment and most closely corresponds to the criteria of equidistance [cp. also Fields et al. 2001].

## 1.4 Dose-response relationships

Annoyance is the only noise effects parameter for which established dose-response relationships exist [Fidell et al. 1991; Miedema & Vos 1998, 1999; Schultz 1978]. Generally, a statistically *monotone correlation between sound level and annoyance* is shown, i.e., the annoyance reaction more or less increases with ascending sound level depending on the underlying level quantity (cp. *chapter 1.4.1*) [Fields 1984, 1993; Rylander et al. 1972, 1980, 1986; Schulz 1978]. Several *integrating dose-response curves* have been established for the description of the psycho-physical relationships between parameters of traffic noise exposure and annoyance by the combination of multiple dose-response curves into a single curve. The precursor of this kind of data aggregation is Schultz [1978]. His curve was extended by the addition of more recent studies by Fidell et al. [1991], and, later, by Schuemer & Schreckenbergl [2000]. The trend of the curve, however, remained more or less identical. This type of data analysis was criticized because of the combination of various acoustic data into one source-unspecific “dose”, as well as for the integration of differently acquired annoyance-variables to one “response” [Kryter 1982]. In continuation of this approach, Miedema [1993, 1998] therefore developed *source-specific dose-response curves*. It became apparent that the gradient of the aircraft noise curve is steeper than those of the other traffic noise sources. This means, that with an equal level increase, more persons feel annoyed by aircraft noise than by road and railway noise.<sup>2</sup>

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<sup>2</sup>From a qualitative standpoint, aircraft noise has the highest annoyance potential compared to any other traffic noises with similar sound energy, whereas these differences increase with ascending sound level [Miedema & Vos 1998]. Expressed in dB-equivalents, in terms of a malus, aircraft noise is about 5dB more annoying than road traffic noise [Miedema 1998]. From a quantitative point of view, aircraft noise is the second noise source, following road traffic noise, by which the German population is disturbed and annoyed. This is the result of a representative survey of the population, conducted by the “Umweltbundesamt” (Federal Environmental Agency) [Ortscheid & Wende 2002]. Using the criteria of being “highly annoyed” that is given when the upper two categories of a 5-point answering scale are used, approximately 18% of the population are affected by road traffic noise and 6% by aircraft noise according to this survey.

The statistical correlation between level quantities and noise annoyance is rarely that high to have a satisfactory variance explanation by the acoustic variables [Fields 1993; Passchier Vermeer 1993; Stallen 1999]. The extent of the impact does increase depending on the kind of acoustic parameters, nonetheless, the inter-individual annoyance reactions to the same stimulus vary greatly. Consequently, the correlations (and therefore the amount of the common variance between independent and dependent variable) are continuously statistically secured. However, they are comparatively low on the individual level, while on the level of the population-based average data they are higher, with a rate of  $r \sim .60$  [Job 1988; Winneke & Liu 1995]. This circumstance implies that non-acoustic factors are also involved in individual noise effects. Summarising reviews can be found in Rohrmann et al. [1978], Guski [1987, 1999, 2001c], Job [1988] and Fields [1993] as well as in *chapter 1.4.2*.

#### 1.4.1 Physical parameters of noise annoyance

For the establishment of the relationship between an acoustic stimulus and the resulting disturbance, it is necessary to apply suitable operationalisations on both sides. On the reaction side, noise annoyance is acquired by means of different scaling instruments (*cp. chapter 1.3*). On the stimulus side, different level quantities, as well as other event describing parameters can be used for this purpose:

In noise effects research, *average noise levels* are still regarded to be the best (objective) measures for the prediction of noise annoyance [Hellbrück 1993; Schick 1997]. Empirical studies on noise annoyance have shown more or less stringent dose-response relationships between acoustic exposure and annoyance reaction. Noise annoyance is usually described by the (A-weighted) energy equivalent noise level  $L_{eq}$  [e.g. Aasvang & Engdahl 1999], which accumulates and averages according to energetic aspects energy and the frequency of the single noise events during the measurement

period.<sup>3</sup> However, studies on the aircraft noise annoyance of airport residents have shown, that the aircraft noise-induced disturbance above 55 dB(A) is generally underestimated by average noise level oriented measures [Kastka 2001a, 2001b]. The acute disturbance effect from intermittent noise (e.g., railway or aircraft noise) is produced mainly by a single event, and it is therefore reasonable to characterize single events with the *maximum noise level*  $L_{\max}$  instead of  $L_{\text{eq}}$ . The  $L_{\max}$  describes the maximum intensity in dB, which is reached, e.g., during an over-flight.

Aside from the sound level, the *number of sound events* (also called *level frequency*) is an important parameter of aircraft noise-induced annoyance reactions. Previous studies [e.g. DFG 1974; Finke et al. 1980] have already shown that annoyance judgements co-vary as much as the average noise level, as well as the number of loud events. According to Fields [1984], the correlation between annoyance and the number of aircraft noise events ranges between an apparent and an unidentifiable influence. Guski [1999] points out that noise affected persons do not only react to a global noise immission, characterized by the average noise level, but rather to noise events, i.e., to number, distribution, duration, level, and meaning of acoustic immissions. Therefore, it is not surprising that, for example, airport residents claim that, despite of quieter aircrafts, the noise has grown louder, since they refer to the increased flight movements and the shorter calm periods between aircraft noise events. While Kalveram [1996] assumes that noise emergencies can be allocated without increasing the noise-psychological annoyance cost of the population, i.e., that the number of flight movements can be increased if the average noise level stays the same (de Lijster [1996] calls this *energy equivalent level-to-frequency conver-*

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<sup>3</sup>The German legislation (act on the protection against aircraft noise, from March 30<sup>th</sup>, 1971) applies the A-weighted, energy equivalent noise level as the basis for assessment values concerning aircraft noise exposure. Maximum noise levels and their frequencies are not used. Contrary to the calculation of other noise sources ( $q = 3$ ), the average level is calculated with a bisection parameter of  $q = 4$ , which means that a sound level increase of 4 dB equals the effect of a duplication of the exposure time. Consequently  $L_{\text{eq}4}$  is always smaller than  $L_{\text{eq}3}$ , except when the sound to be rated continues throughout the entire assessment period.

sions), other researchers support the position that a strong increase of air traffic, with a simultaneous reduction of the emission levels, leads to a qualitative change of the noise exposure. This implies that, today, the affected persons mainly complain about the lack of intermissions in the noise progression. For instance, Kastka [1999] found indications of a number effect in longitudinal studies with the duration of eight years, in which the annoyance reaction of the residents increased with an increasing frequency of noise events, despite identical average noise levels [cp. also Guski 2001b; Kastka 2001a, 2001b]. Kastka developed the noise measure NAT70<sup>4</sup> and used it for the description of the annoyance at several airports.

According to Björkman et al. [1992], the dose-response relationship between aircraft noise exposure and annoyance can best be characterized by means of both parameters *number of noise events and maximum noise level* [cp. also Rylander & Björkman 1988]. In the 1970s and 1980s, numerous field studies were conducted, in which an attempt was made to specify the relationship between both physical variables regarding annoyance [e.g. Fields 1984; Rylander et al. 1972, 1980, 1986; Schultz 1978]. Generally, an increase of annoyance occurs above a specific assessment value (e.g.  $L_{\max} = 70 \text{ dB(A)}_{\text{outside}}$ ), due to an augmentation of over-flights [cp. also Öhrström & Rylander 1990; Öhrström 1995, as well as Sato et al. 1999 with respect to road traffic noise annoyance]. De Lijster [1996] supposes that the number effect depends on the level of aircraft noise exposure: when there is only a little noise exposure, the number of aircraft noise events has less influence on annoyance than the level of the single events (under-energetic number effect). In correspondence to increased exposure, an over-energetic number effect develops. At very high noise exposure levels the number effect de-

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<sup>4</sup>In empirical studies with airport residents, Kastka proves that the resident annoyance (measured in the percentage of highly annoyed persons) can most accurately be depicted by the number of single sound events exceeding  $L_{\max}$  values of 70 dB(A) (Number Above Threshold: NAT70) [Kastka 2001a, 2001b]. As guideline values for residential areas, Kastka recommends a maximum of 60 exceedings during the day and eight during the night. Following the NAT70 concept, Guski [2001b] suggests that noise control should primarily aim to reduce loud sound events, since these enable a higher relief of the affected persons than the mere reduction of the average sound level.

generates, yet without becoming under-energetic. Rylander et al. [1972] found that there is only a strong relationship between sound level and annoyance when there is a great many of sound events (approximately more than 60 starts in 24h). In contrast to this, the extent of noise annoyance barely changes with regard to lower over-flight frequencies (up to 36 starts in 24h) with an increasing sound level, it only starts rising in correlation to levels above 90 dB(A)<sub>outside</sub>. Therefore, at small airports, the number of over-flights related to aircraft noise annoyance seems to play a more important role than the sound level [cp. also Rylander & Björkman 1997; Sato et al. 1999]. The latter is consistent with the results of the study "aircraft noise effects" undertaken by the "Deutsche Forschungsgemeinschaft" [DFG 1974], in which greater importance is given to the number of noise events than to the maximum noise level in the psychological domain, such as noise annoyance [cp. also Gunn et al. 1981].

#### 1.4.2 Psychological parameters of noise annoyance

Since annoyance depends not only on the physical characteristics of unwanted sound, but also on different intervening personal, social and situational factors, generally, the statistical correlation between acoustic exposure and the disturbance effect is not so high that individual annoyance reactions could be reliably predicted by physical parameters. In the context of studies on man-environment-relationships, these non-acoustic parameters are termed *moderators* [Evans & Lepore 1997; Guski 1997]. Moderator variables are always independent from physical stimulus and co-vary with the dependent quantity to be investigated. For the purpose of variance explanation, the involvement of moderators is at least as important as the physical exposure itself. A rule-of-thumb within noise effects research attests that one third of the annoyance is determined by acoustic features, another third by non-acoustic moderators, while the last third of the annoyance cannot be explained yet [Fields 1993; Guski 1997, 1999, 2001c;

Höger 1999; Job 1988; Oliva 1998; Passchier Vermeer 1993; Schick 1996, 1997; Schuemer & Schuemer-Kohrs 1984; Stallen 1999, Vallet 1987].

*Situational or contextual moderator variables* contain mainly characteristics of the environment of the exposed accommodation (e.g., infrastructure, green space, recuperation and shopping possibilities) in terms of an “environmental aesthetic or environmental quality” [Booth 1999; Guski 1987; Oliva 1998]<sup>5</sup>. They also enclose the current action or activity of a person at the moment of the exposure, as well as the time of day (day vs. night). For instance, the comparison of aircraft noise annoyance with an open window results in a difference of approximately 10 dB(A)  $L_{eq3}$  for day and night, which shows that during the night, the residents are as sensitive to a uniform level as to a 10 dB(A) higher sound level during the day [Kastka 2001a].

Among the *social moderators* are the social assessments and attitudes towards a noise source (its “image”)<sup>6</sup>, the confidence in the efforts of source authorities, the history of noise exposure, as well as the residents’ expectations [Fields 1993; Guski 1999]. There are variables, which are specific for aircraft noise because they address aircraft-oriented contents (e.g., harm to one’s health caused by aircraft noise). According to Guski [1999], social moderators play an important role in noise abatement and therefore in the reduction of noise annoyance, since they are not individually different and affect entire groups of people. Therefore, in order to reduce noise annoyance, intensive care of the affected persons is reasonable, and they should

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<sup>5</sup>According to Ortscheid and Wende [2002a], there is a significant correlation between the assessed quality of a residential area and the annoyance due to road traffic noise of  $r \sim -.30$ , which corresponds to a variance explanation less than 9%. The annoyance caused by road traffic noise decreases according to the “better quality” of the residential area.

<sup>6</sup>Various studies in the 1980s, which were mainly dedicated to the source-specific effects of railway, road and other noise sources [Fields & Walker 1982; Finke et al. 1980], showed that large parts of the variance in the noise annoyance judgements can be explained by the consideration of moderators, such as the assumed health risk from the source (up to 26%), the social assessment that noise is avoidable (up to 7%), as well as the general belief that operators could undertake something against the noise. Based on the empirical results of the study “Affection of a city by noise” [Finke et al. 1980], Guski [1987] points out that image-based moderators partially clarify larger parts of the variance than level-based measures.

be informed of planned or predictable efforts in noise reduction, as well as be involved in discussions on effective noise abatement programmes. This should enhance confidence in the persons responsible for causing noise, and also offers the possibility of the cognitive noise control [Felscher-Suhr et al. 2001; Guski 1987, 1999, 2001b].

Finally, important *personal moderators* include the individual noise sensitivity<sup>7</sup>, one's own assessments and attitudes towards the noise source<sup>8</sup>, the perceived and assessed possibilities of coping<sup>9</sup> with noise and the associated "noise adaptation" [Fields 1993; Guski 1987; Miedema & Vos 1999]. Social-demographic attributes, such as age, gender, education, income, living status (owner vs. renter)<sup>10</sup>, or the travelling experiences on different

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<sup>7</sup>The individual noise sensitivity is the most influential personal moderator. It is considered as a stable, general personality characteristic reflecting the individual assessment of one's own sensitivity towards unwanted sounds and the general attitude towards noise [Fields 1993; Job 1988, 1993, 1999; Jones & Davies 1984; Stallen 1999; Stansfeld 1992; Taylor 1984; Weinstein 1978]. McKennell [1963] already proved that persons, who described themselves as noise sensitive, reacted more strongly to the degree of acoustic exposure than those persons, who described themselves as neutral or less noise sensitive (cp. also Öhrström & Rylander [1988] regarding road traffic noise-induced secondary disturbances). Concerning aircraft noise annoyance, correlations ranking about  $r \leq .50$  are generally observed. Following the sound level, noise sensitivity is the second strongest predictor of noise annoyance. According to Guski [1999], the consideration of noise sensitivity can increase the amount of variance explanation of the annoyance reaction by 10%. Expressed in level-equivalents, noise sensitivity, with respect to the annoyance judgement, has an effectivity of 11 dB [Miedema & Vos 1999]. It is partly measured by using single questions (e.g., "How sensitive are you towards noise of any kind?"), most often, however, by a sum of personal statements about the experience with noise by means of specific scale sets [e.g. Weinstein 1978]. A relatively new German-language noise sensitivity questionnaire, verified according to psychometric criteria, is developed by Zimmer & Ellermeier [1997, 1998, 1999].

<sup>8</sup>In a literature analysis, Job [1988] concludes, that individual assessments and attitudes towards the noise source, similar to noise sensitivity, explain more variance in the annoyance variable than the noise level itself [cp. also Berglund & Lindvall 1995]. Attitude variables are measured variously, either it is asked for the importance of the noise source [DFG 1974] or the danger of the source and the therewith associated fear [Finke et al. 1980]. They are also conceptualized with respect to the assessed health risk from aircraft noise [DFG 1974; Finke et al. 1980; Leonard & Borsky 1973; McKennell 1963], to the confidence or distrust towards source authorities [Finke et al. 1980; Leonard & Borsky 1973; McKennell 1963], and also to the general attitude towards air traffic [Kastka 2001b].

<sup>9</sup>According to the transactional stress model, the experienced noise annoyance depends on the affected persons' perceived abilities to successfully cope with the environmental stressors (coping strategies). The extent of cognitive control closely corresponds to this, i.e., in how far affected persons perceive the noise situation as controllable, in terms of the noise being predictable or influenceable, which can substantially reduce the negative noise effects. However, since aircraft noise concerns intermittent sound events, the extent of predictability and control is limited [Glass & Singer 1972; Guski 1999; Stallen 1999].

<sup>10</sup>In comparison to renters, apartment and home owners are less mobile, thus it is harder for them to escape from aircraft noise, which allows the assumption that the aircraft noise annoyance is thereby influenced. However, Ortscheid & Wende [2000, 2002a] could not prove such an effect.

means of transportation<sup>11</sup>, generally have only a small influence [Fields 1993, Miedema & Vos 1999; Oliva 1998].

## **1.5 Acoustic assessment values for the prevention of “considerable” noise annoyance**

Since noise annoyance can affect the individual well-being and therefore also one’s health, according to the WHO, it belongs to the parameters, which fall under the act on the protection from hazardous environmental influences [Paulsen et al. 1992]. The federal immission protection act, “Bundesimmissionsschutzgesetz” (BlmSchG), defines an annoyance as a hazardous environmental influence, provided that it is “considerable” [Guski 2001a; Jansen 1986; Rohrman 1984a]. The formulations in the act on the protection from aircraft noise and in the 16<sup>th</sup> “Bundesimmissionsschutz-Verordnung” (federal immission protection regulation: BlmSchV) are similar. Noise annoyance is the most important indicator for the discrimination between considerable or unacceptable acoustic exposures.

The exact content of the term *considerable* plays an important role in the judicial interpretation as well as in noise effects research. By means of declaring *acoustic assessment values*, legislation and standardisation attempt to determine at which point the environmental immissions become considerable in terms of the BlmSchG. By designating protective areas, in which acoustic assessment values apply, the protection of the affected population should be guaranteed. Psycho-physical dose-response curves are generally linear along the physical exposure axis (i.e., annoyance steadily rises with increasing physical exposure) and do not exhibit any prominent “jumps”, which suggest a qualitative change according to an “effect-threshold”

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<sup>11</sup>Ortscheid & Wende [2000, 2002a] does not find a moderating effect of the individual aircraft travelling experiences on aircraft noise annoyance. This means that, despite different attitudes towards the noise source, the users of aircrafts do not differ from non-users regarding their annoyance experiences.

[Oliva 1998]. Thus, due to the lack of an actual assessment value in international literature, and according to the so-called Schultz criteria, noise immissions with a predicted proportion of 25% to 28% "very" or "highly" annoyed persons are regarded as intolerable [Fidell et al. 1991; Miedema & Vos 1998; Schultz 1978]. In consideration of several aircraft noise annoyance studies, Griefahn et al. [2002] specify a (theoretical) assessment value of  $L_{eq,16h} = 62$  dB(A) as a preventative guideline, above which 25% of highly annoyed persons in the exposed population can be expected. As "threshold" a (theoretical) assessment value of  $L_{eq,16h} = 55$  dB(A) is given. Sound immissions in the range of this value can lead to substantial psychological changes causing adaptation and coping processes.

To what extent the annoyance due to aircraft noise is justifiable for the population is, finally, not a scientific, but a political question. In either case, the designation of a critical assessment value, regardless of its extent, means that a certain amount of people cannot be protected, since assessment values are derived on the basis of averaged data. The interrelation between acoustic exposure and resulting disturbance is moderated by many non-acoustic factors, which, however, are not taken into account in the assessment value determination. This means, that not all people can be equally protected, since the inter-individual variation of the noise reaction is very different, and thus the effectiveness of the protection of single individuals is reduced. However, the less the physical and judicial definition of an assessment value can be associated with the psychologically critical effects, the more people remain in the group of the unprotected in need of protection [Rohrmann 1993].

## 1.6 Methods

A sleep laboratory study was run to investigate the human-specific effects of nocturnal aircraft noise. The study was divided into the four sections STRAIN<sup>12</sup> I to IV. They were laboratory experiments, which took place under controlled, but realistic conditions. In order to avoid the predictability of the aircraft noise, the study sections were applied as double-blind-experiments in an “incomplete randomized block design”. This means that neither the subjects, nor the experimentators knew which or how many aircraft noise events would be presented. Thirteen consecutive nights in the occupational medical simulation facility (AMSAN) of the DLR Institute of Aerospace Medicine served as study period (figure 1). Each subject had a private sleeping cabin.

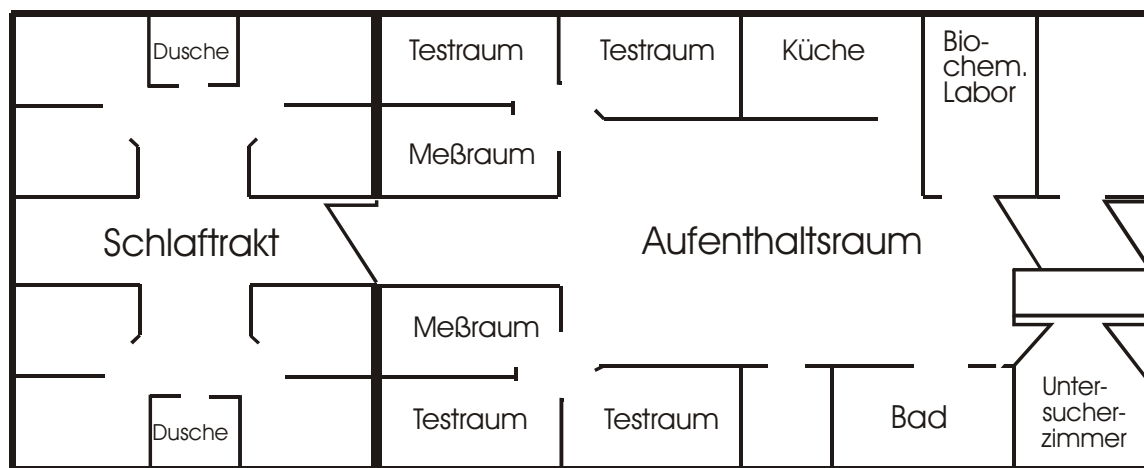


Figure 1: Occupational medical simulation facility (AMSAN): size approximately 300 m<sup>2</sup> (Dusche = shower, Testraum = test room, Küche = kitchen, Biochem. Labor = biochemical laboratory, Meßraum = instrumentation room, Schlaftrakt = sleeping quarters, Bad = bathroom, Aufenthaltsraum = recreational room, Untersucherzimmer = staff room)

The course of the study section STRAIN I is outlined in figure 2. Each of the 4 study phases began on Monday evening and ended on Sunday morning

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<sup>12</sup>STRAIN is the abbreviation for “**S**tudy on Human Specific **R**esponse to **A**ircraft **N**oise”.

of the following week. The first two nights were noise-free: the first night served for adaptation to laboratory conditions, the second night served as baseline night to measure control values, in order to compare these with the following aircraft noise-exposed nights.

		Versuchsnacht												
		1	2	3	4	5	6	7	8	9	10	11	12	13
Studienphase	I	0	0	0	0	0	0	0	0	0	0	0	0	0
	II	0	0	L	L	L	L	L	L	L	L	L	0	0
	III	0	0	L	L	L	L	L	L	L	L	L	0	0
	IV	0	0	L	L	L	L	L	L	L	L	L	0	0

Figure 2: Example STRAIN I (first study section with 32 subjects). Four groups, each with eight persons, were investigated in 13 consecutive nights. In all sequences there were two adaptation or control nights (0). Nights allocated to noise (L) were randomized according to number of events and maximum noise level of the aircraft sounds, the sound exposure was "double blind". Group I served as control group, i.e., no aircraft noise was played (Versuchsnacht = test night, Studienphase = study phase).

Nights 3 to 11 contained randomized aircraft noise exposures with changing *level frequency combinations* and different temporal, equidistant patterns (figure 3). The final two (noise-free) nights were used for additional, comparative control analyses.<sup>13</sup> Figure 3 depicts the number of subjects, whom the level frequency combinations were presented to. For ethical reasons, as well as for reasons of ecological validity, no extreme combinations (e.g. 128 times 80 dB(A) or 4 times 50 dB(A)) were applied ("incomplete multi-factorial experimental design").<sup>14</sup>

<sup>13</sup>In the fourth laboratory study (STRAIN IV), the nights 12 and 13 also entailed aircraft noise exposure, which, however, is disregarded in the analysis.

<sup>14</sup>Incomplete multi-factorial experimental designs do not contain all possible combinations of the treatment categories. Instead, only the combinations which are necessary to get information about hypothesis-oriented main effects are selected [Bortz 1989].

		Number of aircraft noises					
		4	8	16	32	64	128
Maximum noise levels $L_{AS,max}$	45					32	
	50			32	32	32	32
	55	40	40	32	32	32	32
	60	40	40	32	32	32	
	65	32	32	32	32	56	
	70	32	32	32	32		
	75	32	32	32			
	80	32	24				

Figure 3: Level frequency combinations in STRAIN I to IV. The left column contains the maximum noise levels (45 dB(A) to 80 dB(A)), which were distributed equidistantly during the night with the frequency  $n$  (2<sup>nd</sup> row). The number of subjects or nights exposed to a corresponding level frequency combination is depicted in each cell of the matrix.

In the laboratory study, 128 healthy and according to their age normally hearing persons (53 men, 75 women) between the ages of 19 to 65 were examined. The subjects of a study section ( $N = 32$ ) were divided into 4 groups, each with eight persons, who simultaneously completed a single study phase of 13 nights under identical conditions. The subjects were randomly allocated to experimental and control conditions. In the control groups (first phase of STRAIN I and fourth phase of STRAIN II,  $N = 16$ ), no aircraft noise was played throughout the entire examination, merely the noise emissions of the air-conditioning provided a constant background noise level of  $L_{AS,eq} \simeq 30$  dB(A). All subjects spent only the evenings and nights in the AMSAN (from 7 pm to 8 am), in order to influence the normal course of the day as little as possible, ensuring the ecological validity of the study. Each night lights were turned off by 11 pm and on again by 7 am, which allowed for a maximum sleep period time of eight hours.

The term “(aircraft) noise” concerns, as already mentioned, the evaluation of an aircraft sound as an unwanted and disturbing sound event. In the study, its operationalisation was achieved by using the following acoustic parameters in terms of the independent variables:

- *number of aircraft noise events per night* (level frequency),
- *maximum noise level of an aircraft noise event* ( $L_{AS,max}$ ),
- *energy equivalent noise level*  $L_{AS,eq}$  during eight hours of sleep (from 11 pm to 7 am),
- distinction between *starting* and *landing aircrafts*.

Correctly, one should refer to “aircraft sound” instead of “aircraft noise”, since only acoustic indicators were used for the operationalisation. However, since the use of the term “aircraft noise” is well-established in the noise effects research, it will be applied in the following, even though solely acoustic characteristics are meant. Important non-acoustic parameters were also considered and separately measured as psychological moderator variables.

During the 9 nights, in which the experimental groups ( $N = 112$ ) were exposed to aircraft noise events, these were presented via loudspeakers into the beforehand acoustically calibrated sleep cabins. In the various nights, changing maximum noise level frequency combinations with different temporal patterns were played, whereby different gradations of the average noise level were produced (figure 3). Thirty exposition patterns were assigned randomly to the 9 noise nights of each subject. Thus, all study sections were performed in “incomplete block design” (blocks correspond to subjects). The  $L_{AS,max}$  lay between 45 dB(A) and 80 dB(A), and the frequency varied between 4 to 128 events per night, whereas 5 dB(A) or a duplication of the number of events were used as stimulus gradation (figure 3). This

equals energy equivalent noise levels in the range from of 30.0 dB(A) to 54.5 dB(A).<sup>15</sup> The aircraft noise of a single night was distributed equidistantly in the period between 11:15 pm and 6:45 am. An acoustic workstation was used for the time controlled replay.

By means of a questionnaire, the following aircraft noise-induced secondary disturbances in terms of the dependent variables were measured in the morning after waking up:

- *annoyance* due to the nocturnal aircraft noise,
- *sleep quality* and *sleep quantity*,
- *awakening frequency*,
- *subjective aircraft noise exposure, i.e., aircraft noise intensity* and the *frequency of unacceptable aircraft noises* during the past night.

The individual questionnaire items are 5-point answering scales with varying verbal anchoring. The subjective fatigue was additionally measured by a standardized fatigue questionnaire, which was used in the German translation of the American original [Samn & Pirelli 1982]. The 10 items of the FAT have the same 3-point answering format (“2 = worse”, “1 = exact”, “0 = better”) and are combined into a total value (from “0 = wide awake” to “20 = extremely tired”). Annoyance was rated by using a 5-point scale (from “1 = not” to “5 = very” annoyed), corresponding to the recommendations of Felscher-Suhr et al. [2000] and Fields et al. [2001].

The following non-acoustic parameters of aircraft noise annoyance were determined before the study was conducted, by means of a general questionnaire:

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<sup>15</sup>The LAS<sub>eq</sub> was divided into nine categories for descriptive and inferential analysis:  $\leq 33$  dB(A),  $\leq 36$  dB(A),  $\leq 39$  dB(A),  $\leq 42$  dB(A),  $\leq 45$  dB(A),  $\leq 48$  dB(A),  $\leq 51$  dB(A),  $\leq 54$  dB(A), and  $\leq 57$  dB(A). 3 dB(A) gradations were chosen according to a doubling, respectively bisection of the sound energy.

### **a) Situational or contextual moderators**

- *contentment with certain aspects of the residential area,*
- *general residential contentment,*
- *time of residence in the meaning of a temporal successive noise adaptation,*
- *type of domestic noise control (window glazing),*
- *different window positions in the exposed living space.*

### **b) Social moderators**

- *attitudes towards, adaptation to and annoyance due to the three main traffic modes,*
- *health hazard, avoidability and necessity of air traffic, as well as the general attitude towards air traffic (i.e., the “image” of air traffic),*
- *health hazard caused by aircraft noise,*
- *confidence in the persons responsible for causing aircraft noise,*
- *belief in chances of aircraft noise reduction.*

### **c) Personal moderators**

- *noise sensitivity,*
- *subjective adaptation to aircraft noise,*
- *residential status (owner vs. renter),*
- *travelling experiences on aircrafts (flyers vs. non-flyers),*
- *participation in activities against aircraft noise.*

Laboratory studies are normally characterized by a *limited ecological validity* and can indicate only a small section of the research problem, which is ac-

cessible to further analysis. Thus, the study of noise annoyance under laboratory conditions is difficult, since the assessment of aircraft noises with respect to their disturbing potential becomes the main task of the subjects, which does not necessarily correspond to the natural disturbance situation in their domestic environment [e.g. Guski & Bosshardt 1992; Rohrmann 1984]. Therefore, in addition to the sleep laboratory study, a field study (divided into the sections STRAIN V and VI<sup>16</sup>) was conducted in order to verify the laboratory results. The field study took place in the vicinity of the Konrad-Adenauer-Airport Cologne/Bonn, which exhibits high exposure to nocturnal aircraft movements. The measurements were carried out in residential areas, which are affected only by aircraft noise and not by other traffic noises, such as from road or railway traffic. Since flight routes depend on weather conditions, and the number of flight movements is influenced by the day of the week, measurements were made during 9 consecutive nights. Each examination began on Monday evening and ended on the Wednesday morning of the following week. Aside from inside and outside noises, the same dependent variables as in the laboratory study were determined. The recording of the inside and outside noises served for calculation of numerous acoustic parameters. The number of nocturnal aircraft noise events as well as the  $L_{AS,eq}$ <sup>17</sup> were chosen from these for further analysis. Unlike in the laboratory study, the subjects could decide on their own sleeping time according to their usual habits. However, a core sleeping period between 12 am and 6 am had to be maintained, since the study focused on the impact of *nocturnal* aircraft noise. As in the laboratory study, the normal course of the day of the subjects was to be influenced as little as possible. The field study was carried out with 64 persons aged between

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<sup>16</sup>In contrast to laboratory studies which are performed under controlled conditions in order to avoid disturbance variables relevant to the analysis, *field studies* are conducted in a "natural" environment, i.e., unaffected by the experimenter [Bortz & Döring 1995]. In the present studies, this meant investigating the residents of the Cologne/Bonn airport at home under as natural conditions as possible. Hereby, no additional aircraft noise was played via loudspeakers, only the actual occurring aircraft noise outside and inside the bedroom was simultaneously recorded.

<sup>17</sup>This concerns the aircraft noise-specific, A-weighted energy equivalent noise level in the bedroom, which corresponds to the  $NAT35_{inside}$  for the time period between 12 am and 6 am.

19 to 61 years (29 men, 35 women). Twenty persons participated in both, the laboratory as well as the field study.

## 1.7 Objectives

The human-specific psychological effects of nocturnal aircraft noise were examined by means of the following issues:

1. *To what extent does an interrelation between aircraft noise and perceived disturbance exist?* This is a question regarding the empirical function in terms of a *dose-response relationship*, i.e., the secondary reaction is conceptualized as the function of exposure.
2. *Starting from which level of aircraft noise exposure does the perceived disturbance become relevant?* This is a question concerning the so-called *assessment or threshold value*. Dose-response relationships between acoustic exposure and secondary disturbance are supposed to supply "effect-thresholds", above which the noise exposure for a certain part of people (e.g. 28%) is "very" or "highly" annoying. However, a limitation on the percentage of people, who are highly annoyed by noise has the disadvantage that the (likewise quantitatively important) proportion of persons, whose noise annoyance lies in the middle part of the answering scale, is disregarded.
3. *What are the main characteristics of aircraft noise annoyance?* This question concerns the *basic attributes or dimensions* to which an aircraft noise-induced annoyance reaction can be reduced.
4. *What are important parameters influencing aircraft noise annoyance?* This question asks for the *psychological moderators* of annoyance due to aircraft noise.

For the analysis of issues 1 and 2, descriptive (*chapter 1.8.1.1*) as well as inferential (*chapter 1.8.1.2*) inter-individual comparisons between control

groups (N = 16 subjects) and experimental groups (N = 112 subjects) were made, in order to show a *general influence of aircraft noise* on the reaction parameters regardless of its extent. Furthermore, measurements of different study days in the laboratory were compared for the experimental groups.

For the definition of *dose-response curves*, it was hypothesized that the secondary reactions modify with increasing nocturnal aircraft noise exposure in the following way:

- *reduction of sleep quality and sleep quantity,*
- *increase of annoyance, fatigue, awakening frequency, assessed aircraft noise exposure, i.e., aircraft noise intensity, and the frequency of unacceptable aircraft noises.*

Based on these assumptions, descriptive frequency (*chapter 1.8.2.1*), inferential statistics (*chapter 1.8.2.2*) and random effects logistic regression (*chapter 1.8.2.3*) were conducted for the experimental groups. In the inferential statistics, Kruskal-Wallis one-way analysis of variance for testing the main effects for the three aircraft noise parameters  $L_{AS,max}$ ,  $L_{AS,eq}$  and of the number of aircraft noise was conducted. The individual factor stages of the independent variables were compared by means of Mann-Whitney U-tests.

Regarding the third issue, principle component analyses were applied to determine the meaning of the term *aircraft noise annoyance* [Guski et al. 1999; Guski & Schick 2004; Oliva 1998] and to prove the integration of cognitive as well as emotional components into the concept [Koelega 1987]. For this purpose, data were used from the general questionnaire that was distributed before the laboratory study began. Beside the inquiry of annoyance existing before the study (in the meaning of an aircraft noise *pre-annoyance*), the questionnaire asks for a variety of other variables regarding the disturbing impact of aircraft noise at home (*chapter 1.8.3.1*).

The general questionnaire served also for the measurement of important *psychological moderators influencing aircraft noise annoyance* (e.g., per-

sonal attitudes towards the noise source, noise sensitivity), which were considered in the editing of the fourth issue. Non-acoustic, aircraft-noise-relevant moderators were integrated in the modelling of dose-response curves concerning annoyance (*chapter 1.8.2.3*). Furthermore, influence of non-acoustic parameters on aircraft noise *pre-annoyance* was tested by using Kruskal-Wallis one-way analysis of variance (*chapter 1.8.3.2*).

In order to determine the *ecological validity*, i.e., the transferability of the laboratory study onto the circumstances of the real residential environment of the airport residents, a validation of the laboratory results regarding issues 1 to 4 took place by means of a field study. This was conducted with a total of 64 persons, who lived in the vicinity of the Konrad-Adenauer-Airport Cologne/Bonn (*chapter 1.9*).

## **1.8 Results of the sleep laboratory study<sup>18</sup>**

### 1.8.1 Inter-individual comparison of control and experimental groups

#### *1.8.1.1 Descriptive statistics*

Tables 1 and 2 list the measurements of the central tendency (median and mode) and dispersion (range) of the dependent variables for the experimental and control groups in correspondence to the non-metric scale level. Only the measurements following the baseline night and the 9 consecutive aircraft noise-exposed nights are considered.<sup>19</sup>

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<sup>18</sup>The statistical analysis was performed by means of the statistic package SPSS 11.5 for Windows. Due to the non-metric scale level and the insufficient normal distribution of data which appeared in the Kolmogorov-Smirnov-test of the laboratory data, non-parametric procedures were chosen. In all analyses, the probability of rejecting the null hypothesis according to Bonferoni was corrected to  $\alpha/n$ , dependent on the number of conducted individual tests.

<sup>19</sup>The aircraft noise presented in the laboratory included starting as well as landing airplanes, since the results of Mann-Whitney U-test comparing the effect of starting and landing noises only proved significant differences for the variables "sleep quality" (middle rank<sub>landing</sub> = 480.84; middle rank<sub>starting</sub> =

**Statistics**

		sleep quantity	sleep quality	awakening frequency	aircraft noise intensity	annoyance	frequency of unacceptable aircraft noises	fatigue
N	Valid	1117	1117	1117	1117	1117	1117	1117
	Missing	4	4	4	4	4	4	4
Median		2	3	3	2	2	2	10
Mode		2	3	2	2	2	1	9
Range		5	5	5	5	5	5	20

Table 1: Measures of central tendency (median and mode) and dispersion (range) regarding the dependent variables of the experimental groups (N = 112).

**Statistics**

		sleep quantity	sleep quality	awakening frequency	aircraft noise intensity	annoyance	frequency of unacceptable aircraft noises	fatigue
N	Valid	158	157	158	158	158	158	158
	Missing	2	3	2	2	2	2	2
Median		3	3	2	1	1	1	8
Mode		3	3	2	1	1	1	8
Range		3	4	3	2	1	2	18

Table 2: Measures of central tendency (median and mode) and dispersion (range) regarding the dependent variables of the control groups (N = 16).

### 1.8.1.2 Inferential statistics

The inter-individual comparison between control and experimental groups regarding their secondary reactions following nights 3 to 11 (aircraft noise-exposed nights for the experimental groups) was conducted by means of Mann-Whitney U-tests. The results are listed in table 3:

	<b>QN</b>	<b>QL</b>	<b>AW</b>	<b>STÄ</b>	<b>BEL</b>	<b>UNZ</b>	<b>FAT</b>
Mean Rank.....Ex	561.13	566.16	588.57	636.93	628.82	622.33	600.77
.....Co	668.45	629.51	475.62	135.75	192.71	238.35	389.90
Z	-3.966	-2.268	-4.041	-17.436	-15.234	-13.540	-7.145
Asymptotic Sign.	.000**	.023	.000**	.000**	.000**	.000**	.000**

Table 3: Results of Mann-Whitney U-test (test statistic Z) regarding the comparison between the control and experimental groups' secondary reactions following nights 3 to 11. According to the Bonferoni correction ( $\alpha/7 = .007$ ) significant (\*) and very significant differences (\*\*) are denoted (abbreviations: QN = sleep quantity, QL = sleep quality, AW = awakening frequency, STÄ = aircraft noise intensity, BEL = annoyance, UNZ = frequency of unacceptable aircraft noises, FAT = fatigue).

525.84; Z = -2.60; p < .009) and "fatigue" (middle rank<sub>landing</sub> = 532.51; middle rank<sub>starting</sub> = 472.60; Z = -3.285; p < .001). This means that, after a night of aircraft noise exposure from starting aircrafts, the sleep quality is rated as significantly better and the fatigue in the morning as significantly less.

To test inter-individual differences between control and experimental groups, which may have existed before the introduction of the aircraft noise, the results of the U-test following the baseline night (night 2) are listed in table 4:

	<b>QN</b>	<b>QL</b>	<b>AW</b>	<b>STÄ</b>	<b>BEL</b>	<b>UNZ</b>	<b>FAT</b>
Mean Rank.....Ex	64.02	63.59	61.93	63.38	63.31	63.73	64.99
.....Co	63.83	67.07	79.43	68.63	69.13	66.00	56.60
Z	-.021	-.376	-1.894	-1.541	-1.901	-.741	-.833
Asymptotic Sign.	.983	.707	.058	.123	.057	.459	.405

Table 4: Results of Mann-Whitney U-test (test statistic Z) regarding the comparison between the control and experimental groups' secondary reactions following the baseline night (night 2). According to the Bonferoni correction ( $\alpha/7 = .007$ ) significant (\*) and very significant differences (\*\*) are denoted (abbreviations: QN = sleep quantity, QL = sleep quality, AW = awakening frequency, STÄ = aircraft noise intensity, BEL = annoyance, UNZ = frequency of unacceptable aircraft noises, FAT = fatigue).

Regarding evaluations of sleep quantity following nights 3 to 11, the experimental groups show significantly smaller scale values (i.e., less sleep) in comparison to the control groups. In respect to the awakening frequency, the intensity of the aircraft noise, annoyance, frequency of unacceptable aircraft noises, and the degree of fatigue, the values of the experimental groups are significantly higher than those of the control groups. Concerning the assessed sleep quality, the experimental and control groups do not exhibit significant differences. There are also no significant differences between the groups after the baseline night (night 2). Combined, a general effect of the independent variables  $L_{AS,eq}$ ,  $L_{AS,max}$  and level frequency could thus be determined. In the *experimental groups, significant aircraft noise-induced changes* exist for almost all dependent variables. The results regarding the secondary disturbances of the experimental groups are described in detail in the following.

## 1.8.2 Aircraft noise-induced secondary reactions of the experimental groups

### 1.8.2.1 Descriptive statistics

The descriptive statistics concerning the dependent variables contain essentially illustrations of the percentile frequency distribution. Specific values of the central tendency (median and mode) and of the dispersion (range) are given in *chapter 1.8.1.1*.

Figure 4 shows the percentile distribution of the experimental groups' *sleep quality* assessment by means of a 5-point answering scale. Taking into account the baseline night (night 2) and the subsequent 9 aircraft noise-exposed nights, the quartiles  $Q_1$  and  $Q_2 = 2$  as well as  $Q_3 = 3$  result. 54% of the ratings are distributed among the first two scale ranks ("much too little" and "slightly too little" sleep). 43% of the judgements occupy category 3 ("just the right"). The top two scale ranks ("a bit too much" and "much too much" sleep) are barely assigned.

Figures 5 and 6 illustrate the frequency distribution of the assessment of the sleep quality and awakening frequency. Categories 1 and 2 of the *sleep quality* ("not" and "little") are occupied with 21%, the middle ("moderately") is assigned with 40% and the upper categories ("quite" and "very") are occupied with 39%. There are the quartiles  $Q_1$  and  $Q_2 = 3$  and  $Q_3 = 4$ . Concerning *awakening frequency*, the lower scale ranks ("never" and "seldom") are assigned with 50%, the third rank ("occasional") is occupied with 33% and the upper ranks ("often" and "always") are assigned with 17%. This results in the quartiles  $Q_1 = 2$  and  $Q_2$ , respectively  $Q_3 = 3$ .

Figure 7 depicts the percentile frequency distribution of the answers concerning *aircraft noise annoyance* on a 5-point rating scale. This results in the quartiles  $Q_1 = 1$ ,  $Q_2 = 2$  and  $Q_3 = 3$ . As illustrated, the vast majority of

the subjects (approximately 60%)<sup>20</sup> feels “not”, or only a “little” annoyed by the applied aircraft noise. 20% state feeling “quite” or “very” annoyed, while another 20% feel “moderately” annoyed. The relatively high number of people, who chose the lowest scale rank can be attributed to the fact that, on the one hand, a decision had to be made between “not annoyed” and any other category of annoyance and, on the other hand, that the lowest rank did not allow for further differentiation. In this sense, one could refer to a “floor effect”. The distribution of the answers concerning *aircraft noise intensity* and *frequency of unacceptable aircraft noises* resembles that of the annoyance (figures 8 and 9). Solely with regard to the aircraft noise intensity, the first category (“not”) is explicitly less occupied (18%). There are no “ceiling effects” with respect to all dependent variables.

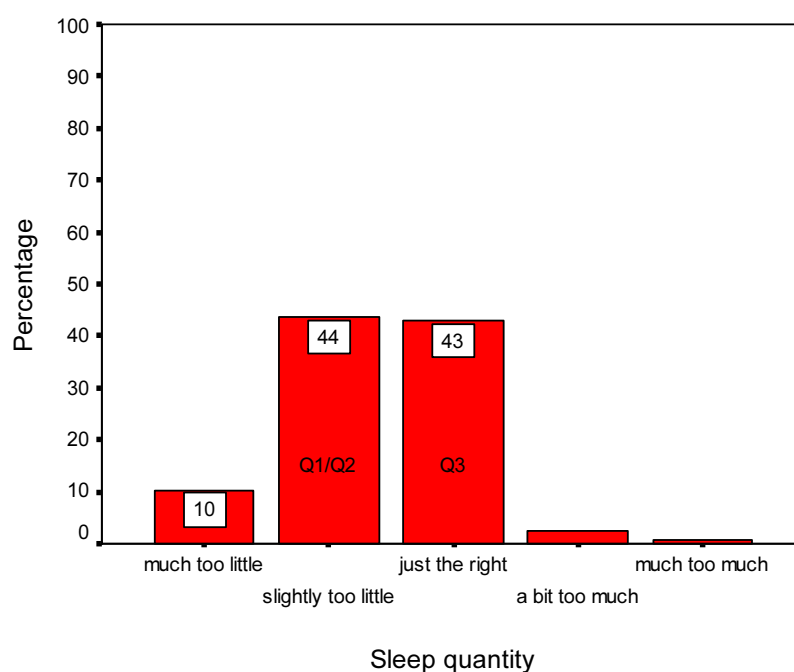


Figure 4: Percentile distribution of the experimental groups' (N = 112) sleep quantity evaluation (“How much sleep did you get during the past night?”) averaged over the nights 2 to 11.

<sup>20</sup>Missing percentages (here 1%) are due to missing values.

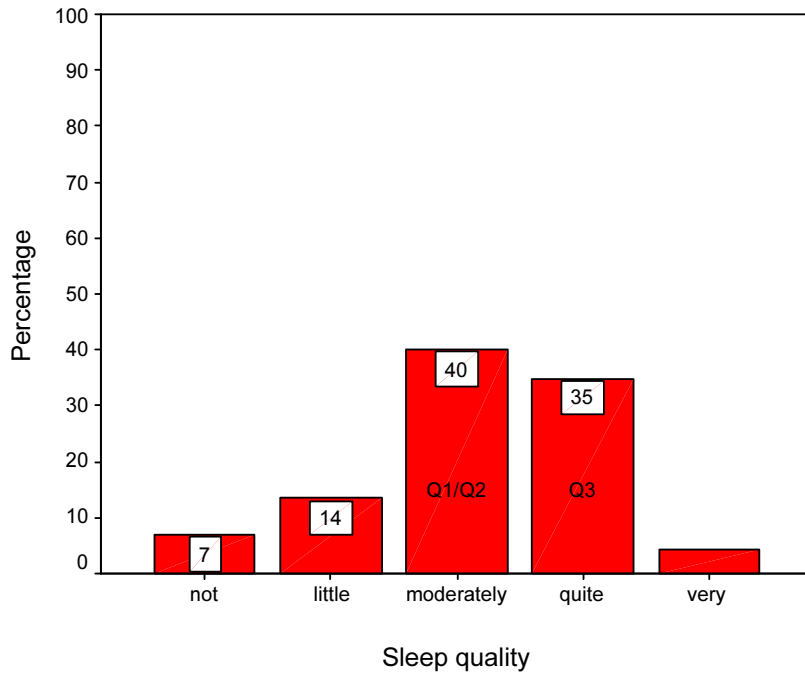


Figure 5: Percentile distribution of the experimental groups' (N = 112) sleep quality evaluation (*"How good was your sleep during the past night?"*) averaged over the nights 2 to 11.

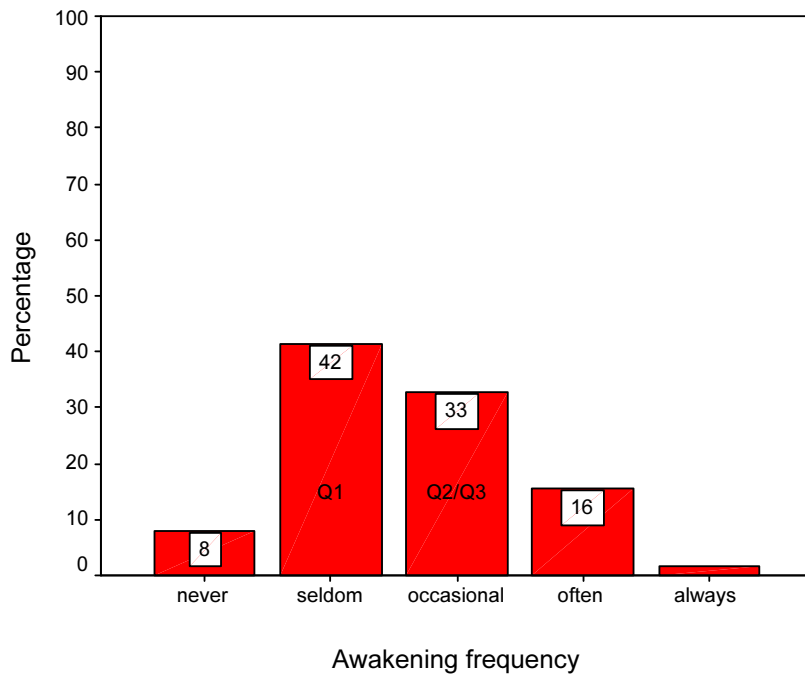


Figure 6: Percentile distribution of the experimental groups' (N = 112) awakening frequency evaluation (*"How often did wake up during the past night?"*) averaged over the nights 2 to 11.

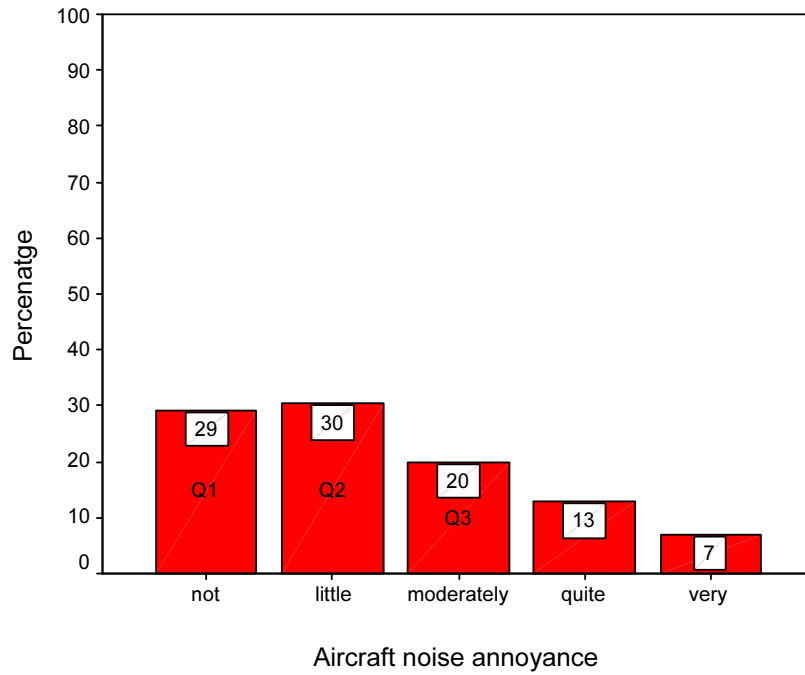


Figure 7: Percentile distribution of the experimental groups' (N = 112) annoyance evaluation ("How much have you been annoyed by aircraft noise during the past night?") averaged over the nights 2 to 11.

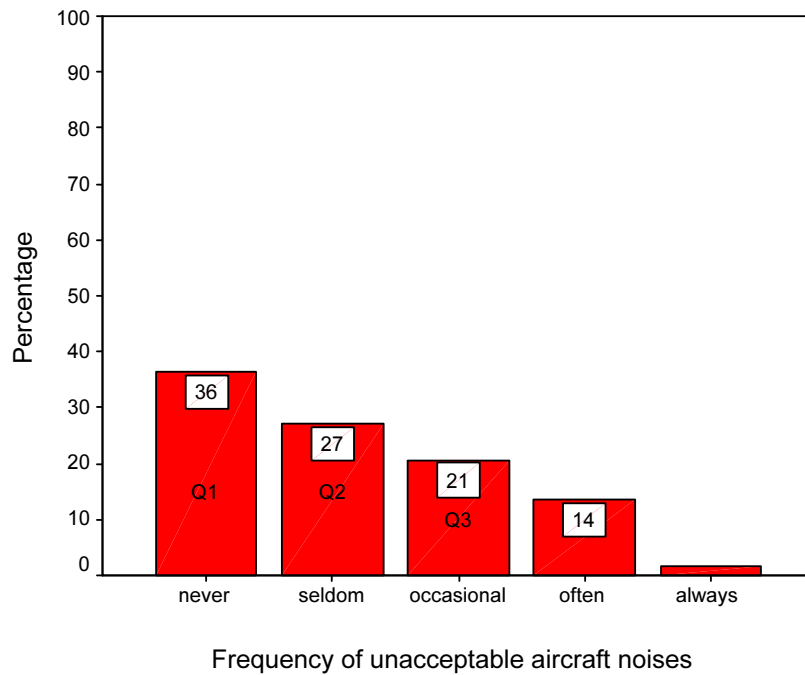


Figure 8: Percentile distribution of the experimental groups' (N = 112) evaluation of the frequency of unacceptable aircraft noises ("How often did you hear unacceptable aircraft noises during the past night?") averaged over the nights 2 to 11.

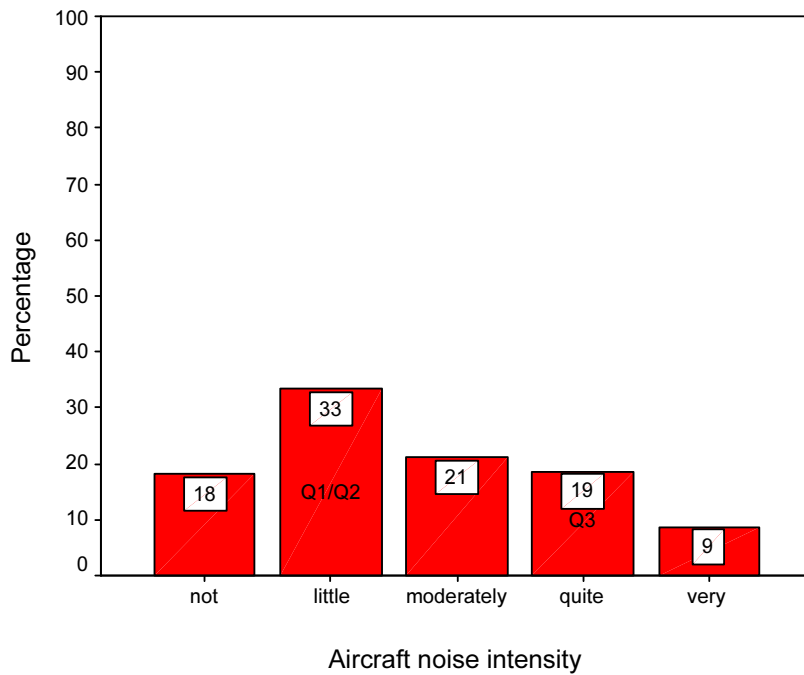


Figure 9: Percentile distribution of the experimental groups' (N = 112) aircraft noise intensity evaluation ("How much did you hear the aircraft noise during the past night?") averaged over the nights 2 to 11.

### 1.8.2.2 Inferential statistics

#### 1.8.2.2.1 Measurement value progress in the course of time

In order to determine a general influence of aircraft noise, measurements from various laboratory days are compared with each other. The secondary reactions of following measurement days in the laboratory are compared:

- a) first night vs. second night in the laboratory (i.e., adaptation and baseline nights): "first night effect"<sup>21</sup>
- b) baseline night vs. first aircraft noise-exposed night (nights 1 and 2)
- c) first night vs. last aircraft noise-exposed night (nights 3 and 11)

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<sup>21</sup>The term "first night effect" denotes the first night in a sleep laboratory, in which the individual sleep behaviour differs qualitatively and quantitatively from that in the familiar domestic environment [Agnew et al. 1996]. This effect disappears after the second night [Basner et al. 2000, 2001; Grieffahn 1985; Öhrström & Björkman 1988].

d) last aircraft noise-exposed night vs. subsequent noise-free night (nights 11 and 12)

e) final two noise-free nights (nights 12 and 13): “last night effect”

Since aircraft noise was also presented in nights 12 and 13 of the last study section (STRAIN IV), the comparisons a) and b) refer to the entire experimental sample (N = 112), while comparisons c) and d) only refer to the subjects from STRAIN I to III (N = 80).

	1 <sup>st</sup> vs. 2 <sup>nd</sup> night (first night eff.)	2 <sup>nd</sup> vs. 3 <sup>rd</sup> night	3 <sup>rd</sup> vs. 11 <sup>th</sup> night	11 <sup>th</sup> vs. 12 <sup>th</sup> night	12 <sup>th</sup> vs. 13 <sup>th</sup> night (last night eff.)
Z Sign	QN2 - QN1 (15NR, 57PR, 40B) -4.571 .000**	QN3 - QN2 (57NR, 13PR, 42B) -5.125 .000**	QN11 - QN3 (11NR, 26PR, 42B) -2.642 .018	QN12 - QN11 (6NR, 37PR, 36B) -4.132 .000**	QN13 - QN12 (14NR, 5PR, 60B) -1.784 .074
Z Sign	QL2 - QL1 (10NR, 62PR, 40B) -5.549 .000**	QL3 - QL2 (62NR, 14PR, 36B) -5.268 .000**	QL11 - QL3 (19NR, 31PR, 29B) -1.907 .056	QL12 - QL11 (7NR, 51PR, 36B) -5.828 .000**	QL13 - QL12 (24NR, 14PR, 40B) -1.395 .163
Z Sign	AW2 - AW1 (60NR, 18PR, 34B) -4.788 .000**	AW3 - AW2 (8NR, 78PR, 26B) -7.346 .000**	AW11 - AW3 (33NR, 18PR, 28B) -2.093 .036	AW12 - AW11 (55NR, 2PR, 22B) -6.492 .000**	AW13 - AW12 (18NR, 18PR, 43B) -.714 .475
Z Sign	STÄ2 - STÄ1 (5NR, 5PR, 102B) .000 1.000	STÄ3 - STÄ2 (0NR, 108PR, 4B) -9.095 .000**	STÄ11 - STÄ3 (31NR, 19PR, 29B) -.772 .440	STÄ12 - STÄ11 (75NR, 1PR, 3B) -7.576 .000**	STÄ13 - STÄ12 (1NR, 0PR, 78B) -1.000 .317
Z Sign	BEL2 - BEL1 (5NR, 4PR, 103B) -.333 .739	BEL3 - BEL2 (0NR, 102PR, 10B) -8.842 .000**	BEL11 - BEL3 (31NR, 21PR, 27B) -.448 .654	BEL12 - BEL11 (69NR, 1PR, 9B) -7.267 .000**	BEL13 - BEL12 (1NR, 0PR, 77B) -1.000 .317
Z Sign	UNZ2 - UNZ1 (5NR, 5PR, 102B) .000 1.000	UNZ3 - UNZ2 (0NR, 84PR, 28B) -8.094 .000**	UNZ11 - UNZ3 (30NR, 24PR, 25B) -.110 .912	UNZ12 - UNZ11 (61NR, 1PR, 16B) -6.871 .000**	UNZ13 - UNZ12 (1NR, 0PR, 76B) -1.000 .317
Z Sign	FAT2 - FAT1 (54NR, 33PR, 28B) -2.617 .009**	FAT3 - FAT2 (25NR, 70PR, 17B) -5.186 .000**	FAT11 - FAT3 (35NR, 28PR, 15B) -1.203 .229	FAT12 - FAT11 (46NR, 9PR, 23B) -4.844 .000**	FAT13 - FAT12 (28NR, 24PR, 26B) -.287 .774

Table 5: Results of Wilcoxon-test (test statistic Z) regarding the comparison between the experimental groups' secondary reactions following different measurement days in the laboratory. According to the Bonferoni correction ( $\alpha/5 = .01$ ) significant (\*) and very significant differences (\*\*) are denoted (abbreviations: QN = sleep quantity, QL = sleep quality, AW = awakening frequency, STÄ = aircraft noise intensity, BEL = annoyance, UNZ = frequency of unacceptable aircraft noises, FAT = fatigue; NR = negative ranks, PR = positive ranks, B = links).

Wilcoxon-tests were conducted for the comparison between the respective measurement days (table 5). A so-called “first night effect” exists for the secondary reactions *sleep quantity* and *sleep quality*, for the *awakening frequency* as well as for *fatigue*, this means that, subjectively, the subjects sleep significantly better in the second night (with regard to quantity and

quality), wake up significantly less frequently and are less tired in the morning [cp. Agnew et al. 1966; Basner et al. 2000, 2001; Griefahn 1985; Öhrström and Björkman 1988]. In comparison to the baseline night, the first aircraft noise-exposed night shows a *significant aircraft noise effect for all dependent variables*, i.e., the subjects sleep significantly worse in the first noise night, wake up more frequently, are more exhausted in the mornings, experience the noise as more intensive and unacceptable, and are more annoyed than in the quiet baseline night. There are no significant differences between the first and last aircraft noise-exposed nights. In the first noise-free night following the final aircraft noise night, a significant “improvement” of the secondary disturbances occurs, i.e., data change in reverse with regard to the comparison between the baseline and first noise nights (see above). A so-called “last night effect” cannot be proven for any of the variables.

In order to illustrate the results, the measurement value progress of the secondary reactions of *all* experimental groups (N = 112) during the course of the laboratory study (13 nights) is shown by the following box-plots<sup>22</sup> (figures 10 to 16).

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<sup>22</sup>The schematically shown dispersion of the answers in figure 10, is based on the box-plot procedure by Tukey [1977]. The lowest boundary corresponds to the boundary of the first quartile and the upper line represents the boundary of the third quartile. Thus, the boxes in the figure contain the middle 50% of the distribution. The middle horizontal line indicates the median. The vertical lines above and below the boxes show the area in which other answers occur, provided that they lie within the 1.5-fold inter-quartile interval. An inter-quartile interval is the distance between the first and third quartile. Each more extreme deviation is indicated with a circle, provided that it lies within the 3-fold inter-quartile interval. Values with an even higher deviation are indicated with a star.

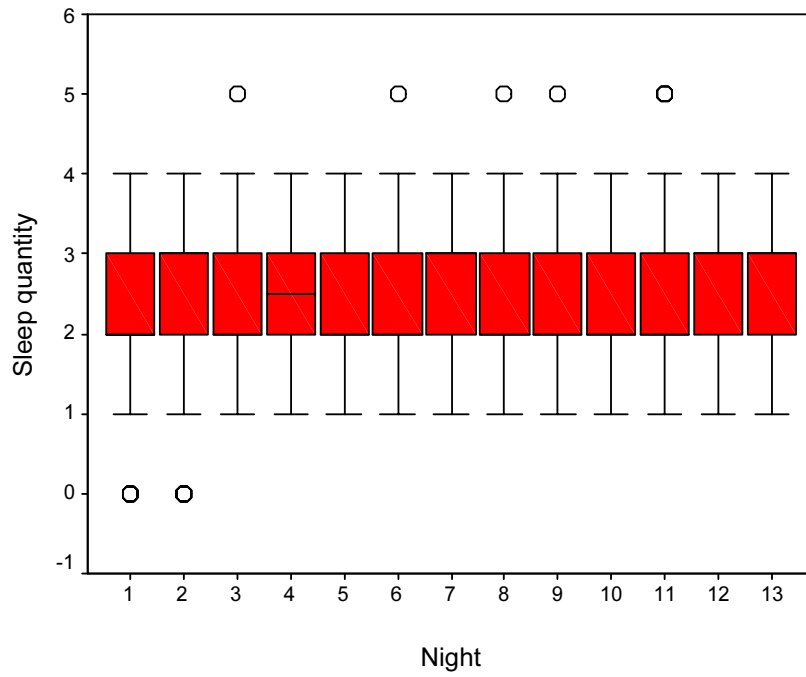


Figure 10: Box-plot of the experimental groups' (N = 112) sleep quantity evaluation ("1 = much too little" to "5 = much too much") in the course of the sleep laboratory study.

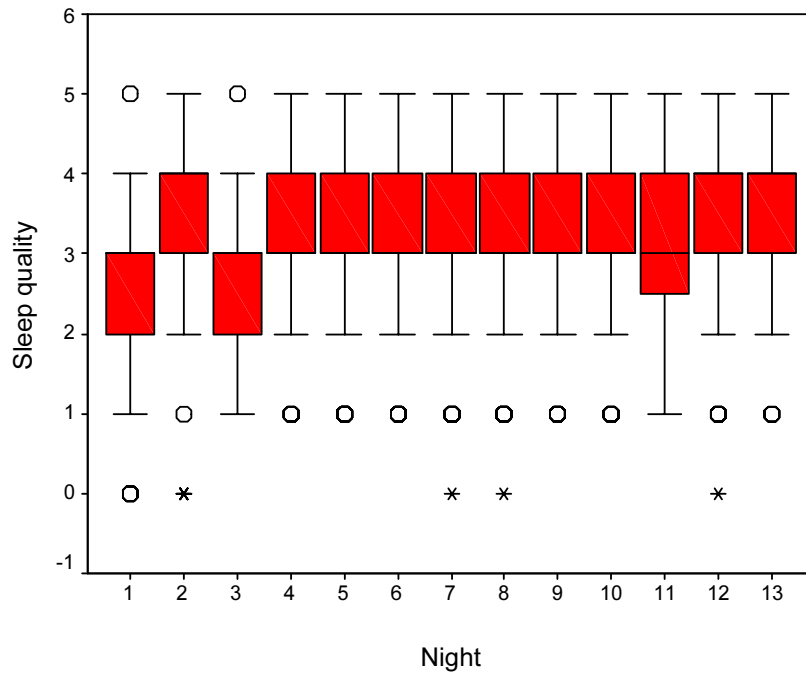


Figure 11: Box-plot of the experimental groups' (N = 112) sleep quality evaluation ("1 = not" to "5 = very") in the course of the sleep laboratory study.

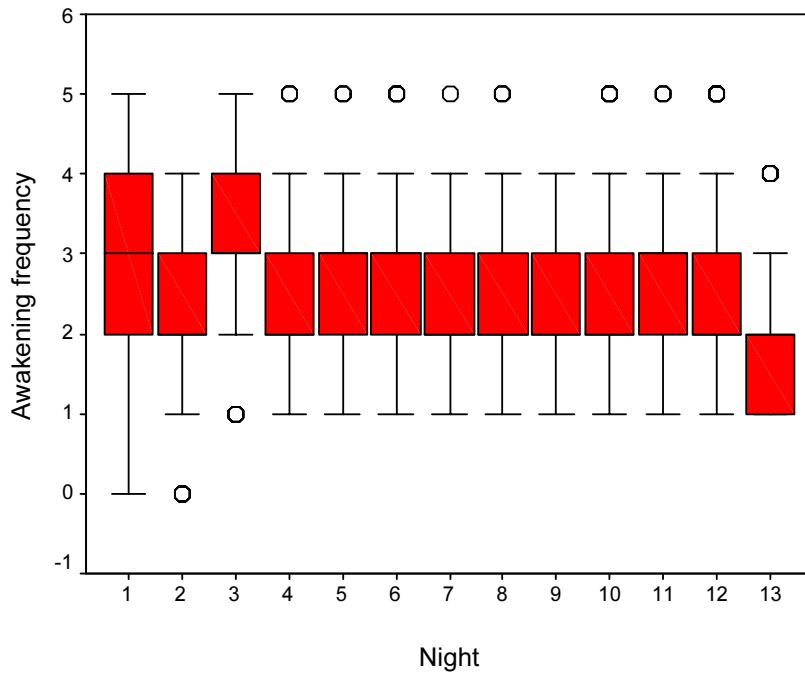


Figure 12: Box-plot of the experimental groups' (N = 112) awakening frequency evaluation ("1 = never" to "5 = always") in the course of the sleep laboratory study.

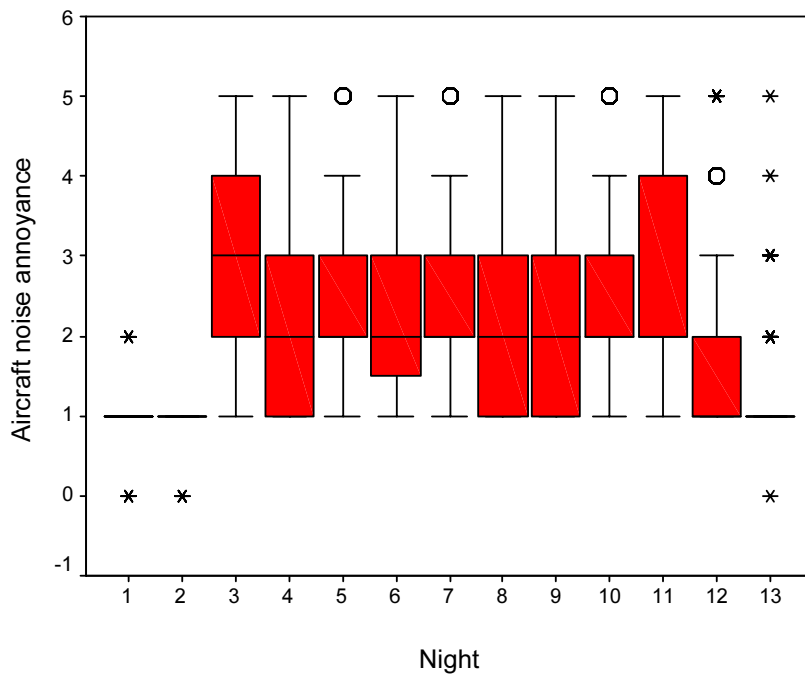


Figure 13: Box-plot of the experimental groups' (N = 112) aircraft noise annoyance evaluation ("1 = not" to "5 = very") in the course of the sleep laboratory study.

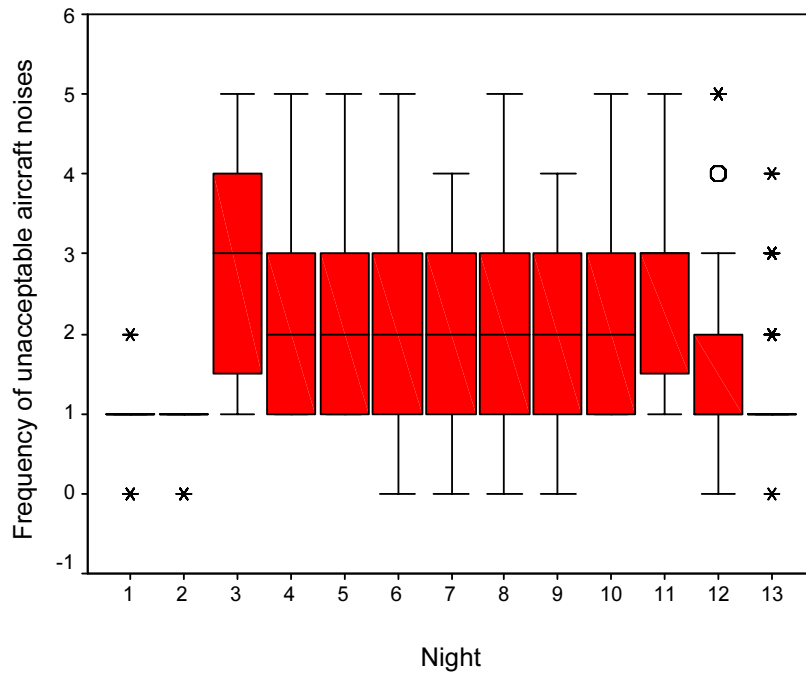


Figure 14: Box-plot of the experimental groups' (N = 112) evaluation of the frequency of unacceptable aircraft noises ("1 = never" to "5 = always") in the course of the sleep laboratory study.

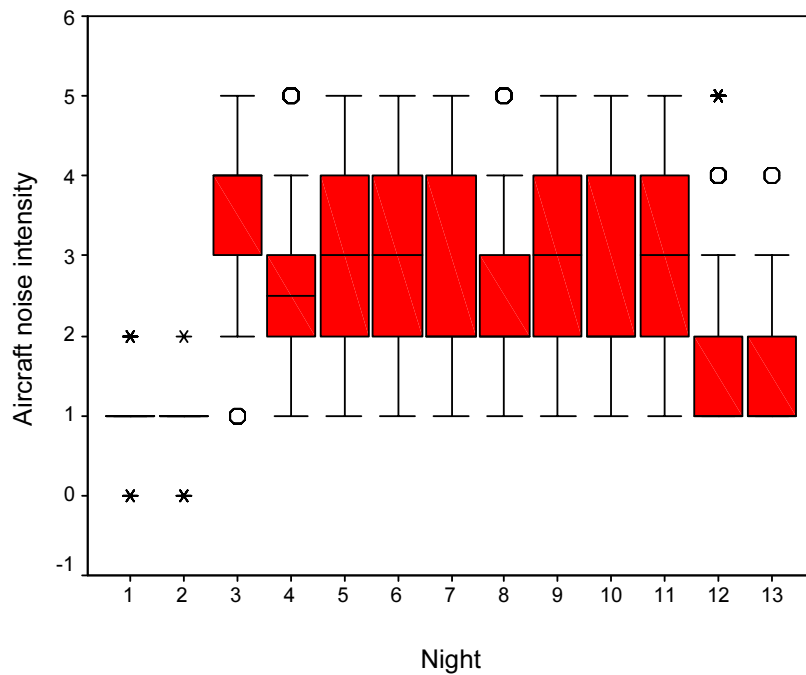


Figure 15: Box-plot of the experimental groups' (N = 112) aircraft noise intensity evaluation ("1 = not" to "5 = very") in the course of the sleep laboratory study.

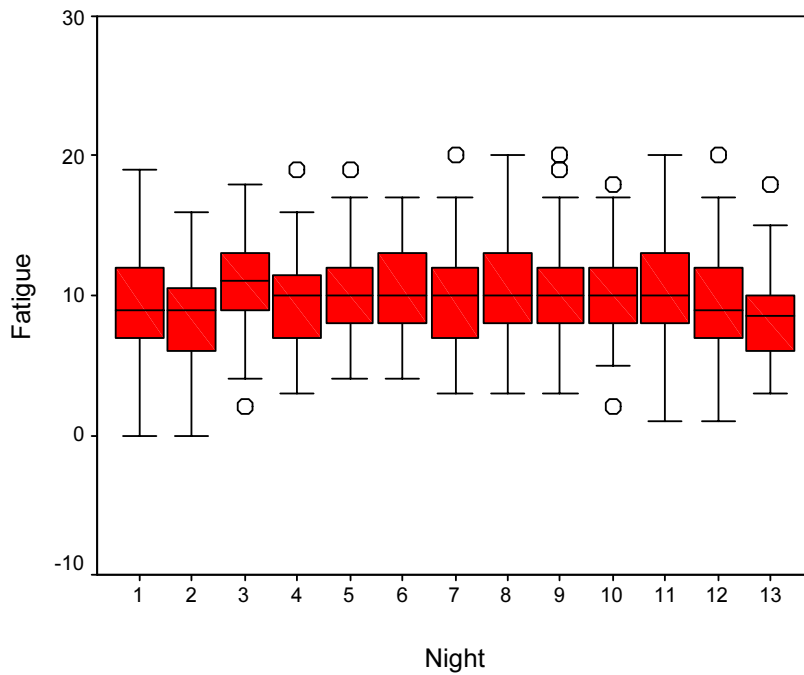


Figure 16: Box-plot of the experimental groups' (N = 112) fatigue evaluation ("0 = wide awake" to "20 = extremely tired") in the course of the sleep laboratory study.

#### 1.8.2.2.2 Physical aircraft noise parameters

For the derivation of *dose-response curves*, the hypothesis, that an *increasing nocturnal aircraft noise exposure* (operationalized by means of the independent variables  $L_{AS,max}$ ,  $L_{AS,eq}$  and level frequency) leads to:

- *reduction of the sleep quality and sleep quantity,*
- *increase of annoyance, fatigue, awakening frequency, rated aircraft noise exposure, i.e., aircraft noise intensity, and frequency of unacceptable aircraft noises*

was verified by means of inferential statistics.

Kruskal-Wallis one-way analysis of variance shows *significant main effects for the three aircraft noise parameters with regard to all analyzed secondary reactions* of the experimental groups (table 6).

		QN	QL	AW	STÄ	BEL	UNZ	FAT
<b>L<sub>AS,max</sub></b>	Chi-Quadrat	27.143	31.367	40.886	341.559	255.718	205.762	26.787
	Df	8	8	8	8	8	8	8
	Asymptotic Sign.	.001*	.000**	.000**	.000**	.000**	.000**	.001*
<b>L<sub>AS,eq</sub></b>	Chi-Quadrat	47.619	71.684	91.478	446.633	363.147	302.643	42.785
	Df	9	9	9	9	9	9	9
	Asymptotic Sign.	.000**	.000**	.000**	.000**	.000**	.000**	.000**
<b>Level frequency</b>	Chi-Quadrat	42.841	56.103	82.898	309.940	242.506	207.218	46.872
	Df	6	6	6	6	6	6	6
	Asymptotic Sign.	.000**	.000**	.000**	.000**	.000**	.000**	.000**

Table 6: Results of Kruskal-Wallis one-way analysis of variance regarding the influence of L<sub>AS,max</sub>, L<sub>AS,eq</sub> und level frequency on the experimental groups' secondary reactions (N = 112). According to the Bonferoni correction ( $\alpha/3 = .016$ ) significant (\*) and very significant differences (\*\*) are denoted (abbreviations: QN = sleep quantity, QL = sleep quality, AW = awakening frequency, STÄ = aircraft noise intensity, BEL = annoyance, UNZ = frequency of unacceptable aircraft noises, FAT = fatigue).

Single comparisons of the treatment categories of the physical variables were conducted by means of Mann-Whitney U-test:

Table 7 summarizes all *significant* results of the U-test for the paired comparisons of *level frequencies* (N = 6) with regard to all secondary reactions. Tables of the non-significant comparisons, as well as of the results regarding the comparison of the baseline night with all treatment categories of the independent variables, are refrained from. The subjective *sleep quantity* only has significantly higher scale values comparing 4 aircraft noise events per night with 64 events. The baseline night differs significantly from all level frequencies with  $n > 4$ . With regard to the assessed *sleep quality*, the two lowest level frequency categories  $n = 4$  and  $n = 8$  exhibit significantly higher measurement values in comparison with the treatment levels above  $n = 16$  (only exception: 8 and 16 events per night do not differ significantly). The quiet condition of the baseline night differs significantly compared to categories with  $n \geq 32$ . The rated *awakening frequency* is significantly lower for  $n = 4$  or 8 aircrafts per night than for all level frequencies with  $n \geq 16$ . However, 8 and 16 events per night do not differ again randomly. Furthermore, 16 aircraft noise events lead to significantly less awakenings than 128 events. The quiet condition differs significantly from all number of events categories with  $n \geq 16$ . The *aircraft noise intensity* is sig-

nificantly less pronounced for 4 aircrafts per night than for all other frequencies. In addition to this, 8 aircraft noise events are experienced as significantly less intense than 128 events. The noise-free night differs significantly from all level frequencies with  $n \geq 8$ . The *annoyance* due to aircraft noise has a significantly smaller effect for 4 aircrafts per night than for 32, 64 or 128 events. The same applies to the comparison of 8 with 64 or 128 aircraft events. Finally, there is a significant difference between 16 and 128 aircrafts per night. In comparison to all level frequencies with  $n \geq 8$ , the baseline night has significantly lower scale values. Regarding the estimated *frequency of unacceptable aircraft noises*, 4 events per night exhibit significantly lower measurement values than all other treatment categories. Furthermore, 8 aircraft events differ significantly from 128 events per night. Compared to the baseline night, the same results as for the annoyance occur. Concerning *fatigue*, 4 aircraft events differ from 32, 64 and 128 aircrafts per night. There are significant differences between the quiet condition and all level frequencies of  $n > 4$ .

Paired comparison Level frequency		QN	QL	AW	STÄ	BEL	UNZ	FAT
Mean Rank	<b>4</b>	213.89	211.86	192.08	183.82	193.12	185.46	196.79
	<b>8</b>	192.69	194.80	215.37	223.97	214.30	222.27	210.48
Z		-2.027	-1.565	-2.173	-3.615	-1.888	-3.327	-1.182
Asymptotic Sign.		.043	.118	.030	.000**	.059	.001*	.237
Mean Rank	<b>4</b>	209.03	216.42	181.76	176.91	185.41	175.93	196.79
	<b>16</b>	189.17	181.17	218.73	223.99	214.77	225.05	210.48
Z		-1.898	-3.256	-3.444	-4.276	-2.643	-4.464	-1.958
Asymptotic Sign.		.058	.001*	.001*	.000**	.008	.000**	.050
Mean Rank	<b>4</b>	197.31	206.36	158.48	159.00	163.07	162.23	166.41
	<b>32</b>	166.78	155.07	217.02	216.34	211.08	212.17	206.75
Z		-3.001	-4.857	-5.557	-5.332	-4.448	-4.681	-3.628
Asymptotic Sign.		.003	.000**	.000**	.000**	.000**	.000**	.000**
Mean Rank	<b>4</b>	217.64	221.64	168.40	167.78	170.25	166.65	176.50
	<b>64</b>	171.65	167.15	227.05	227.75	224.97	229.01	217.93
Z		-4.359	-5.042	-5.442	-5.426	-4.930	-5.665	-3.634
Asymptotic Sign.		.000**	.000**	.000**	.000**	.000**	.000**	.000**
Mean Rank	<b>4</b>	142.95	147.04	122.53	122.82	124.01	123.61	126.78
	<b>128</b>	113.52	100.28	179.56	178.63	174.77	176.08	165.82
Z		-2.886	-4.422	-5.460	-5.180	-4.679	-4.915	-3.499
Asymptotic Sign.		.004	.000**	.000**	.000**	.000**	.000**	.000**
Mean Rank	<b>8</b>	185.97	196.05	161.47	169.34	166.81	170.86	166.60
	<b>32</b>	172.57	160.04	203.04	193.26	196.41	191.37	196.67
Z		-1.348	-3.454	-3.993	-2.261	-2.781	-1.930	-2.741
Asymptotic Sign.		.178	.001*	.000**	.024	.005	.054	.006
Mean Rank	<b>8</b>	206.09	210.36	172.99	180.40	174.77	176.29	177.19
	<b>64</b>	176.77	172.14	212.56	204.55	210.64	208.99	208.01
Z		-2.841	-3.577	-3.710	-2.216	-3.272	-2.983	-2.735
Asymptotic Sign.		.005	.000**	.000**	.027	.001*	.003	.006
Mean Rank	<b>8</b>	136.34	140.69	121.31	123.92	122.54	124.20	124.23
	<b>128</b>	118.51	104.97	165.23	157.12	161.42	156.25	156.16
Z		-1.804	-3.455	-4.293	-3.170	-3.673	-3.040	-2.935
Asymptotic Sign.		.071	.001*	.000**	.002*	.000**	.002*	.003
Mean Rank	<b>16</b>	132.02	134.12	120.09	120.50	119.89	122.40	122.22
	<b>128</b>	116.00	109.75	151.61	150.39	152.21	144.72	145.26
Z		-1.634	-2.422	-3.131	-2.929	-3.140	-2.166	-2.174
Asymptotic Sign.		.102	.015	.002*	.003	.002*	.030	.030

Table 7: Significant results of Mann-Whitney U-test (test statistic Z) regarding the comparison between level frequencies (N = 6). According to the Bonferoni correction ( $\alpha/21 = .002$ ) significant (\*) and very significant differences (\*\*) are denoted (abbreviations: QN = sleep quantity, QL = sleep quality, AW = awakening frequency, STÄ = aircraft noise intensity, BEL = annoyance, UNZ = frequency of unacceptable aircraft noises, FAT = fatigue).

Table 8 depicts the *significant* results of the U-test for the paired comparisons of the *maximum noise levels* (N = 8) with regard to all secondary reactions. It is also refrained from illustrating the comparison of the baseline night with all treatment categories of the aircraft noise parameter, as well as the non significant paired comparisons. The assessments of the *sleep*

*quantity* do not differ significantly within the level categories of the  $L_{AS,max}$ . Merely the baseline night exhibits significantly lower scale values concerning maximum noise levels  $\geq 60$  dB(A). Similar results apply to the *sleep quality*, whereas the quiet condition differs significantly from levels above 65 dB(A). Concerning *awakening frequency*, the level category 45 dB(A) has significantly lower measurement values than 70 dB(A). Regarding differences to the baseline night, the same results as for the sleep quantity can be observed. With respect to the rating of the *aircraft noise intensity*, 50 dB(A) as well as 60 dB(A) differ significantly less from all level categories above 70 dB(A). The treatment category 55 dB(A) is also significantly different from maximum noise levels above 65 dB(A). Differences in the quiet condition occur in the paired comparisons for levels above 55 dB(A). 45 dB(A) and 55 dB(A) have a significantly smaller annoyance effect compared to maximum noise levels above 65 dB(A). The treatment category 50 dB(A) differs significantly from all  $L_{AS,max}$  above 70 dB(A). Additionally, 60 dB(A) and 80 dB(A) are significantly different in their *annoying impact*. Concerning comparisons with the baseline night, the same results as for aircraft noise intensity occur. This also applies to the ratings of the *frequency of unacceptable aircraft noises*. Based on the paired comparison of the categories of the  $L_{AS,max}$ , significantly lower measurement values can be observed for 50 dB(A) and 55 dB(A) in comparison to the maximum noise levels 70 dB(A) and 75 dB(A). The  $L_{AS,max} = 45$  dB(A) also differs significantly from all levels above 65 dB(A). The same results as for the sleep quantity apply to the degree of *fatigue*, i.e., no significant differences exist.

Paired comparison LAS <sub>max</sub>		QN	QL	AW	STÄ	BEL	UNZ	FAT
Mean Rank	<b>45</b>	89.45	96.05	61.94	55.95	64.08	64.89	71.23
	<b>50</b>	78.26	76.61	85.14	86.64	84.61	84.40	82.82
	Z	-1.313	-2.244	-2.705	-3.537	-2.342	-2.263	-1.271
Asymptotic Sign.		.189	.025	.007	.000**	.019	.024	.204
Mean Rank	<b>45</b>	114.70	121.20	83.31	69.41	75.89	75.55	91.92
	<b>60</b>	102.64	101.46	108.35	110.88	109.70	109.76	106.79
	Z	-1.147	-1.821	-2.274	-3.780	-3.050	-3.089	-1.291
Asymptotic Sign.		.251	.069	.023	.000**	.002	.002	.197
Mean Rank	<b>45</b>	123.03	133.58	82.28	61.95	69.88	71.20	92.92
	<b>65</b>	105.97	104.14	113.06	116.60	115.22	114.99	111.21
	Z	-1.562	-2.622	-2.702	-4.741	-3.912	-3.785	-1.535
Asymptotic Sign.		.118	.009	.007	.000**	.000**	.000**	.125
Mean Rank	<b>45</b>	92.64	99.50	58.00	41.52	49.89	49.23	73.80
	<b>70</b>	77.46	75.75	86.13	90.25	88.15	88.32	82.18
	Z	-1.824	-2.749	-3.248	-5.511	-4.309	-4.416	-.920
Asymptotic Sign.		.068	.006	.001*	.000**	.000**	.000**	.358
Mean Rank	<b>45</b>	72.98	78.95	48.89	35.08	39.52	39.08	54.30
	<b>75</b>	61.67	59.68	69.70	74.31	72.83	72.97	67.90
	Z	-1.612	-2.718	-2.965	-5.346	-4.542	-4.639	-1.805
Asymptotic Sign.		.107	.007	.003	.000**	.000**	.000**	.071
Mean Rank	<b>45</b>	48.41	52.06	35.19	25.80	28.44	30.94	40.30
	<b>80</b>	40.59	38.43	48.43	53.99	52.43	50.94	45.40
	Z	-1.531	-2.614	-2.601	-5.248	-4.428	-3.753	-.922
Asymptotic Sign.		.126	.009	.009	.000**	.000**	.000**	.357
Mean Rank	<b>50</b>	130.82	130.86	123.57	110.62	114.24	113.02	131.04
	<b>70</b>	126.18	126.14	133.43	146.38	142.76	143.98	125.96
	Z	-.546	-.538	-1.130	-4.012	-3.177	-3.466	-.552
Asymptotic Sign.		.585	.591	.259	.000**	.001*	.001*	.581
Mean Rank	<b>50</b>	114.11	114.91	111.13	97.89	99.64	99.91	109.46
	<b>75</b>	110.36	109.29	114.32	131.98	129.64	129.29	116.55
	Z	-.460	-.679	-.391	-4.038	-3.538	-3.476	-.814
Asymptotic Sign.		.645	.497	.696	.000**	.000**	.001*	.416
Mean Rank	<b>50</b>	92.32	92.80	91.84	81.64	82.89	86.30	92.28
	<b>80</b>	89.55	88.43	90.70	114.86	111.92	103.82	89.65
	Z	-.351	-.539	-.143	-4.039	-3.498	-2.135	-.309
Asymptotic Sign.		.726	.590	.886	.000**	.000**	.033	.757
Mean Rank	<b>55</b>	204.36	210.98	184.74	172.98	175.77	182.00	187.37
	<b>65</b>	186.60	179.15	208.67	221.90	218.76	211.75	205.70
	Z	-1.701	-2.939	-2.210	-4.450	-3.891	-2.698	-1.608
Asymptotic Sign.		.089	.003	.027	.000**	.000**	.007	.108
Mean Rank	<b>55</b>	175.93	179.95	156.41	144.45	150.13	152.68	165.92
	<b>70</b>	155.17	148.68	186.75	206.08	196.90	192.78	171.37
	Z	-2.091	-3.030	-2.957	-5.886	-4.451	-3.817	-.503
Asymptotic Sign.		.036	.002	.003	.000**	.000**	.000**	.615

Table 8: Significant results of Mann-Whitney U-test (test statistic Z) regarding the comparison between LAS<sub>max</sub> (N = 8). According to the Bonferoni correction ( $\alpha/37 = .001$ ) significant (\*) and very significant differences (\*\*) are denoted (abbreviations: QN = sleep quantity, QL = sleep quality, AW = awakening frequency, STÄ = aircraft noise intensity, BEL = annoyance, UNZ = frequency of unacceptable aircraft noises, FAT = fatigue).

Paired comparison LAS,max		QN	QL	AW	STÄ	BEL	UNZ	FAT
Mean Rank	<b>55</b>	157.46	161.37	144.98	133.31	136.33	139.25	145.40
	<b>75</b>	140.23	131.80	167.15	192.30	185.79	179.48	166.22
Z		-1.735	-2.887	-2.196	-5.666	-4.744	-3.869	-1.933
Asymptotic Sign.		.083	.004	.028	.000**	.000**	.000**	.053
Mean Rank	<b>55</b>	134.10	136.45	127.83	118.93	120.96	125.81	129.66
	<b>80</b>	119.13	110.12	143.15	177.27	169.49	150.91	136.14
Z		-1.423	-2.412	-1.427	-5.273	-4.366	-2.272	-.565
Asymptotic Sign.		.155	.016	.154	.000**	.000**	.023	.572
Mean Rank	<b>60</b>	157.63	158.90	146.48	136.73	141.28	140.10	155.32
	<b>70</b>	145.45	143.70	160.78	174.19	167.93	169.55	148.63
Z		-1.316	-1.577	-1.471	-3.818	-2.698	-2.984	-.657
Asymptotic Sign.		.188	.115	.141	.000**	.007	.003	.511
Mean Rank	<b>60</b>	139.93	141.79	133.84	123.35	125.85	126.47	133.41
	<b>75</b>	130.22	126.80	141.37	160.61	156.02	154.89	142.17
Z		-1.063	-1.596	-.796	-3.881	-3.128	-2.954	-.882
Asymptotic Sign.		.288	.111	.426	.000**	.002	.003	.378
Mean Rank	<b>60</b>	117.39	118.57	115.03	106.44	107.96	111.86	116.25
	<b>80</b>	109.32	105.48	117.02	145.02	140.06	127.38	113.06
Z		-.859	-1.343	-.202	-3.887	-3.204	-1.559	-.309
Asymptotic Sign.		.390	.179	.840	.000**	.001*	.119	.758

Continuation of table 8

Table 9 illustrates the *significant* results of the U-test for paired comparisons of the *energy equivalent noise levels* (N = 9) with regard to all secondary reactions. Concerning the assessed *sleep quantity*, merely the category  $\leq 33$  dB(A) differs significantly from  $\leq 45$ , 48 and 51 dB(A) within the level categories of the LAS,eq. In comparison to the baseline night, significant differences appear for levels above 39 dB(A). The latter also applies to the *sleep quality*. Additionally, with regard to the evaluation of the sleep quality,  $\leq 33$  dB(A) differs significantly from  $\leq 39$ , 42, 45, 48 and 51 dB(A), as well as  $\leq 36$  dB(A) from  $\leq 48$  dB(A). With respect to the perceived *awakening frequency*, the category  $\leq 33$  dB(A) also exhibits significantly lower scale values than  $\leq 36$ , 39, 42, 45, 48 and 51 dB(A). The category  $\leq 36$  dB(A) differs significantly from  $\leq 45$  dB(A). Significant differences between the quiet condition and the treatment categories of the LAS,eq occur above 36 dB(A). The *aircraft noise intensity* is perceived as significantly less intense for  $\leq 33$  dB(A) than for all higher categories of the LAS,eq. The category  $\leq 36$  dB(A) is significantly different from  $\leq 39$ , 42, 45, 48 and 51 dB(A), as well as  $\leq 39$  dB(A) differs from  $\leq 51$  dB(A). In the paired comparison with the quiet condition, the same findings as for the awakening frequency result.  $\leq 33$  dB(A)

has a significantly smaller *annoyance* effect than  $\leq 36, 39, 42, 45, 48, 51$  and  $54$  dB(A). The same applies to  $\leq 36$  dB(A) with regard to  $\leq 42, 45, 48$  and  $51$  dB(A), and to  $\leq 39$  dB(A) compared to  $\leq 48$  dB(A). In comparison to the baseline night, the same differences that apply to the awakening frequency and the aircraft noise intensity occur. This also concerns the judgement of the *frequency of unacceptable aircraft noises*. The category  $\leq 33$  dB(A) has significantly lower scale values than  $\leq 36, 39, 42, 45, 48, 51$  and  $54$  dB(A), as does the category  $\leq 36$  dB(A) in comparison to  $\leq 45, 48$  and  $51$  dB(A). Finally, there is a significant difference between  $\leq 39$  dB(A) and  $\leq 51$  dB(A). Concerning *fatigue*, there are no significant differences between the individual categories of the energy equivalent noise level. Merely the quiet condition differs from all categories above  $39$  dB(A).

Paired comparison LAS,eq	QN	QL	AW	STÄ	BEL	UNZ	FAT
Mean Rank $\leq 33$	218.65	229.72	198.28	183.78	186.43	189.32	212.13
$\leq 36$	213.15	201.29	235.00	250.54	247.70	244.61	220.15
Z	-.506	-2.541	-3.276	-5.973	-5.403	-4.912	-.672
Asymptotic Sign.	.613	.011	.001*	.000**	.000**	.000**	.502
Mean Rank $\leq 33$	184.69	193.38	157.61	142.09	147.77	152.70	164.38
$\leq 39$	160.86	145.72	208.05	235.09	225.18	216.59	196.24
Z	-2.331	-4.495	-4.815	-8.792	-7.236	-6.052	-2.845
Asymptotic Sign.	.020	.000**	.000**	.000**	.000**	.000**	.004
Mean Rank $\leq 33$	175.43	184.05	153.68	138.71	138.24	145.90	156.77
$\leq 42$	153.21	136.04	196.51	226.32	227.25	212.00	190.35
Z	-2.189	-4.583	-4.108	-8.268	-8.342	-6.272	-3.010
Asymptotic Sign.	.029	.000**	.000**	.000**	.000**	.000**	.003
Mean Rank $\leq 33$	185.78	190.76	149.25	134.56	137.79	138.06	159.60
$\leq 45$	146.39	137.15	214.27	241.58	235.57	235.07	195.05
Z	-3.859	-5.089	-6.165	-10.061	-9.116	-9.092	-3.174
Asymptotic Sign.	.000**	.000**	.000**	.000**	.000**	.000**	.002
Mean Rank $\leq 33$	170.29	179.36	141.33	129.00	129.01	132.74	150.46
$\leq 48$	136.10	115.04	203.37	232.02	231.99	223.33	182.17
Z	-3.343	-6.084	-5.916	-9.637	-9.546	-8.493	-2.832
Asymptotic Sign.	.001*	.000**	.000**	.000**	.000**	.000**	.005
Mean Rank $\leq 33$	156.56	160.18	132.86	122.49	125.49	125.79	141.97
$\leq 51$	119.06	107.68	193.47	226.06	216.64	215.70	164.86
Z	-3.578	-4.851	-5.612	-9.454	-8.278	-8.228	-1.987
Asymptotic Sign.	.000**	.000**	.000**	.000**	.000**	.000**	.047
Mean Rank $\leq 33$	129.57	131.63	123.36	118.17	119.13	119.11	124.98
$\leq 54$	112.58	97.79	157.29	194.63	187.74	187.84	145.61
Z	-1.335	-2.576	-2.621	-5.880	-5.210	-5.292	-1.473
Asymptotic Sign.	.182	.010	.009	.000**	.000**	.000**	.141
Mean Rank $\leq 33$	121.27	121.27	118.70	115.70	117.51	117.78	120.70
$\leq 57$	102.28	102.34	138.09	179.91	154.69	150.94	110.28
Z	-1.181	-1.141	-1.186	-3.923	-2.243	-2.036	-.586
Asymptotic Sign.	.237	.254	.236	.000**	.025	.042	.558
Mean Rank $\leq 36$	175.13	177.53	161.08	153.77	157.76	161.65	159.76
$\leq 39$	157.72	153.82	180.56	192.43	185.95	179.63	182.70
Z	-1.736	-2.292	-1.886	-3.720	-2.683	-1.713	-2.112
Asymptotic Sign.	.083	.022	.059	.000**	.007	.087	.035
Mean Rank $\leq 36$	166.11	168.86	155.98	147.46	146.62	152.40	151.76
$\leq 42$	150.08	144.98	168.90	184.71	186.28	175.54	176.74
Z	-1.613	-2.342	-1.260	-3.591	-3.807	-2.215	-2.315
Asymptotic Sign.	.107	.019	.208	.000**	.000**	.027	.021
Mean Rank $\leq 36$	176.10	175.25	151.87	143.52	145.95	145.31	155.05
$\leq 45$	144.39	145.88	186.40	200.87	196.65	197.77	180.88
Z	-3.170	-2.862	-3.338	-5.508	-4.836	-4.991	-2.387
Asymptotic Sign.	.002	.004	.001*	.000**	.000**	.000**	.017

Table 9: Significant results of Mann-Whitney U-test (test statistic Z) regarding the comparison between LAS,eq (N = 9). According to the Bonferoni correction ( $\alpha/45 = .001$ ) significant (\*) and very significant differences (\*\*) are denoted (abbreviations: QN = sleep quantity, QL = sleep quality, AW = awakening frequency, STÄ = aircraft noise intensity, BEL = annoyance, UNZ = frequency of unacceptable aircraft noises, FAT = fatigue).

Paired comparison LAS <sub>eq</sub>	QN	QL	AW	STÄ	BEL	UNZ	FAT
Mean Rank ≤ 36	161.02	165.36	142.53	132.47	133.17	136.65	145.14
≤ 48	134.04	124.64	174.10	195.91	194.38	186.84	168.45
Z	-2.702	-3.970	-3.076	-6.085	-5.825	-4.785	-2.160
Asymptotic Sign.	.007	.000**	.002	.000**	.000**	.000**	.031
Mean Rank ≤ 36	147.70	147.79	131.73	123.68	126.69	126.54	136.04
≤ 51	117.45	117.17	164.23	187.82	178.98	179.42	151.61
Z	-2.971	-2.934	-3.091	-6.028	-4.885	-4.932	-1.411
Asymptotic Sign.	.003	.003	.002	.000**	.000**	.000**	.158
Mean Rank ≤ 39	116.07	117.88	108.30	101.31	100.60	101.50	111.88
≤ 48	107.74	105.33	118.10	127.42	128.36	127.17	113.32
Z	-1.041	-1.514	-1.185	-3.088	-3.263	-3.027	-.165
Asymptotic Sign.	.298	.130	.236	.002	.001*	.002	.869
Mean Rank ≤ 39	103.91	102.13	95.91	90.68	92.31	90.06	101.29
≤ 51	92.95	96.17	107.37	116.80	113.87	117.92	97.68
Z	-1.409	-.738	-1.419	-3.178	-2.605	-3.370	-.424
Asymptotic Sign.	.159	.461	.156	.001*	.009	.001*	.671

Continuation of table 9

In order to illustrate the analyses, the dispersion of the annoyance rating of the experimental groups depending on the number of aircraft noise events, the maximum noise level as well as to the energy equivalent noise level, will be exemplarily shown in the following. Obviously, the control night without noise exposure has no annoying impact. Figure 17 reveals that the annoyance increases with rising level frequencies, whereas three exposure categories can be descriptively differentiated: category 1 (slightest effect): 4 and 8 events/night, category 2 (medium effect): 16 events/night, category three (strongest effect): 32, 64 and 128 events/night. The disturbance effect does not differ within these three categories. A possible explanation for this is that the study does not have a complete multi-factorial design (cp. *chapter 1.6*). The dispersion of the smallest exposure category (upwards) is highest, with two scale categories compared to the other level frequencies (one-level spread). With regard to the annoyance effect of the maximum noise level, 4 effect categories can be descriptively determined (figure 18): category 1: 45 dB(A), category 2: 50 dB(A) and 55 dB(A), category 3: 60 dB(A) and 65 dB(A), and category 4: 70, 75, 80 dB(A). Within these categories the annoying influence does not differ, which is most likely also caused by the incomplete multi-factorial experimental design. The dispersion in the second category (upwards) is highest with two scale categories, compared

to the other maximum noise levels (one-level spread). Figure 19 also shows an increase of annoyance depending on rising aircraft noise exposure, which, however, decreases in the highest category, due to the unequal cell allocation of the experimental design. Category  $\leq 33$  dB(A) exhibits the smallest disturbance effect,  $\leq 36$  dB(A) and 39 dB(A) lie in the middle domain. The highest annoyance is seen in  $\leq 42$  dB(A) to 54 dB(A), whereas a differentiation between the individual categories is not possible. The dispersion of  $\leq 36$  dB(A), as well as of  $\leq 57$  dB(A) is (upwardly) highest with two scale categories, in comparison to the other categories (one-level spread).

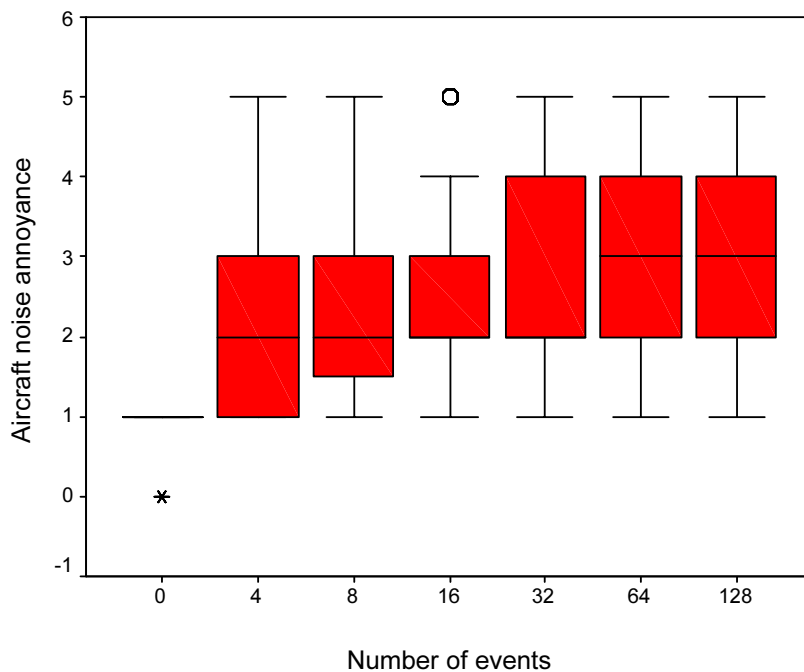


Figure 17: Box-plot of the experimental groups` (N = 112) annoyance rating depending on number of aircraft events (averaged over 8 level categories of the LAS,max).

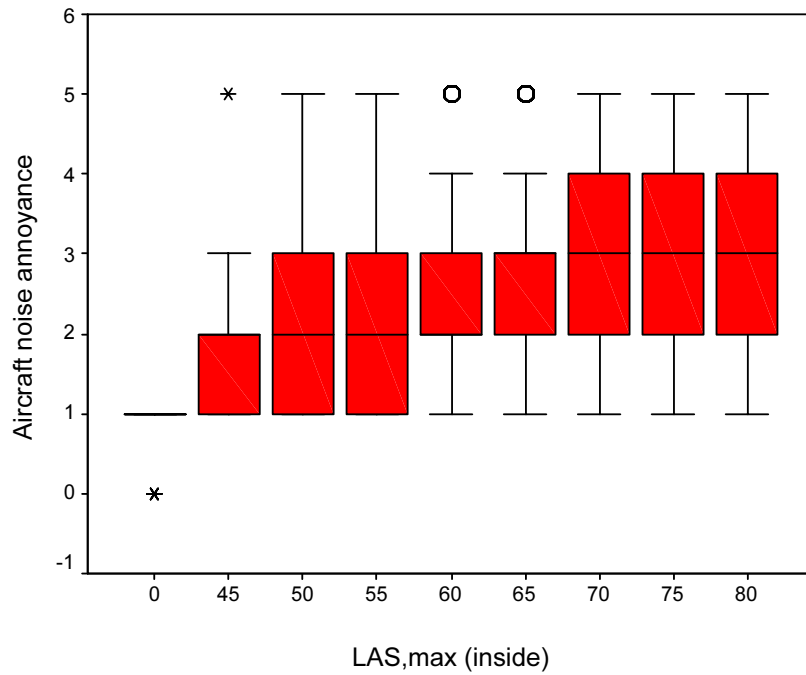


Figure 18: Box-plot of the experimental groups` (N = 112) annoyance rating depending on LAS,max (averaged over 6 level frequency categories).

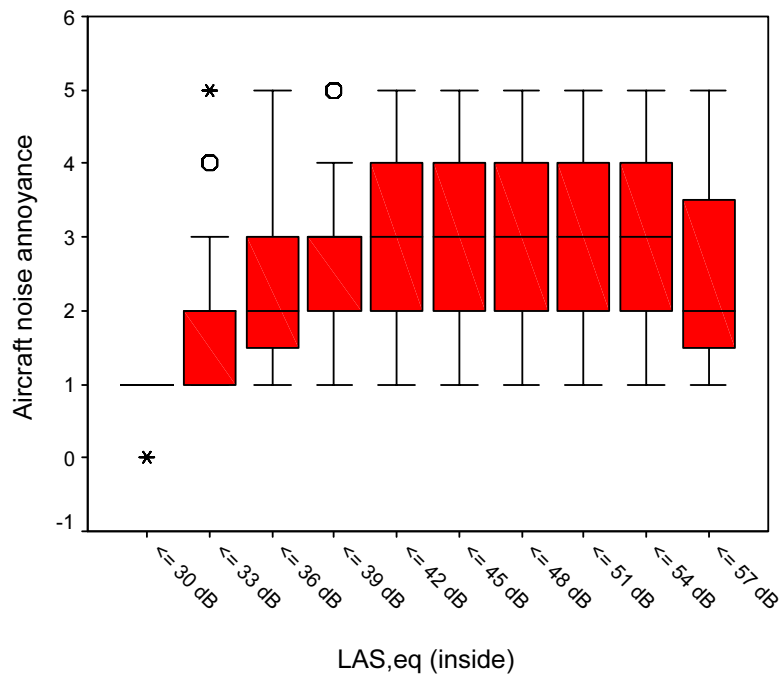


Figure 19: Box-plot of the experimental groups` (N = 112) annoyance rating depending on LAS,eq.

### 1.8.2.3 Dose-response curves

To what extent is there an interrelation between aircraft noise exposure and the perceived disturbance? From which level of aircraft noise exposure does this become relevant? These are questions concerning *dose-response relationships*, in which a secondary disturbance is conceptualized as the function of exposure. They also concern the *effect-threshold*, above which substantial psychological changes take place. In order to derive dose-response curves, the *logistic regression analysis* (LRA) has proven useful in noise effects research [e.g. Ollerhead et al. 1992]. The LRA is based on a mathematical model, which describes the relationships between different (e.g., physical and psychological) parameters on a dichotomous dependent variable.<sup>23</sup> A dichotomous dependent variable is a quantity that either takes place (1) or does not take place (0). The range of values of the logistic function  $f(z)$  lies between 0 and 1, which corresponds to a range of probability between 0% and 100%. In the present analysis, a *random effects logistic regression* was used.

Since *annoyance* is the *statistically most important psychological noise effect*, the LRA was limited to the examination of this parameter. For this purpose, it was necessary to convert the original 5-point annoyance judgments into a dichotomous dependent variable. Often in studies concerning noise annoyance, mainly the group of persons, who are distributed in the upper 25% to 30% of the answering scale (on a 5-point scale the categories 4 and 5) based on the Schultz criteria [1978], and are considered as "highly annoyed", is considered. The lower limit of this domain is internationally used as a minimum value for the individual high annoyance [e.g.

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<sup>23</sup>The variable  $z$  in the exponent of the e-function is an index that combines multiple parameters. In the model of the LRA it forms the linear sum of variables ( $U_k$ ) multiplied by coefficients ( $\beta_k$ ) and a constant ( $\alpha$ ):  $z = \alpha + \beta_1 U_1 + \beta_2 U_2 + \dots + \beta_k U_k$

The terms  $\alpha$  and  $\beta$  are unknown parameters, that are estimated by the LRA on the basis of the existing measurement data by means of the Maximum-Likelihood-Method. After this estimation, the  $z$ -term can be calculated for a specific combination of variables and be placed into the logistic function. If  $z = 0$ , then the probability of the occurrence of the examined event constitutes 50%. For positive  $z$  the probability is higher than 50%, while for negative  $z$  it is lower than 50% and it asymptotically approaches the values 1 and 0 respectively.

Fidell et al. 1991; Miedema & Vos 1998; Schultz 1978]. Limiting the number of people, who are highly annoyed by aircraft noise has the disadvantage that the (quantitatively also important) number of persons, whose noise annoyance lies in the middle of the answering scale, is ignored. Data from the regularly conducted surveys by the Federal Environmental Agency, shows that the number of highly annoyed persons does not change noteworthy, while there is a considerable increase of “not so highly” annoyed persons [Ortscheid 2001]. In order to take into account the range of “medium” annoyance and based on the fact that only 20% of all annoyance ratings are distributed among the categories 4 and 5 (figure 7 in *chapter 1.8.2.1*), the categories 3, 4 and 5 were combined (value = 1, i.e., existence of aircraft noise annoyance) for the generation of a dichotomous dependent variable, whereas the categories 1 and 2 indicated the non-existence of aircraft noise annoyance (value = 0). Ahead of the actual LRA, the interrelation between independent physical and psychological moderator variables and aircraft noise annoyance was descriptively tested in order to show possible interactions. It could then be decided, which parameters should be included in the final regression models. At this point, a detailed description of these very extensive results will be refrained from. Based on the conducted pre-analysis, and under consideration of literature, the following variables were integrated in the modelling:

#### **a) Physical parameters**

- *number of aircraft noise events per night* (level frequency)
- *maximum noise level of a flight event*  $L_{AS,max}$
- *energy equivalent noise level*  $L_{AS,eq}$

#### **b) Psychological parameters**

- **personal moderators:** *pre-annoyance due to aircraft noise, noise sensitivity, adaptation to aircraft noise, age, gender*

- **social moderators:** assessed *health hazard, necessity and avoidability of air traffic, health hazard caused by aircraft noise, general attitude towards air traffic*

In literature, the energy equivalent noise level, as well as the maximum noise level combined with the number of aircraft noise events, are seen as valid physical indicators for the prediction of aircraft noise annoyance (cp. *chapter 1.4.1*). Correspondingly, two logistic regression models were developed. With the exception of age and gender all moderators were included as continuous variables into the models even though they were partially measured on an ordinal scale level. In descriptive analysis, it was examined whether the assumption of linearity on the logit scale was valid. To begin the iterative modelling process, the single effects of the physical and psychological parameters with respect to the dichotomous annoyance variable were tested by means of the LRA. All parameters proved to be individually statistically significant ( $p \leq .050$ ). In the next step, quadratic terms were formed for all physical factors, and their significance was tested together with the non-quadratic parameters. Similar as the linear regression that postulates a linear relationship between independent and dependent variable, the logistic regression assumes linearity referring to the logit scale. In addition to the descriptive linearity analysis described above, the possibility of a non-linear relationship was tested statistically by the addition of a quadratic term into the regression equation. In the case of a non-linear relationship, both the variable and its quadratic form remain in the model. Thereby, solely the  $L_{AS,eq}^2$  is significant. In both models, all listed moderators were integrated and tested for significance. Non-significant parameters were excluded and the remaining were retested. This was continued until all variables proved to be significant. *In both regression models (model L1: number of events and  $L_{AS,max}$  and model L2:  $L_{AS,eq}$  and  $L_{AS,eq}^2$ ), the moderators gender, pre-annoyance due to aircraft noise and the rated "necessity of air traffic" remained (tables 10 and 11).*

	<b>Value</b>	<b>DF</b>	
<b>Deviance</b>	1037,8918	998	
<b>Parameter Estimates</b>			
	<b>Coefficient</b>	<b>Std.error</b>	<b>p-value</b>
<b>Intercept</b>	-8,5058	1,2173	< 0,001
<b>Number of events</b>	0,0314	0,0033	< 0,001
<b>LAS,max</b>	0,1349	0,0124	< 0,001
<b>Gender (1 = male)</b>	-0,8370	0,3271	0,0105
<b>Pre-annoyance</b>	0,5710	0,1529	< 0,001
<b>Necessity of air traffic</b>	-0,5088	0,1933	0,0085
<b>Variance component random effects</b>	1,4189	0,1589	

Table 10: Logistic regression model L1 with regard to the aircraft noise parameters number of events and maximum noise level  $L_{AS,max}$  as well as significant psychological moderators ( $p \leq .050$ ).

	<b>Value</b>	<b>DF</b>	
<b>Deviance</b>	1021,4068	998	
<b>Parameter Estimates</b>			
	<b>Coefficient</b>	<b>Std.error</b>	<b>p-value</b>
<b>Intercept</b>	-29,6899	3,9553	< 0,001
<b>LAS,eq</b>	1,3740	0,1886	< 0,001
<b>LAS,eq x LAS,eq</b>	-0,0148	0,0023	< 0,001
<b>Gender (1 = male)</b>	-0,7976	0,3420	0,0197
<b>Pre-annoyance</b>	0,5814	0,1613	< 0,001
<b>Necessity of air traffic</b>	-0,5258	0,2046	0,0102
<b>Variance compon. random effects</b>	1,4757	0,1638	

Table 11: Logistic regression model L2 with regard to the aircraft noise parameter energy equivalent noise level  $L_{AS,eq}$  and significant psychological moderators ( $p \leq .050$ ).

The quality of both models is measured by the ratio value/degree of freedom DF, which constitutes 1.04 in model 1 and 1.02 in model 2. This is an indicator for very good fit ( $\leq 1.00$ ), i.e., the regression models represent the data very good.

Figure 20 shows the percentage of people annoyed by aircraft noise (categories  $\geq 3$ , i.e., moderately and highly annoyed) depending on the maximum noise level  $L_{AS,max}$  and the number of aircraft noise events, as predicted by the regression model L1. The psychological parameters considered in the model correspond to the median of the experimental group (gender = female, pre-annoyance due to aircraft noise = 2, "necessity of air traffic" = 4). It can be seen that the  $L_{AS,max}$  and the number of aircraft noise events have a significant influence: the extent of annoyance rises with increasing

$L_{AS,max}$ , as well as with the number of events, which corresponds to previous studies concerning aircraft noise effects [e.g. Fields 1984; Rylander et al. 1972, 1980, 1986]. 128 noise events of 55 dB(A) leads to the highest predicted number of annoyed persons (80%). Four events with a maximum noise level of 70 dB(A) cause only 52% annoyed persons even though this level frequency combination yields the same average noise level as 128 times 55 dB(A). In contrast to previous studies, the number of those annoyed also significantly increases with rising noise level at low over-flight frequencies (< 16 over-flights per night).

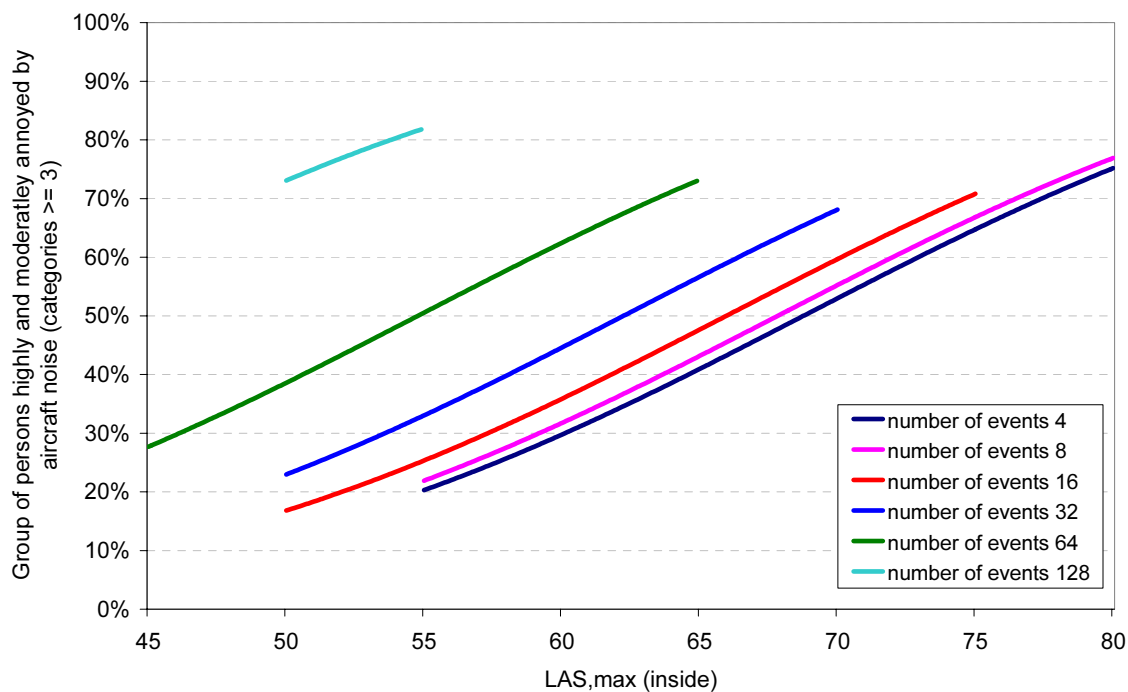


Figure 20: Group of people highly and moderately annoyed by aircraft noise (categories  $\geq 3$ ) depending on the maximum noise level  $L_{AS,max}$  and the number of aircraft events predicted by the regression model L1.

Figure 21 presents the number of those annoyed by aircraft noise (categories  $\geq 3$ ) depending on the energy equivalent noise level  $L_{AS,eq}$ , as predicted by the regression model L2. Similar to figure 20, the psychological parameters in the model correspond to the median of the experimental groups (see above). A significant increase of the extent of the annoyance due to increasing  $L_{AS,eq}$  results. The  $L_{AS,eq}$  has a range from 15% at 30.6 dB(A) to approximately 70% at 46.6 dB(A). The percentile amount of annoyed persons

decreases at a higher  $L_{AS,eq}$  ( $> 46.6$  dB(A)). This is presumably due to the underlying level frequency combinations of higher maximum noise levels  $\geq 65$  dB(A) combined with lower frequencies  $\leq 32$  (cp. figure 3). This finding indicates the relevance of the number of nocturnal air activities with regard to the resulting annoyance reaction that decreases in the case of less noisy events during the night [Kastka & Faust 1998].

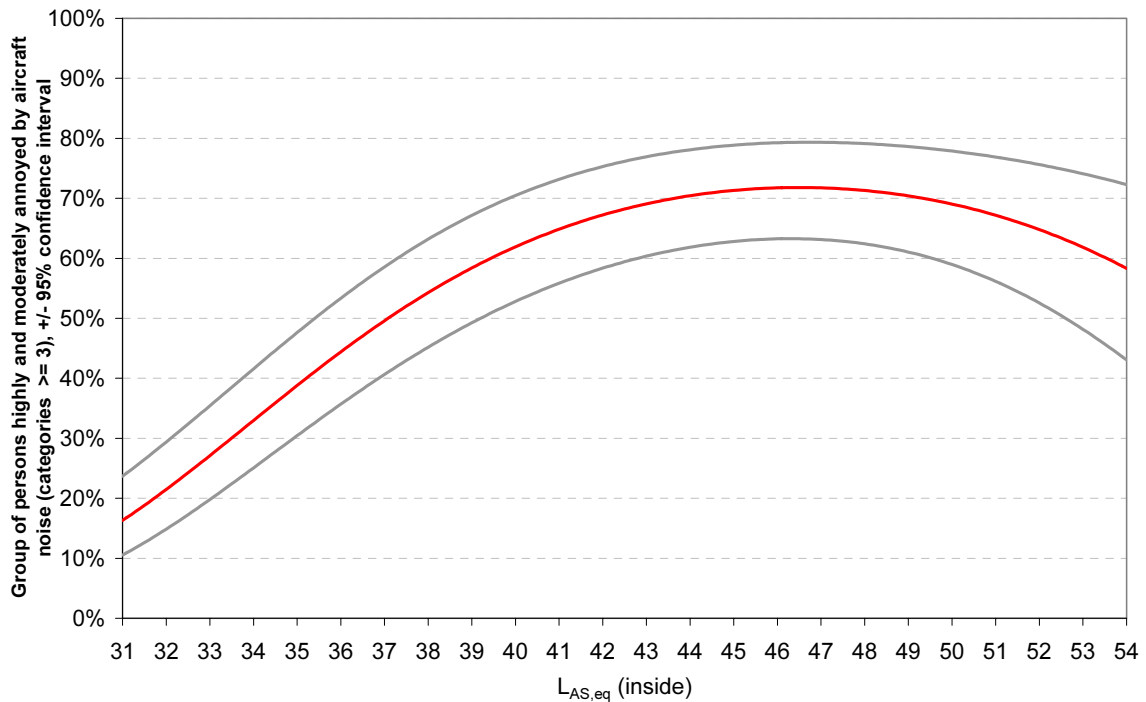


Figure 21: Group of people highly and moderately annoyed by aircraft noise (categories  $\geq 3$ ) depending on the energy equivalent noise level  $L_{AS,eq}$  predicted by the regression model L2.

The influence of the contributing moderator variables is separately shown for both regression models in figures 22 to 28, whereas the median was assumed for all non-regarded parameters. It should be reminded that for L1, the figures 22 to 24, which present the number of events as independent variable, solely refer to  $L_{AS,max} = 55$  dB(A). In contrast to this, in figure 25 the  $L_{AS,max}$  solely applies as independent variable for a level frequency of  $n = 16$ . Apparently, for both laboratory-specific regression models, the expected group of aircraft noise annoyed persons is:

- significantly higher for *women* than for *men*
- significantly larger for highly *aircraft noise pre-annoyed persons* than by *not pre-annoyed persons*
- significantly lower for a “*very high necessity*” than for a “*no necessity of air traffic*”

For a better understanding of the results, aside from the extreme value comparison for the pre-annoyance and the “necessity of air traffic”, the predicted percentage for the median is given.

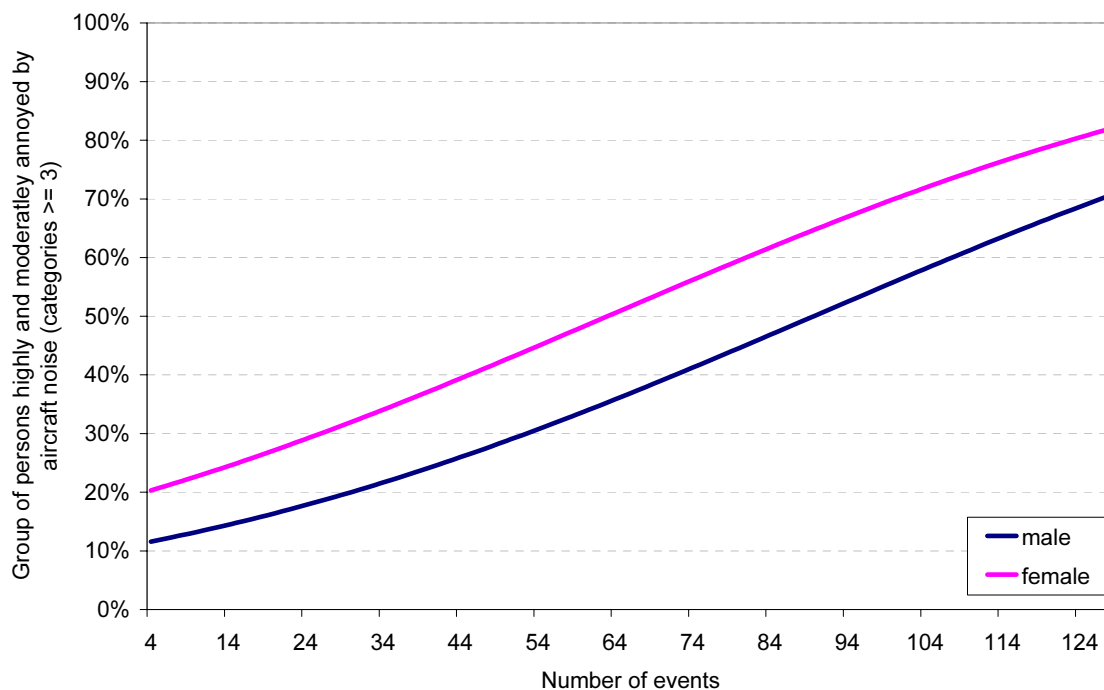


Figure 22: Group of people highly and moderately annoyed by aircraft noise (categories  $\geq 3$ ) depending on the number of aircraft events and the gender predicted by the regression model L1 at  $L_{AS,max} = 55$  dB(A).

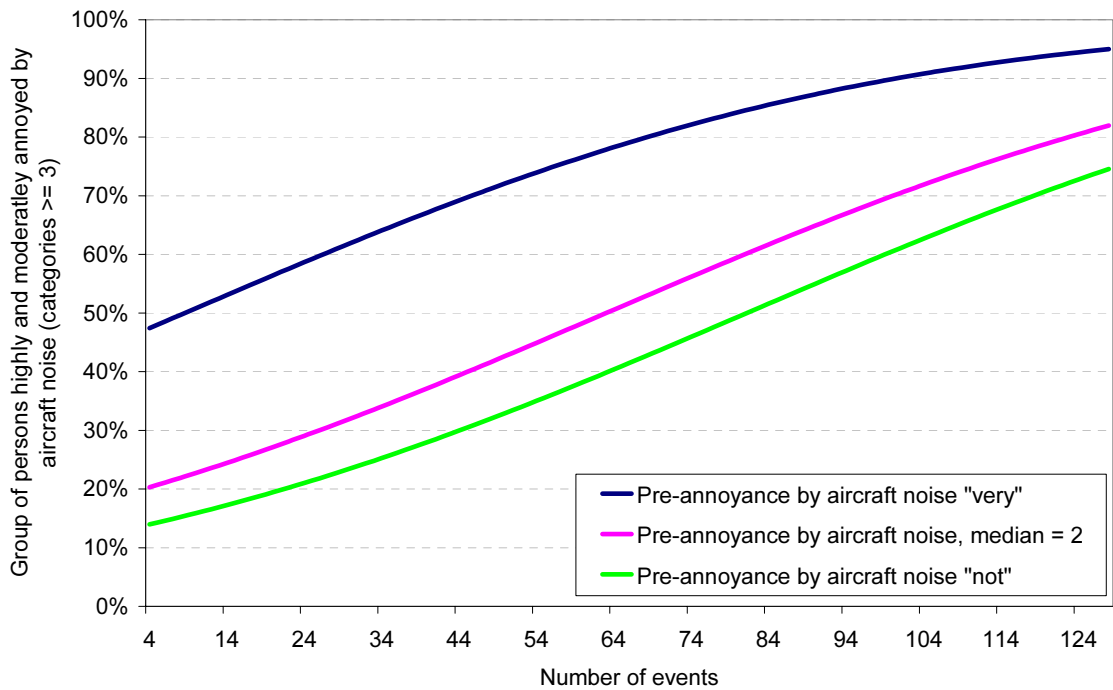


Figure 23: Group of people highly and moderately annoyed by aircraft noise (categories  $\geq 3$ ) depending on the number of aircraft events and the degree of aircraft noise pre-annoyance ("not", median, "very") predicted by the regression model L1 at  $L_{A5,max} = 55$  dB(A).

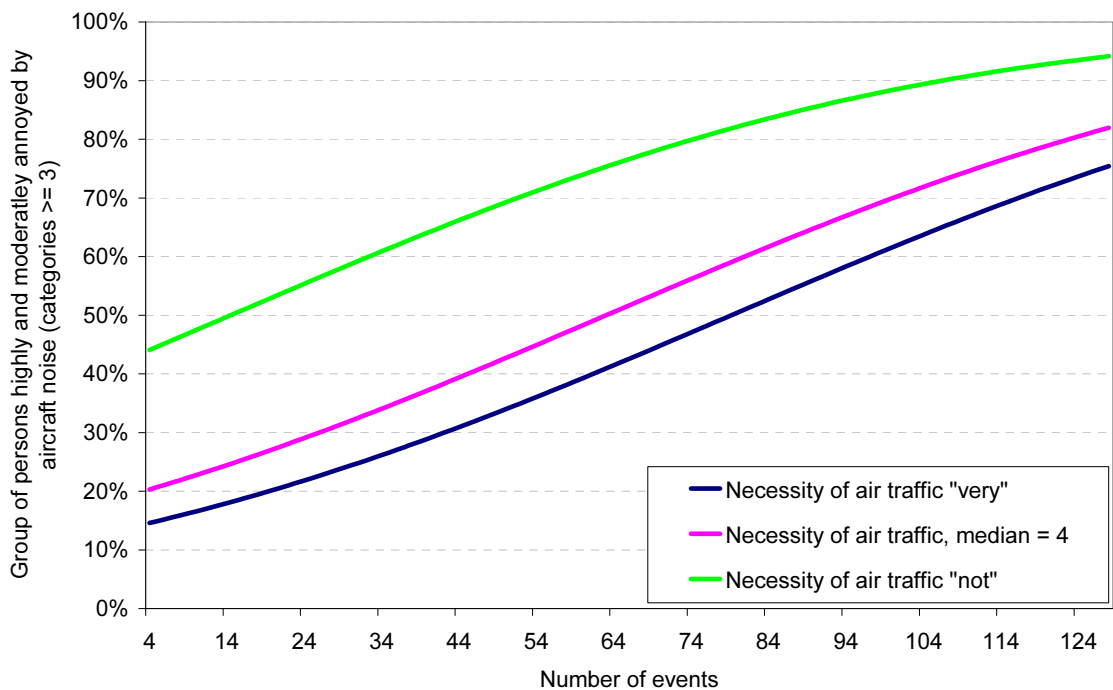


Figure 24: Group of people highly and moderately annoyed by aircraft noise (categories  $\geq 3$ ) depending on the number of aircraft events and the rated "necessity of air traffic" ("not", median, "very") predicted by the regression model L1 at  $L_{A5,max} = 55$  dB(A).

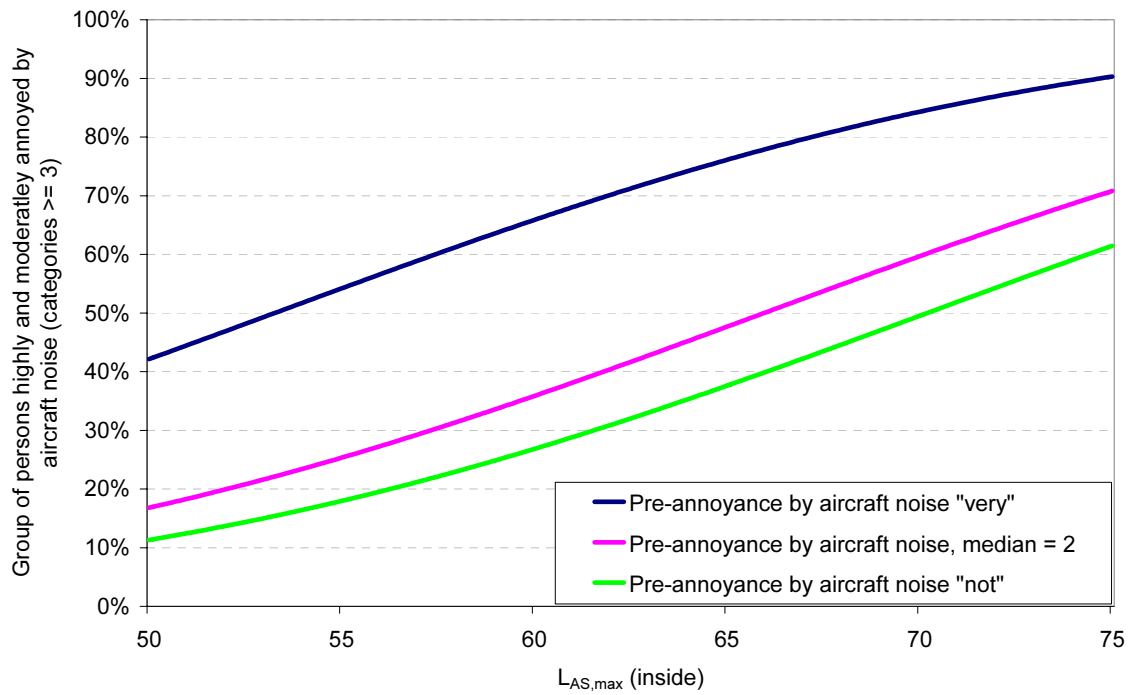


Figure 25: Group of people highly and moderately annoyed by aircraft noise (categories  $\geq 3$ ) depending on the maximum noise level  $L_{AS,max}$  and the degree of aircraft noise pre-annoyance ("not", median, "very") predicted by the regression model L1 at a level frequency of 16.

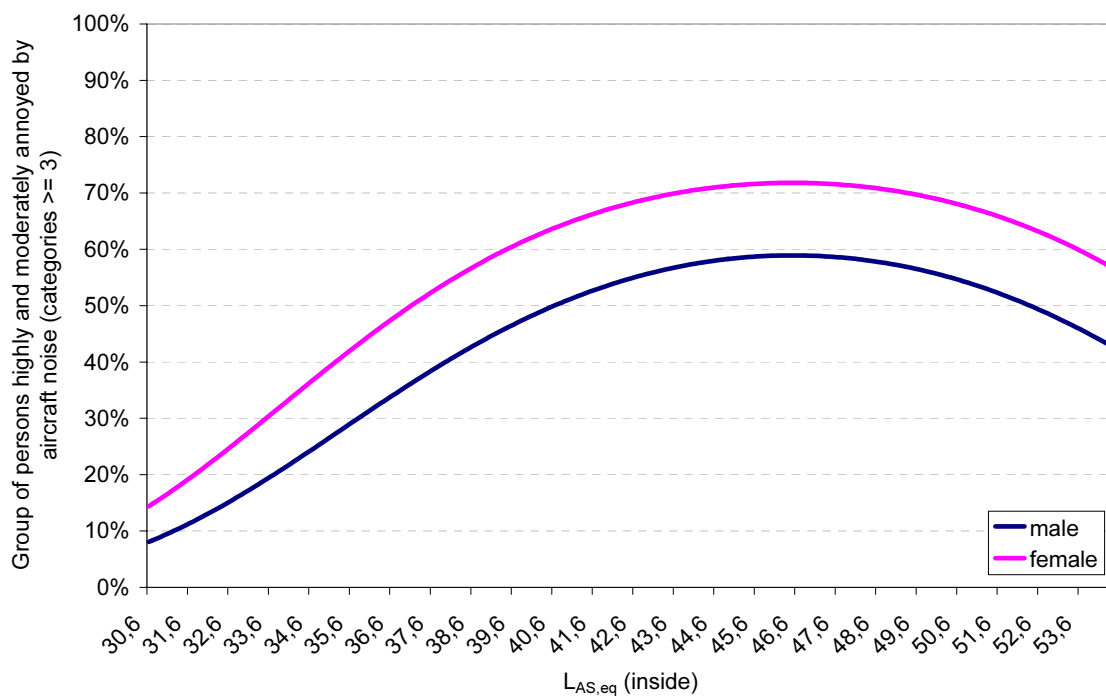


Figure 26: Group of people highly and moderately annoyed by aircraft noise (categories  $\geq 3$ ) depending on the energy equivalent noise level  $L_{AS,eq}$  and the gender predicted by the regression model L2.

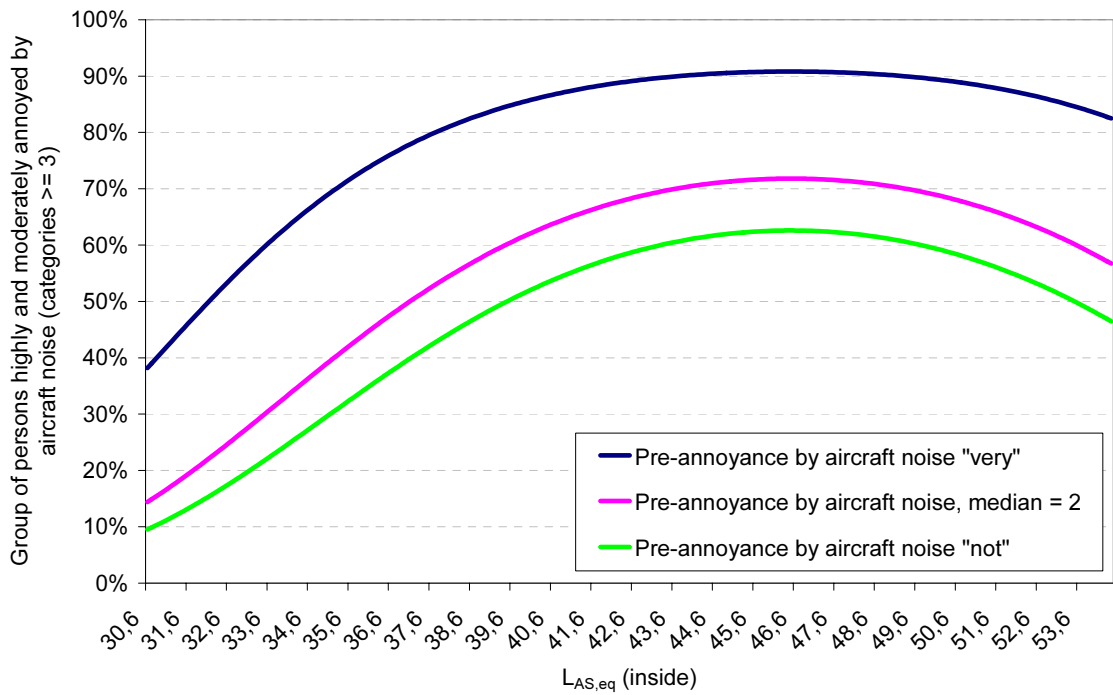


Figure 27: Group of people highly and moderately annoyed by aircraft noise (categories  $\geq 3$ ) depending on the energy equivalent noise level  $L_{AS,eq}$  and the degree of pre-annoyance ("not", median, "very") predicted by the regression model L2.

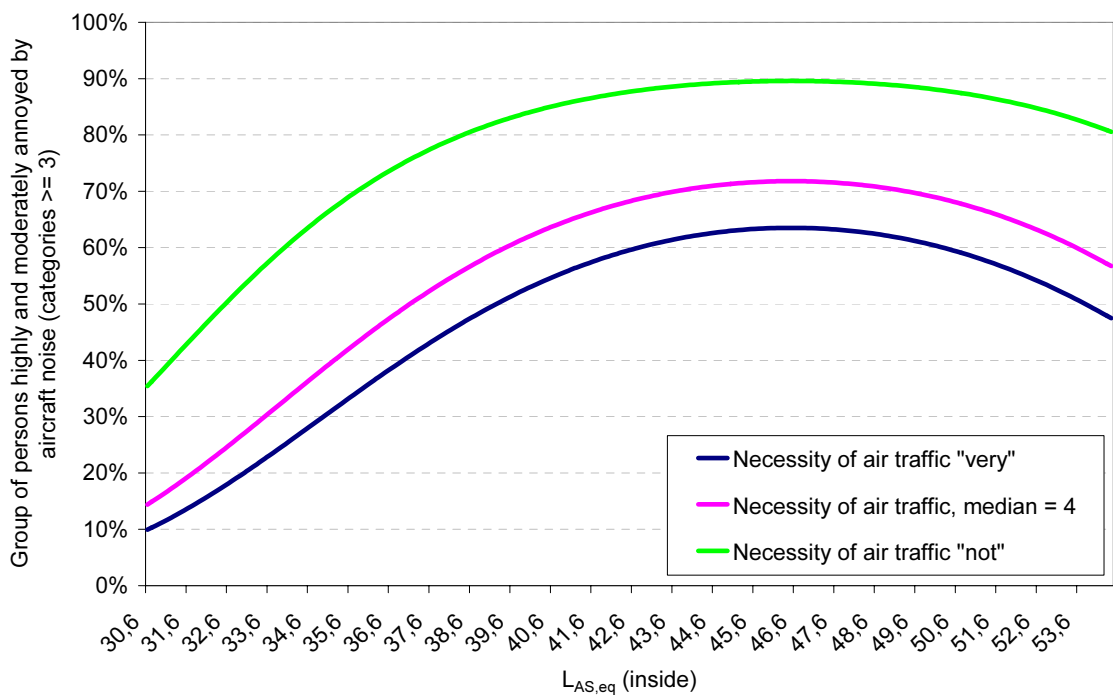


Figure 28: Group of people highly and moderately annoyed by aircraft noise (categories  $\geq 3$ ) depending on the energy equivalent noise level  $L_{AS,eq}$  and the rated "necessity of air traffic" ("not", median, "very") predicted by the regression model L2.

### 1.8.3 Annoyance due to aircraft noise before the laboratory study

The following chapter focuses on the annoying impact of aircraft noise existing at home *before* the laboratory study (in terms of an aircraft noise *pre-annoyance*).<sup>24</sup> The following issues are examined in detail:

- a) *main characteristics of aircraft noise annoyance,*
- b) *psychological moderators of aircraft noise annoyance.*

For this purpose, data is used from the general questionnaire that had been posted before the study took place. Beside annoyance, the questionnaire inquires a variety of other variables regarding the disturbing impact of aircraft noise (and other noise sources). The questionnaire mainly includes items with a 5-point answering scale (generally from “1 = not or never” to “5 = very or always”).

#### 1.8.3.1 Semantic analysis of aircraft noise pre-annoyance

Based on the principal component analysis, the attempt was made to specify the meaning of the term *aircraft noise annoyance* [cp. also Guski et al 1999; Guski & Schick 2004; Oliva 1998]. For this, the hypothesis was postulated, that the concept of aircraft noise annoyance essentially integrates cognitive and emotional aspects [Koelega 1987], i.e., it concerns the disturbance of activities (communication, recuperation, relaxation and sleep), which are accompanied by feelings of unease, irritation and discontent (cp. *chapter 1.2.1*). In order to verify this assumption, varimax-rotated principal component analysis (PCA) was conducted according to the Kaiser criteria. To interpret the three main factors, which together explain 42.9% of the total variance, only items with loadings of  $>.50$  were taken into account. The results in table 12 confirm that the term *annoyance corresponds to the*

---

<sup>24</sup>The pre-annoyance by aircraft noise was already considered as a psychological moderator variable in the logistic regression (cp. *chapter 1.8.2.3*).

*concept of aircraft noise-induced disturbances of activities such as communication, recuperation and sleep [cp. Guski et al. 1999; Kastka 2001a].*

The first, unipolar principal component (approximately 28% variance explanation) combines all experienced disturbances of the mentioned activities due to aircraft noise in one's residence, such as "disturbance of relaxation and leisure time", "disturbance of conversations", "prevention of reading/thinking", "prevention of falling asleep", "afraid", "increasing the volume of the radio/TV". Predominant affects are "petulance", "being reluctant to come home and spend time outside" and "lack of pleasure in leisure time". In the cognitive domain, the belief in "individual health hazard caused by aircraft noise" dominates. Other items describe aircraft noise intensity outside and inside with either tilted or closed (bedroom) windows and the frequency of unacceptable aircraft noises during day and night.

The second, bipolar factor (approximately 8% variance explanation) contains parameters, which do not deal with the disturbance from aircraft noise, but rather with the social assessment of air traffic (its "image") [cp. Guski 1999]. On one hand these items regard its "avoidability" and its potential "health hazard", while on the other hand they consider the "necessity", "eco friendliness", the general attitude towards air traffic, and the adaptation to aircraft noise.

The third component (approximately 7% variance explanation) includes only affective attributes, which focus on the (dis-)contentment concerning aspects in the vicinity of the exposed residence (possibilities of recuperation, air quality) in terms of the so-called "environmental aesthetic" [Booth 1999; Guski 1987; Oliva 1998].

**Rotated component matrix**

	component		
	1 (27,9%)	2 (8,4%)	3 (6,6%)
disturbance of relaxation and leisure time	.833	.161	-.074
disturbance of conversations	.766	-.045	-.162
aircraft noise intensity, tilted bedroom window	.744	.101	.492
frequency of unacceptable aircraft noises during day	.738	.210	.226
prevention of reading/thinking	.734	.005	-.271
petulance	.728	.165	-.160
prevention of falling asleep	.727	.163	.141
aircraft noise intensity, closed bedroom window	.712	.195	.439
aircraft noise intensity, tilted window	.708	.022	.386
to do without open the windows	.694	.208	.119
lack of pleasure in recreational time	.673	.295	-.122
aircraft noise intensity, closed window	.667	.075	.422
frequency of unacceptable aircraft noises during night	.651	.217	.408
aircraft noise intensity, outside	.643	.101	.440
increasing the volume of the radio/TV	.607	.002	-.005
being reluctant to spend time outside	.603	.182	-.070
individual health hazard caused by aircraft noise	.594	.379	.132
being reluctant to come home	.551	.131	-.203
afraid	.545	.031	-.069
to do without visitors	.506	-.115	-.362
trembling of walls and clinking of windows	.466	-.045	-.076
to do without telephone calls	.298	-.264	-.140
necessity of air traffic	-.068	-.742	-.032
health hazard caused by air traffic	.228	.658	-.036
general attitude towards air traffic	-.180	-.641	.018
avoidability of air traffic	.083	.639	.075
eco friendliness of air traffic	.016	-.563	-.175
adaptation to aircraft noise	-.260	-.506	-.082
general health hazard caused by aircraft noise	.186	.502	-.058
reliability of air traffic	-.027	-.463	-.093
insecurity of air traffic	.032	.439	-.119
contentment with public transportation system	.065	-.265	-.240
contentment with air quality	-.029	.043	.571
contentment with recreation possibilities	.000	.023	.539
contentment with outer appearance	.016	-.035	.440
overall residential contentment	.073	-.146	.403
contentment with shopping possibilities	.008	-.118	-.352
contentment with proximity to work place	.127	-.089	-.192

method of extraction: principal component analysis according to the Kaiser criteria

Table 12: Varimax-rotated principal component analysis of aspects regarding aircraft noise pre-annoyance. Data from the general questionnaire of the laboratory sample (N = 128) are considered. For the factor interpretation items with loadings > .50 (grey-shaded) have been taken into account.

### 1.8.3.2 The influence of psychological moderators on aircraft noise pre-annoyance

Figure 29 depicts the percentile distribution of the annoyance judgements before the study by means of a 5-point answering scale. This results in the quartiles  $Q_1 = 2$  ("little" annoyed) and  $Q_2$  and  $Q_3 = 3$  ("moderately" annoyed). More than  $\frac{3}{4}$  of the assessments are distributed among the first three scale categories. 13% feel "quite" or "very" annoyed by aircraft noise.

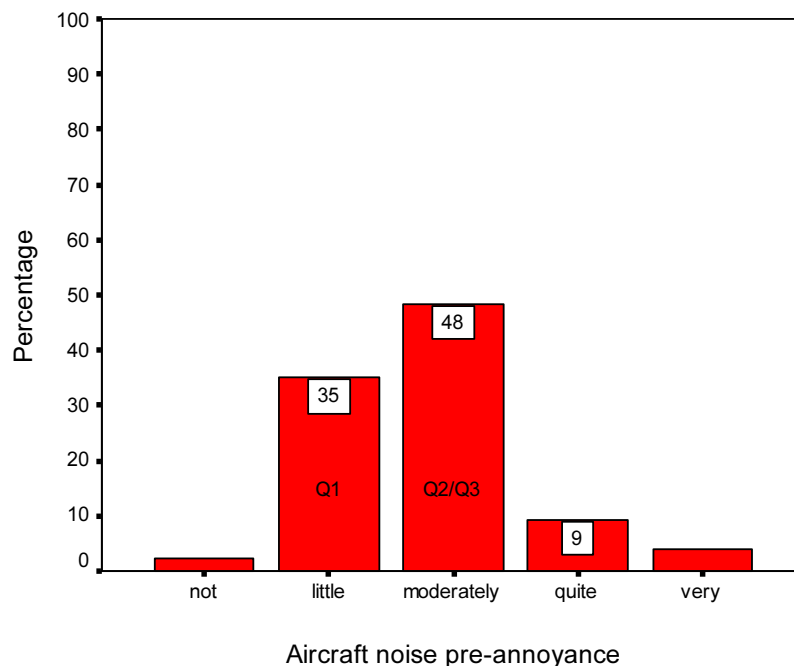


Figure 29: Percentile distribution of the annoyance evaluation ("How much are you annoyed by aircraft noise?") before the laboratory study (N = 128).

On average, the subjects remember 3.35 unacceptable aircraft noises (standard deviation = 6.94) during the day (from 6 am to 10 pm), and 2.07 noises (standard deviation = 3.45) during the night.

Based on the qualitative analysis of the general questionnaire, it can be proven that about one third of the responders (approximately 37%) feels highly annoyed by certain flight situations before STRAIN began ("Are you highly annoyed by specific aircraft noise situations?"). These mainly concern flight situations during the night and early in the morning (a total of 24

namings to an open question which allows multiple answers); in 14 other cases, military aircraft and strafers are experienced as highly annoying. The level (29 namings), as well as noise-induced awakenings (6 namings), are named as primary reasons for the considerable annoyance. 20% are of the opinion that especially these highly annoying flight situations should be implicitly avoided.

Annoyance ratings generally develop from long-term experiences in and with a specific exposure situation. They have a high inter-individual variation, since they depend on numerous non-acoustic parameters (cp. *chapter 1.4.2*). Kruskal-Wallis one-way analysis of variance concerning the influence of psychological moderators on aircraft noise pre-annoyance was conducted. For this purpose, median splits of the laboratory sample (N = 128) were carried out, i.e., the subjects were allocated to two independent partial samples, such as "highly" ( $\geq$  median) and "less" ( $<$  median) noise sensitive.

#### **a) Situational or contextual moderators**

Green spaces, good shopping possibilities and transport connections can have a positive moderating effect, i.e., residential variables, which are assessed as positive, generally decrease noise effects in terms of the "environmental aesthetic" [Booth 1999; Guski 1987; Oliva 1998]. In the analysis, the influence of the contentment with the residential area ("*How satisfied are you with... in your residential area?*") was tested regarding:

- *outer appearance* (median = 4.0),
- *air quality* (median = 4.0),
- *access to the public transportation system* (median = 4.0),
- *proximity to the work place* (median = 4.0),
- *shopping possibilities* (median 4.0),
- *recuperation and relaxation possibilities* (median = 4.0).

In addition, the contribution of the *overall residential contentment* (median = 4.0) (*"How satisfied are you overall with your residential area?"*) to the assessed aircraft noise pre-annoyance was examined. There are no significant differences between satisfied and less satisfied subjects with regard to all examined aspects of the residential area, i.e., a positive moderating influence of the surroundings in terms of an environmental aesthetic cannot be found.

An important feature in political discussions is the *time of residence* of noise-exposed persons in the affected area: while politicians and in part also the affected persons are of the opinion that with time one can "adapt to" the noise and therefore better cope with it the longer one lives with the noise, to date, there are hardly any empirically supported indications for such a process. The findings of the present survey do not show a significant effect of the time of residence (median = 6.25 years) on aircraft noise pre-annoyance.

All subjects were asked for the *type of domestic noise control (window glazing)*. 88% state having double window glazing in their residence. 10% have single and the remaining 2% have threefold window glazing. 64% of the responders are "quite" or "very" satisfied with the sound insulation of the closed windows, while 28% are "moderately" and 8% are "not" or "little" satisfied. About 51% of the subjects would like to have better noise control in their homes. Based on Kruskal-Wallis one-way analysis of variance, differences in the domestic window glazing accompany significant differences concerning aircraft noise pre-annoyance ( $\chi^2_{(2, .000)} = 19.462$ ), whereas the threefold glazing exhibits the highest mean rank, followed by the single and finally the double glazing (figure 30). Therefore, *the existence of different noise controls has a significant influence on the annoyance reaction* [cp. Paulsen et al. 1992]. Based on a study concerning aircraft noise exposure in the vicinity of the Düsseldorf Airport, no significant annoyance differences were found in residents with and without noise controlled windows [Kastka 1990].

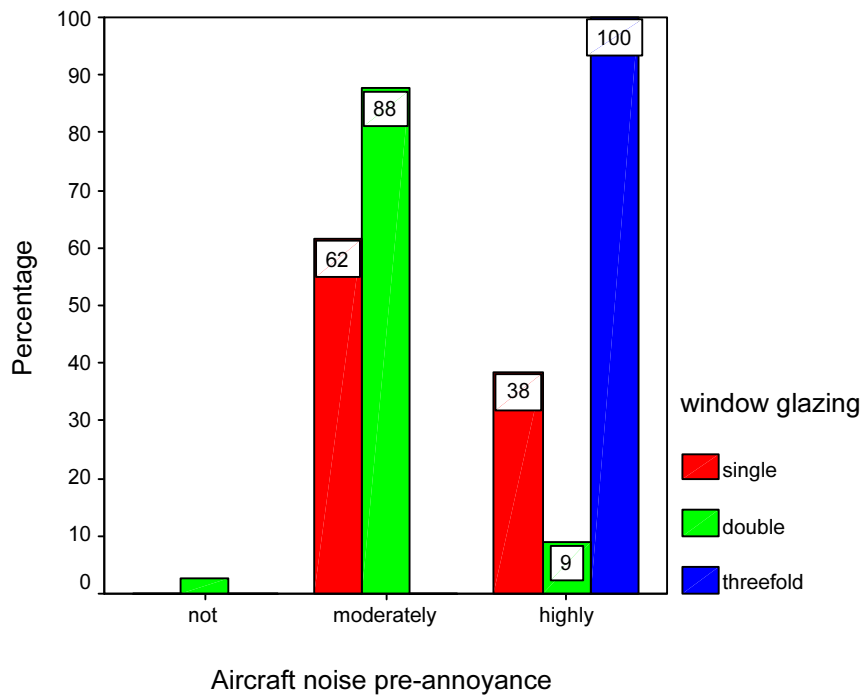


Figure 30: Aircraft noise pre-annoyance depending on domestic noise control (window glazing) *before* the laboratory study (N = 128).

According to Kastka [2001a], a differentiation between the *respective window positions in the exposed living space* is methodically significant in studies concerning aircraft noise effects. In the Friedman-test, significant differences between the assessed *aircraft noise intensity* ( $\chi^2_{(4, .000)} = 255.823$ ) and *pre-annoyance* ( $\chi^2_{(4, .000)} = 176.875$ ) are shown depending on different *room-acoustic conditions* at home (figures 31 and 32). Wilcoxon paired comparisons mostly exhibit significant differences between the respective room-acoustic conditions regarding aircraft noise intensity and pre-annoyance. At this point, a table of the results of the single comparisons will be refrained from. Merely the conditions “bedroom window closed” vs. “window closed”, and “bedroom window tilted” vs. “window tilted” do not have significant differences with regard to both variables. The conditions which are most sensitive are “tilted-window-situations” and “outside”, where the outside condition is more sensitive than the “tilted-window-situations” for the rated aircraft noise intensity [cp. Kastka 1990, 1999, 2001a].

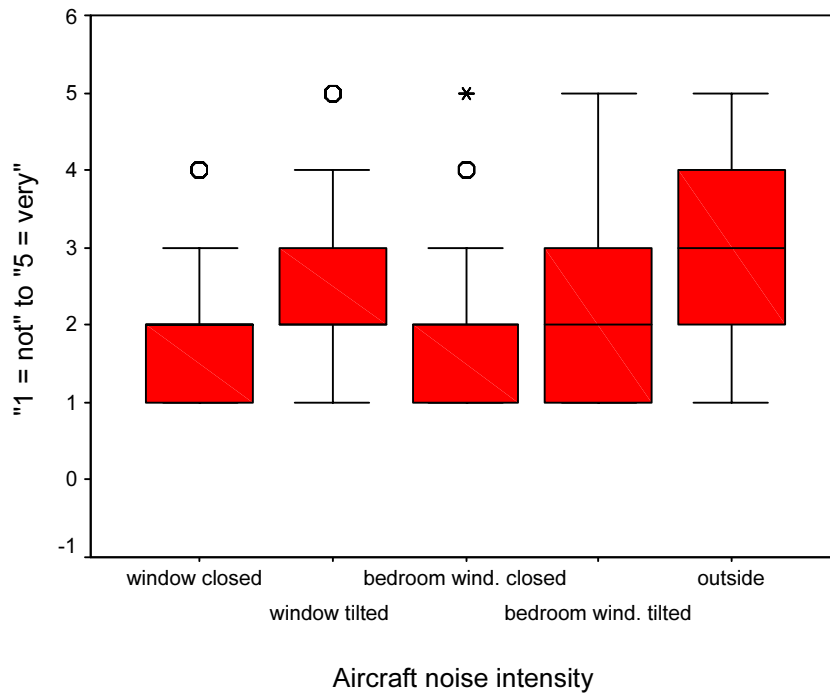


Figure 31: Aircraft noise intensity under different room-acoustic conditions at home (*"How much do you hear the aircraft noise...?"*) before the laboratory study (N = 128).

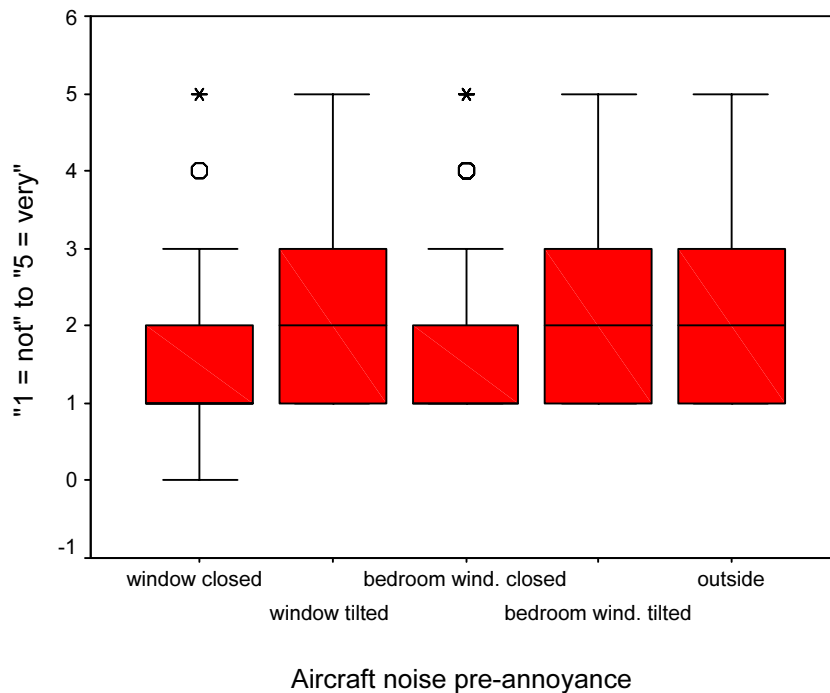


Figure 32: Aircraft noise pre-annoyance under different room-acoustic conditions at home (*"How much are you annoyed by aircraft noise...?"*) before the laboratory study (N = 128).

## b) Social moderators

The Friedman-test shows significant differences between the general *attitudes towards the main traffic modes road, railway and air traffic* ( $\chi^2_{(2, .000)} = 15.763$ ), whereas railway traffic is judged as significantly more positive in the Wilcoxon paired comparison as road and air traffic. However, attitudes towards road and air traffic do not differ significantly (figure 33). According to the Friedman-test, significant differences between the mentioned traffic modes ( $\chi^2_{(2, .000)} = 97.398$ ) can again be found with respect to the *noise annoyance*. Wilcoxon-tests confirm the railway bonus with respect to road and air traffic (noise). In comparison to road and air traffic, noise immissions from railway traffic are rated as significantly less annoying. Aircraft noise is hereby assessed as significantly more annoying than road noise (figure 34). In terms of *noise adaptation*, significant differences can be observed between the three main traffic modes ( $\chi^2_{(2, .005)} = 10.550$ ). Compared to the adaptation to railway or air traffic, the adaptation to road traffic noise is significantly easier than to railway or aircraft noise (figure 35).

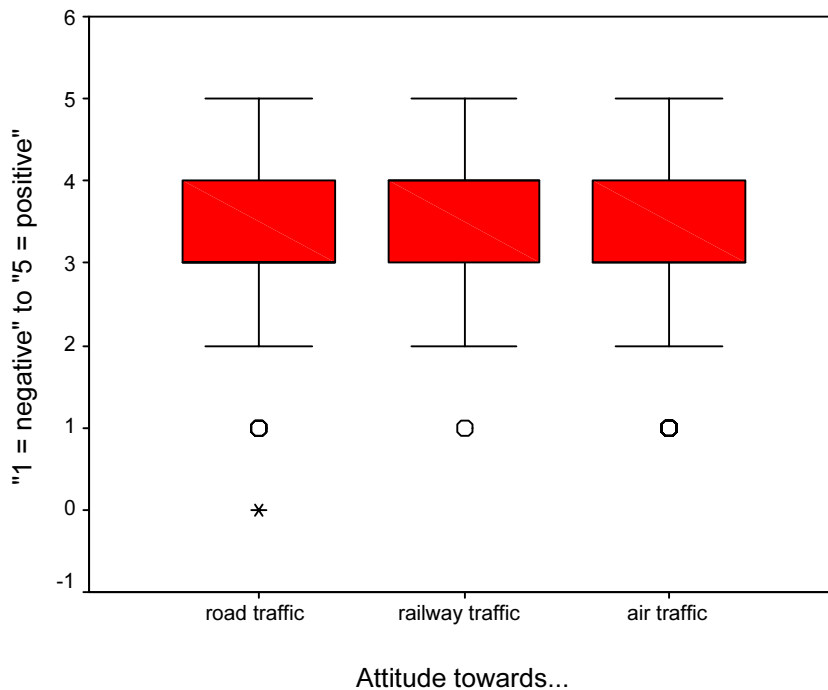


Figure 33: Attitudes towards the three main traffic modes ("What is your overall attitude towards the following traffic modes?") before the laboratory study (N = 128).

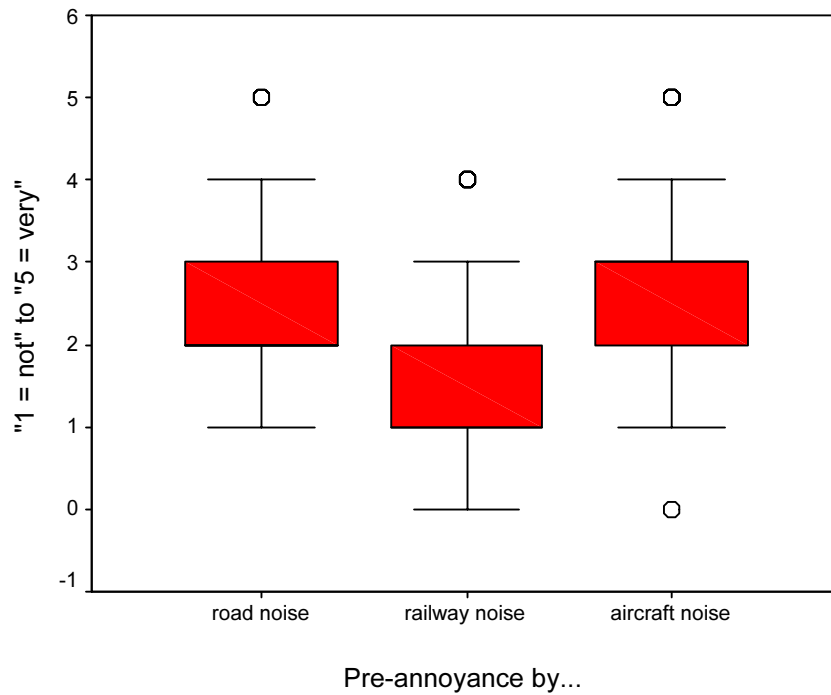


Figure 34: Traffic noise pre-annoyance ("How much are you annoyed by the following kinds of noise...?") before the laboratory study (N = 128).

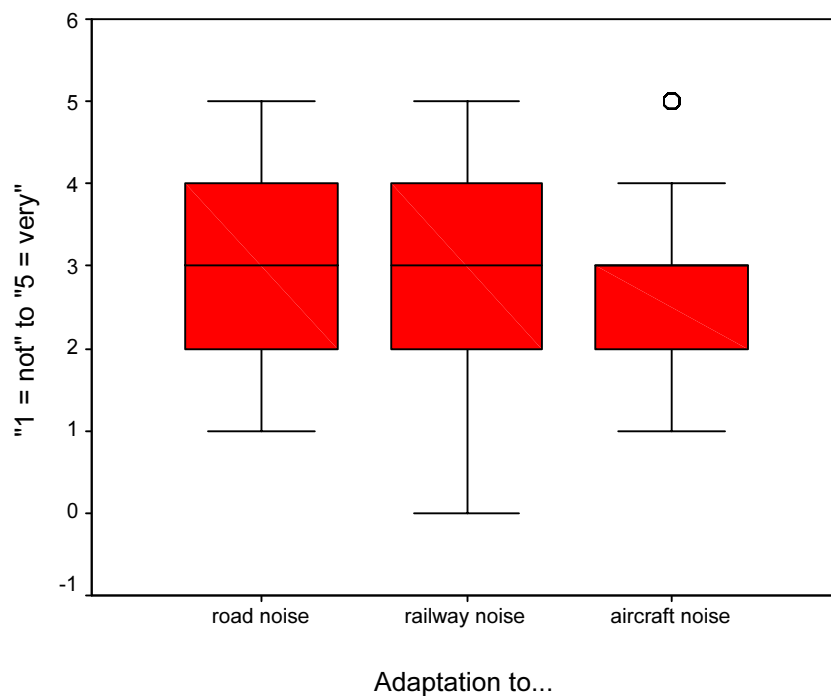


Figure 35: Traffic noise adaptation ("How good can you generally adapt with the following kinds of noise ...?") before the laboratory study (N = 128).

Aside from the assessment of danger, the rating of health hazard renders the highest (psychological) contribution to the explanation of noise effects among the image variables [Guski 1987]. The evaluation of the necessity of

noise and of the possibilities of avoiding it, also play a remarkable role. According to the subjects, the source of aircraft noise - the air traffic- has the image to be "quite necessary", "moderately harmful", "little eco friendly" and "little avoidable" (figure 36).

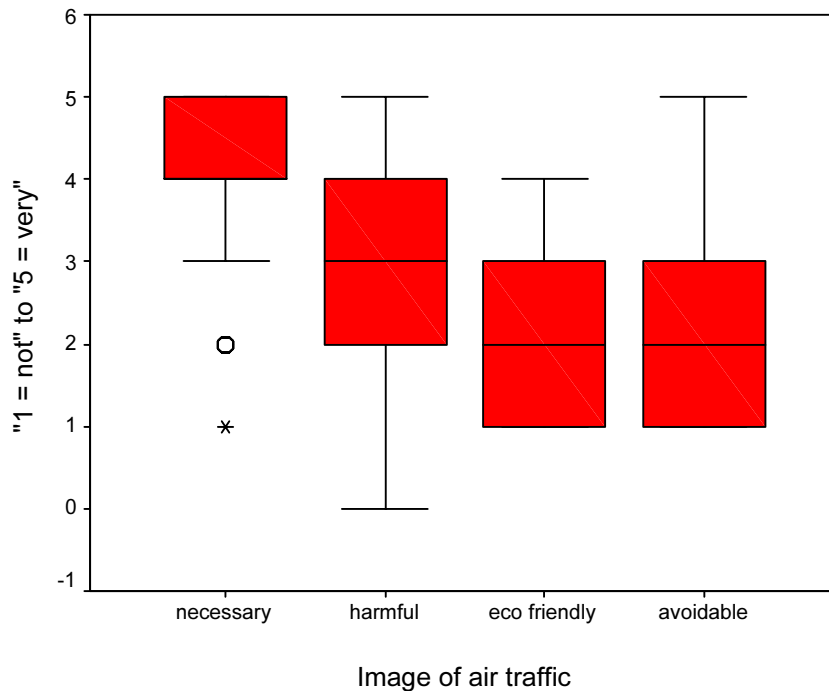


Figure 36: Image of air traffic ("In general, do you regard air traffic as...?") before the laboratory study (N = 128).

The inferential statistics indicate a significant effect of the *image-variables* assessed "necessity" ( $\chi^2_{(1, .012)} = 6.249$ ; median = 4.0), "health hazard" ( $\chi^2_{(1, .001)} = 11.059$ ; median = 3.0) and "eco friendliness" ( $\chi^2_{(1, .001)} = 11.209$ ; median = 2.0) of the air traffic, i.e., the less "necessary" and "eco friendly" and the more "harmful" the image of the air traffic is, the higher the aircraft noise pre-annoyance is. The same applies to the rated *health hazard caused by aircraft noise* ( $\chi^2_{(1, .030)} = 4.706$ ; median = 3.0), i.e., a subjectively higher evaluated hazard potential is associated with a higher annoyance. It should be noted, that the "general health hazard caused by aircraft noise" is significantly higher than the "individual health hazard" is assessed (Wilcoxon-test:  $Z_{(p \leq .000)} = -8.810$ ) (figure 37). The results also show a significant influence of the *general attitude* towards air traffic ( $\chi^2_{(1, .002)} = 9.538$ ; median = 3.0) on the annoying impact of aircraft noise. Thus, the annoyance ex-

perience is moderated by a negatively biased attitude towards air traffic. However, the rated "possibilities of avoiding air traffic" (median = 2.0) are proved to be insignificant.

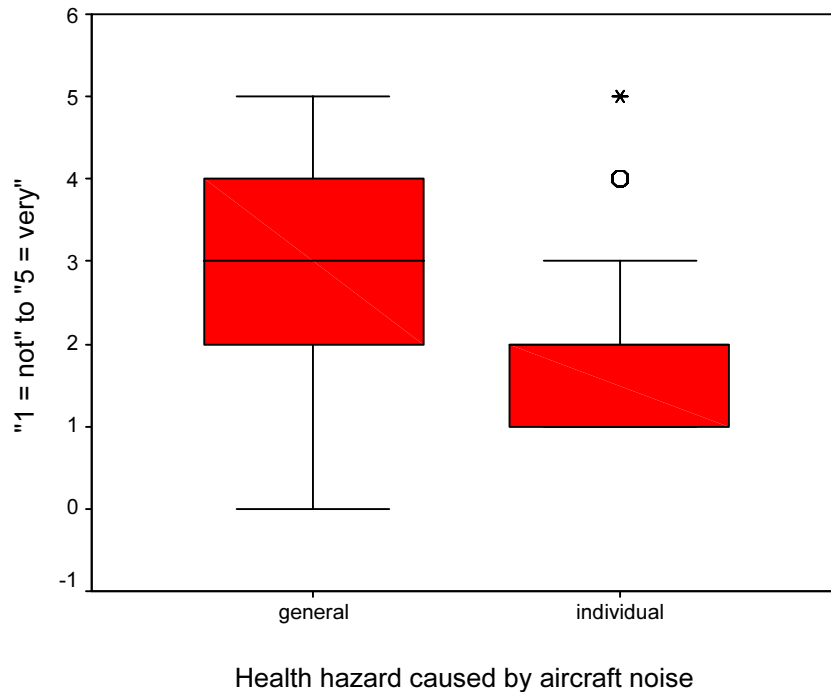


Figure 37: Health hazard caused by aircraft noise (*"How much aircraft noise generally harms the health?"* and *"How much aircraft noise harms your own health?"*) before the laboratory study (N = 128).

The assessment of the effort to decrease noise made by the state and public, as well as by other people and institutions perceived as responsible for causing noise, also plays a decisive role regarding noise effects [Felscher-Suhr et al. 2001; Fields 1993; Guski 1987, 1999, 2001b]. Figure 38 shows the extent of confidence that is placed in potential aircraft noise responsible. At this, "aircraft manufacturers", "communities and cities" and the "airport" dominate.

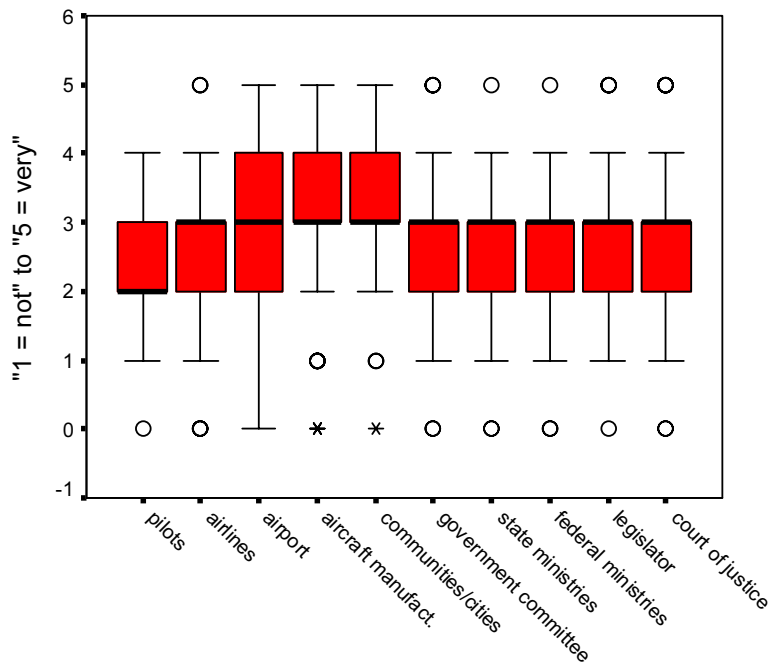


Figure 38: Confidence in people and institutions perceived as responsible for reducing aircraft noise ("To your mind, how much lobby the following persons and institutions for an aircraft noise reduction?") before the laboratory study (N = 128).

Based on the statistical analysis, it becomes apparent that the *confidence in the aircraft noise responsables* "airport" ( $\chi^2_{(1, .000)} = 12.337$ ; median = 3.0), "airlines" ( $\chi^2_{(1, .000)} = 13.892$ ; median = 3.0), "aircraft manufacturers" ( $\chi^2_{(1, .021)} = 5.354$ ; median = 3.0), "state and federal ministries" ( $\chi^2_{(1, .001)}$  respectively  $.003$ ) = 11.129 and 8.910 respectively; median = 3.0), "court of justice" ( $\chi^2_{(1, .042)} = 4.131$ ; median = 3.0), and "legislator" ( $\chi^2_{(1, .013)} = 6.122$ ; median = 3.0), associated with the belief in successful *chances of aircraft noise reduction* ( $\chi^2_{(1, .000)} = 20.875$ ; median = 3.0), have a systematic influence on aircraft noise pre-annoyance. A moderating effect of the confidence in the remaining possible responsables cannot be proven. This signifies that a lack of confidence in airports and politics regarding serious efforts of decreasing aircraft noise, as well as to the perceived lack of chances of an efficient noise reduction, cause a higher pre-annoyance. 32% believe that the chances of aircraft noise reduction are either "bad" or "very bad". Another 20% are of the opinion that "good" chances exist (figure 39). Economic interests are stated as the main reason against a successful aircraft noise reduction.

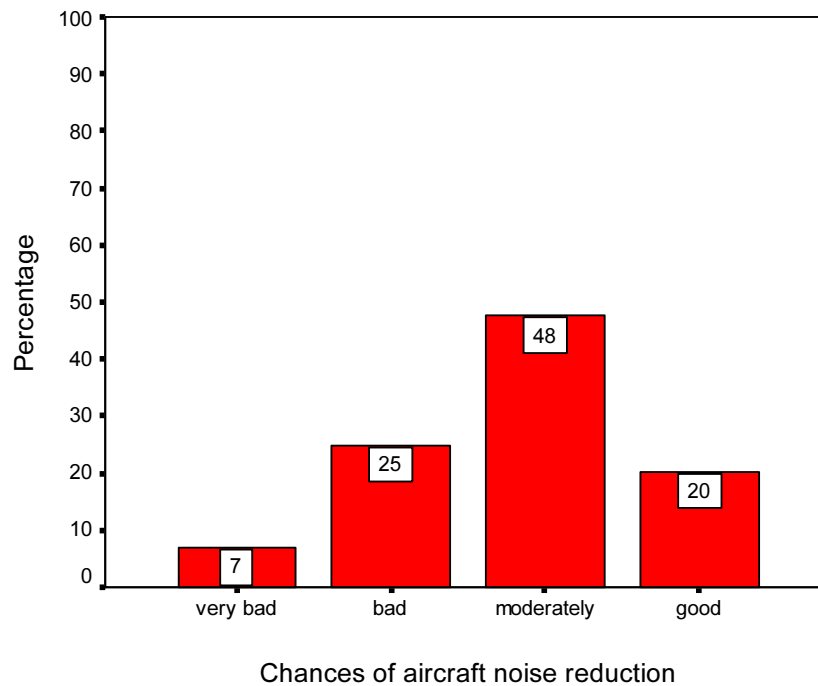


Figure 39: Chances of aircraft noise reduction (“To your mind, how good are the chances of a successful aircraft noise reduction?”) before the laboratory study (N = 128).

### c) Personal moderators

The inferential statistics show significant effects for *individual noise sensitivity*<sup>25</sup> ( $\chi^2_{(1, .000)} = 106.908$ ; median = 3.0) and *subjective aircraft noise adaptation* ( $\chi^2_{(1, .000)} = 12.627$ ; median = 3.0). The *participation in activities against aircraft noise*<sup>26</sup> (active vs. non-active) also has a statistically important influence ( $\chi^2_{(1, .043)} = 4.088$ ). 10% declare already having taken part in activities against aircraft noise. These activities are usually in the form of demonstrations, public events and the submission of written complaints to the airport. The personal aircraft noise concern is given as the main reason for their activity. A moderating impact of *travelling experiences on aircrafts* (flyers vs. non-flyers) and of *residential status* (owner vs. renter) does not exist.

<sup>25</sup>In STRAIN I to IV, the operationalisation of the noise sensitivity was done by means of the 5-point single item “How sensitive towards noise of any kind do you believe yourself to be?”. In order to consider the multi-dimensionality of the construct [e.g. Job 1999; Zimmer & Ellermeier 1999], an additional, separate questionnaire concerning the measurement of individual noise sensitivity [Zimmer & Ellermeier 1997, 1998, 1999] has been in use since the field study.

<sup>26</sup>“Have you ever in any way taken part in an activity against aircraft noise?”

## 1.9 Results of the field study<sup>27</sup>

### 1.9.1 Aircraft noise-induced secondary reactions of the field subjects

#### 1.9.1.1 Descriptive statistics

Table 13 contains the measurements of the central tendency (median and mode) and dispersion (range) of the dependent variables for the field subjects in correspondence to the non-metric scale level. All 9 study nights are considered.

		Statistics						
		sleep quantity	sleep quality	awakening frequency	aircraft noise intensity	aircraft noise annoyance	frequency of unacceptable aircraft noises	fatigue
N	Valid	569	573	573	573	573	573	573
	Missing	7	3	3	3	3	3	3
	Median	3	3	2	1	1	1	9
	Mode	3	4	2	1	1	1	10
	Range	3	5	4	5	5	4	19

Table 13: Measures of central tendency (median and mode) and dispersion (range) regarding the dependent variables of the field subjects (N = 64).

Figure 40 shows the percentile distribution of the *sleep quantity* assessments of the field subjects. This results in the quartiles  $Q_1 = 2$ , and  $Q_2$  and  $Q_3 = 3$ . 48% of the ratings are distributed among the first two categories ("much too little" and "slightly too little" sleep). Another 48% of the ratings fall into category 3 ("just the right"). The fourth category ("a bit too much" sleep) is barely, while the fifth category ("much too much" sleep) is not at all represented. In comparison to the distribution in the laboratory study, there are barely any differences. Figures 41 and 42 illustrate the frequency distribution of the evaluation of the sleep quality and awakening

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<sup>27</sup>Due to the non-metric scale level and the insufficient normal distribution of data which appeared in the Kolmogorov-Smirnov-test of the field data, non-parametric procedures were chosen. In all analyses, the probability of rejecting the null hypothesis according to Bonferoni was corrected to  $\alpha/n$ , dependent on the number of conducted individual tests.

frequency. Categories 1 and 2 of the *sleep quality* ("not" and "little") are occupied with 18%, the middle ("moderately") is assigned with 36% and the upper categories ("quite" and "very") are occupied with 46%. There are the quartiles  $Q_1$  and  $Q_2 = 3$  and  $Q_3 = 4$ . This about corresponds to the distribution in the laboratory study. Regarding *awakening frequency*, the lower scale ranks ("never" and "seldom") are assigned with 71%, the third rank ("occasional") is occupied with 22% and the fourth rank ("often") is assigned with 5%. This results in the quartiles  $Q_1$  and  $Q_2 = 2$ , as well as  $Q_3 = 3$ . Contrary to the laboratory study, the fifth category ("always") has not been chosen at all.

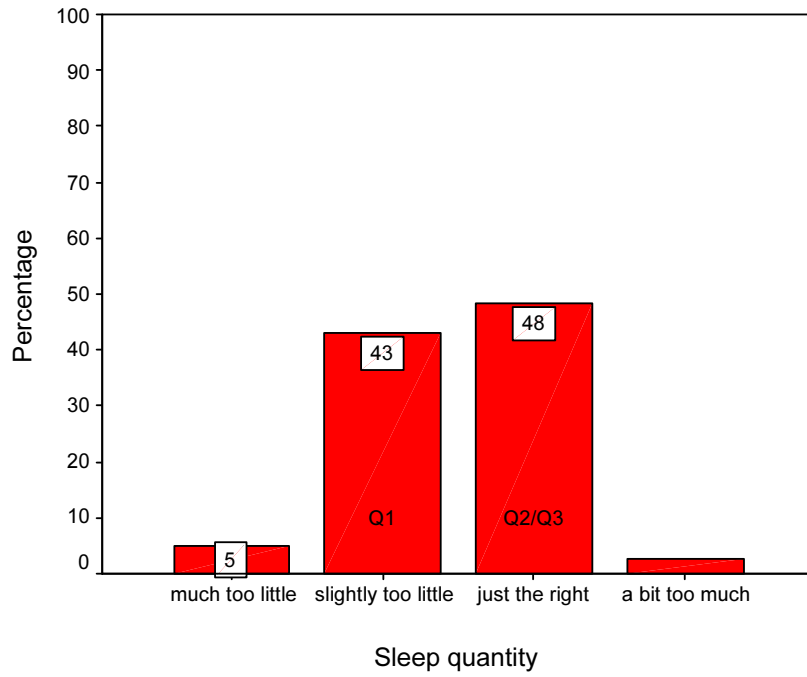


Figure 40: Percentile distribution of the field subjects' (N = 64) sleep quantity evaluation ("How much sleep did you get during the past night?") averaged over 9 nights.

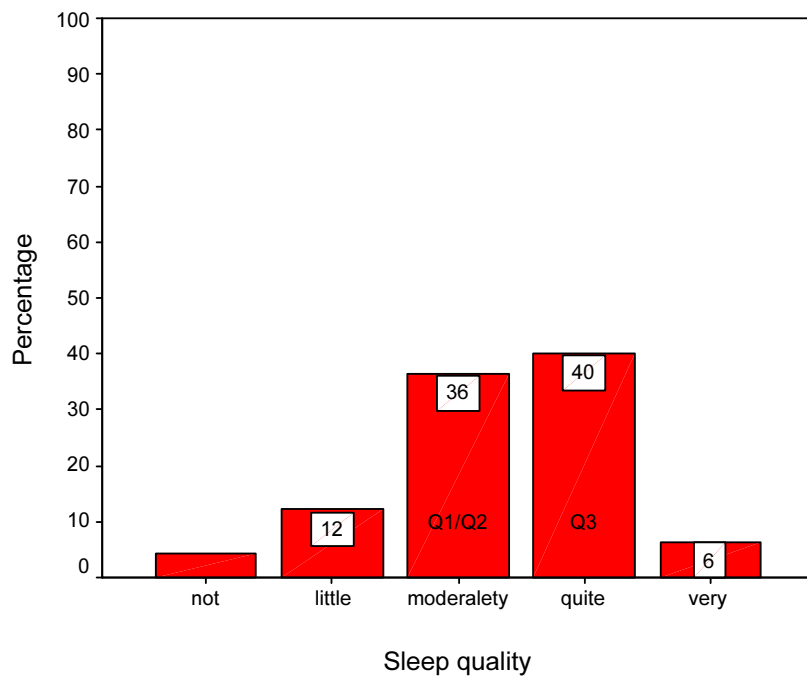


Figure 41: Percentile distribution of the field subjects' (N = 64) sleep quality evaluation ("How good was your sleep during the past night?") averaged over 9 nights.

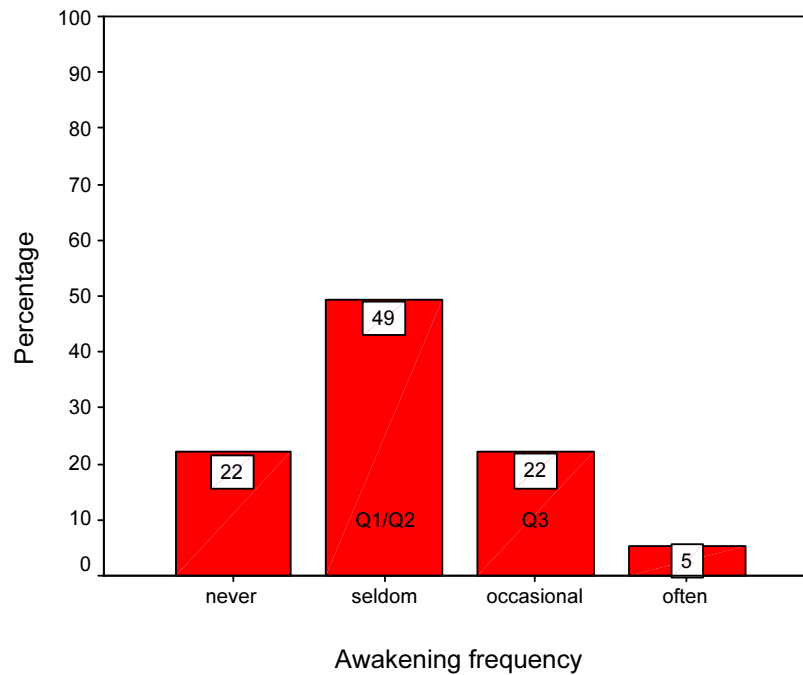


Figure 42: Percentile distribution of the field subjects' (N = 64) awakening frequency evaluation ("How often did wake up during the past night?") averaged over 9 nights.

Figure 43 reflects the percentile frequency distribution of the answers regarding *annoyance* from aircraft noise in the residential area. The quartiles  $Q_1$  and  $Q_2 = 1$  and  $Q_3 = 2$  are given. As is illustrated, the majority of the subjects (87%) is "not", or only "little" annoyed by nocturnal aircraft noise at home. 9% state being "moderately" annoyed. The upper two categories ("quite" and "very") are represented by only 4%. Similar to the laboratory study, the strong representation of the first category can be interpreted as a "floor effect". However, it should be reminded that in the laboratory study the categories 1 and 2 were represented with 30% each, 60% combined, while the categories 3 to 5 were used more often. In the field study, the assessment of the *aircraft noise intensity* and the *frequency of unacceptable aircraft noises* are distributed similarly to the annoyance (figures 44 and 45). In contrast to the laboratory, the fifth category was not represented in the judgement of the frequency of unacceptable aircraft noises.

"Ceiling effects" do not exist for any of the field study's dependent variables.

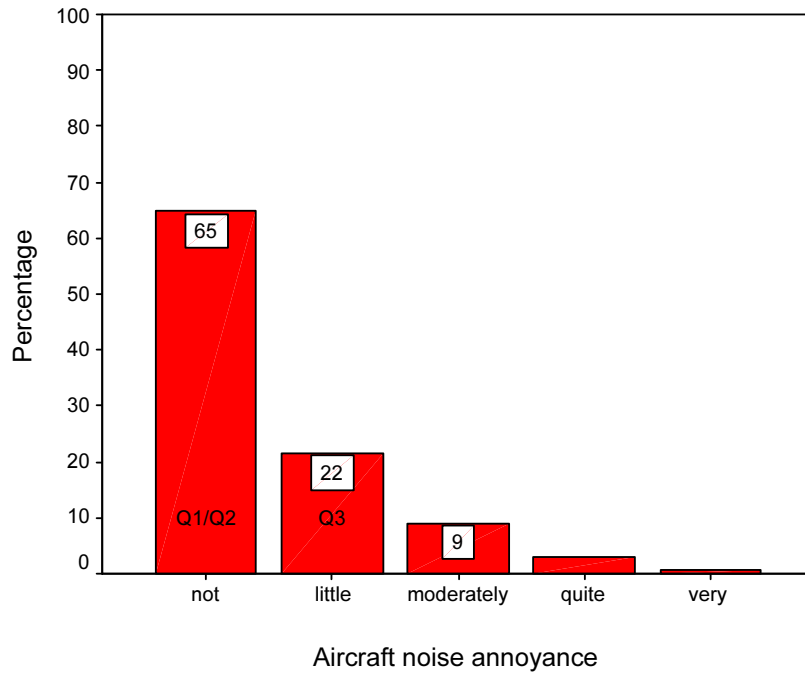


Figure 43: Percentile distribution of the field subjects' (N = 64) annoyance evaluation ("How much have you been annoyed by aircraft noise during the past night?") averaged over 9 nights.

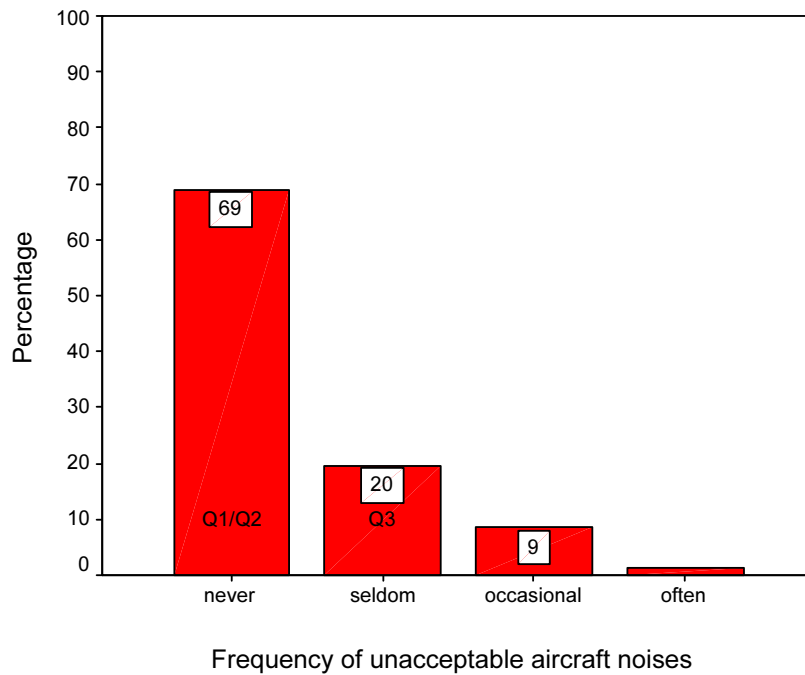


Figure 44: Percentile distribution of the field subjects' (N = 64) evaluation of the frequency of unacceptable aircraft noises ("How often did you hear unacceptable aircraft noises during the past night?") averaged over 9 nights.

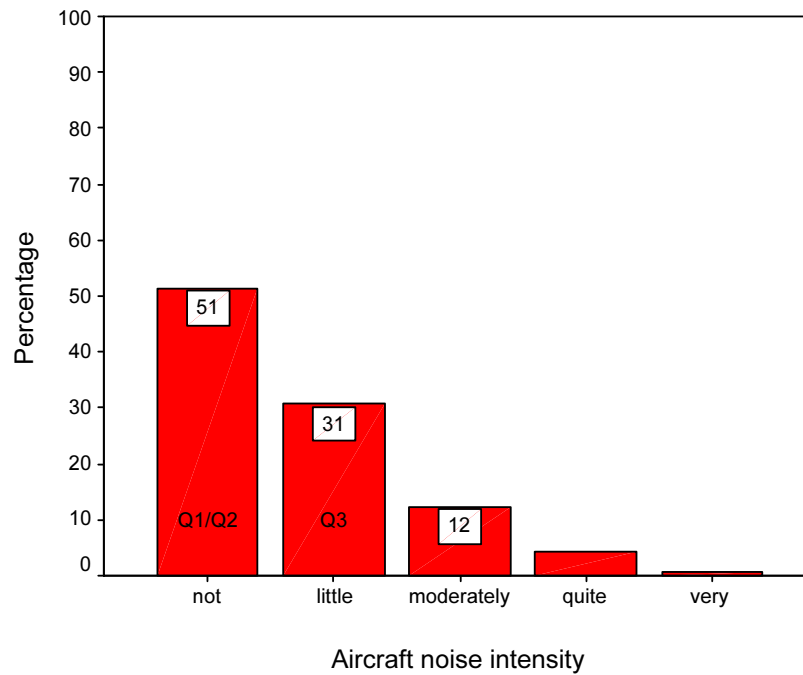


Figure 45: Percentile distribution of the field subjects' (N = 64) aircraft noise intensity evaluation ("How much did you hear the aircraft noise during the past night?") averaged over 9 nights.

### 1.9.1.2 Inferential statistics concerning the measurement value progress in the course of time

In order to determine a general influence of aircraft noise, data from different measurement days in the field are compared by means of Wilcoxon-tests (table 14). The secondary reactions of the following days are compared with each other:

- a) first night vs. second night: "first night effect"
- b) second night vs. sixth night: "weekend effect"
- c) eighth night vs. ninth night: "last night effect"

Similarly to the laboratory study, a so-called "first night effect" exists for the secondary reactions *sleep quality* and *sleep quantity*, i.e., the subjects sleep qualitatively and quantitatively better in the second night than in the first [cp. Agnew et al. 1966; Basner et al. 2000, 2001; Griefahn 1985; Öhrström & Björkman 1988]. Neither a "weekend effect" nor a "last night ef-

fect” can be proven for any of the dependent variables. The latter corresponds to the findings of the laboratory study (cp. *chapter 1.8.2.2.1*).

	1 <sup>st</sup> vs. 2 <sup>nd</sup> night (first night eff.)	2 <sup>nd</sup> vs. 6 <sup>th</sup> night (weekend effect)	8 <sup>th</sup> vs. 9 <sup>th</sup> night (last night effect)
Z Sign	QN2 - QN1 (3NR, 29PR, 30B) -4.516 .000**	QN6 - QN2 (8NR, 22PR, 33B) -2.611 .009	QN9 - QN8 (11NR, 18PR, 33B) -1.178 .239
Z Sign	QL2 - QL1 (4NR, 41PR, 19B) -5.370 .000**	QL6 - QL2 (12NR, 24PR, 28B) -1.778 .075	QL9 - QL8 (12NR, 19PR, 32B) -1.046 .296
Z Sign	AW2 - AW1 (29NR, 10PR, 25B) -2.591 .010	AW6 - AW2 (26NR, 9PR, 29B) -2.326 .020	AW9 - AW8 (12NR, 16PR, 35B) -.391 .696
Z Sign	STÄ2 - STÄ1 (28NR, 15PR, 21B) -1.939 .052	STÄ6 - STÄ2 (21NR, 8PR, 34B) -2.053 .040	STÄ9 - STÄ8 (11NR, 11PR, 41B) -.102 .919
Z Sign	BEL2 - BEL1 (20NR, 10PR, 34B) -1.557 .120	BEL6 - BEL2 (18NR, 9PR, 37B) -1.717 .086	BEL9 - BEL8 (10NR, 10PR, 43B) -.772 .440
Z Sign	UNZ2 - UNZ1 (16NR, 13PR, 35B) -.915 .360	UNZ6 - UNZ2 (14NR, 9PR, 41B) -1.089 .276	UNZ9 - UNZ8 (9NR, 11PR, 43B) -.389 .697
Z Sign	FAT2 - FAT1 (23NR, 23PR, 18B) -.973 .330	FAT6 - FAT2 (35NR, 24PR, 5B) -2.520 .012	FAT9 - FAT8 (26NR, 22PR, 15B) -1.137 .255

Table 14: Results of Wilcoxon-test (test statistic Z) regarding the comparison between the field subjects’ secondary reactions following different measurement days. According to the Bonferoni correction ( $\alpha/3 = .02$ ) significant (\*) and very significant differences (\*\*) are denoted (abbreviations: QN = sleep quantity, QL = sleep quality, AW = awakening frequency, STÄ = aircraft noise intensity, BEL = annoyance, UNZ = frequency of unacceptable aircraft noises, FAT = fatigue; NR = negative ranks, PR = positive ranks, B = links).

The measurement value progress of all secondary reactions over the time period of the entire field study (9 nights) is shown in the following by means of box-plots (figures 46 to 52).

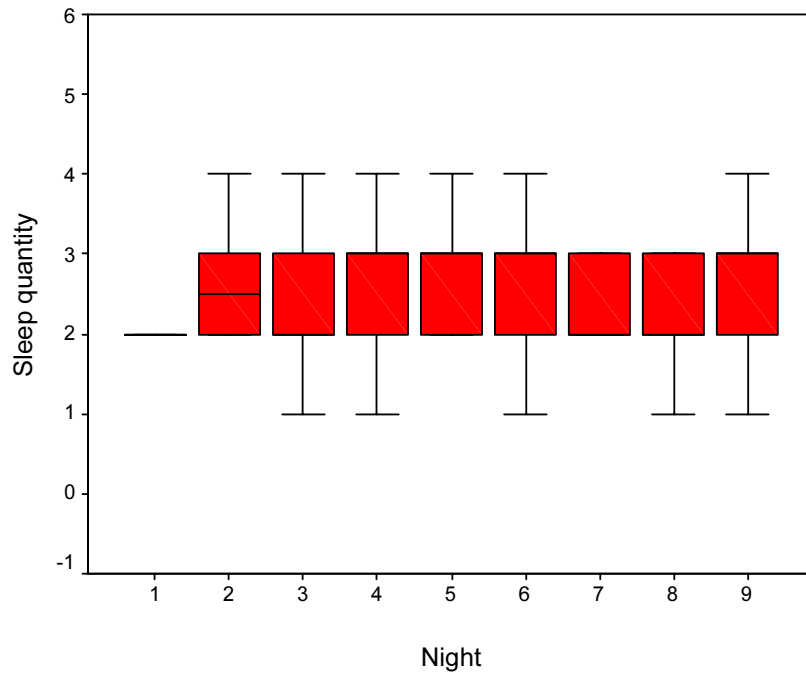


Figure 46: Box-plot of the field subjects' (N = 64) sleep quantity evaluation ("1 = much too little" to "5 = much too much") in the course of the field study.

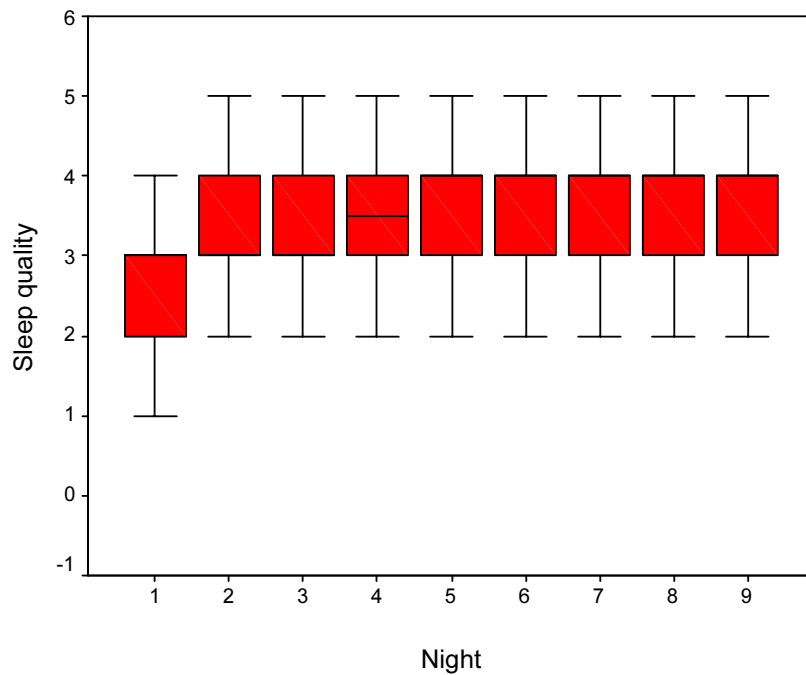


Figure 47: Box-plot of the field subjects' (N = 64) sleep quality evaluation ("1 = not" to "5 = very") in the course of the field study.

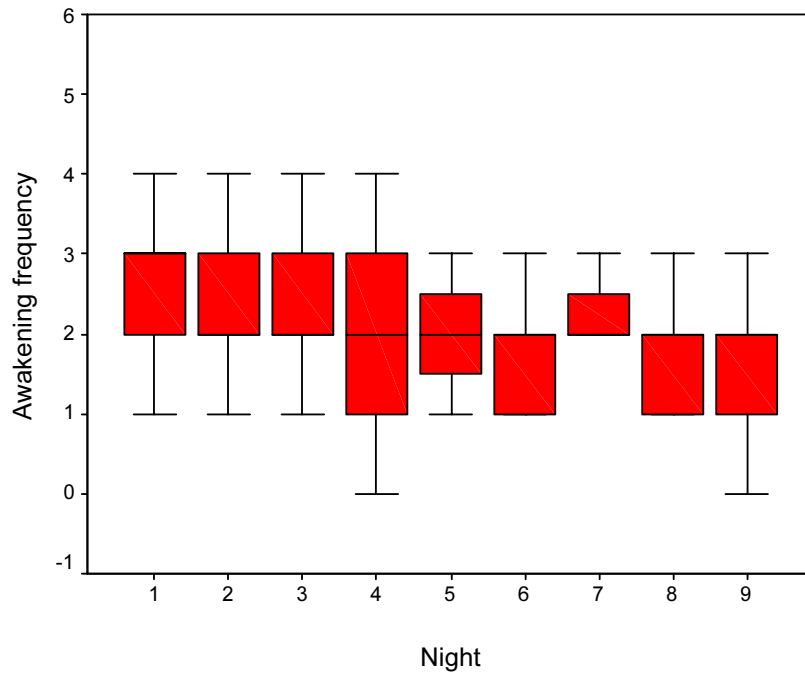


Figure 48: Box-plot of the field subjects' (N = 64) awakening frequency evaluation ("1 = never" to "5 = always") in the course of the field study.

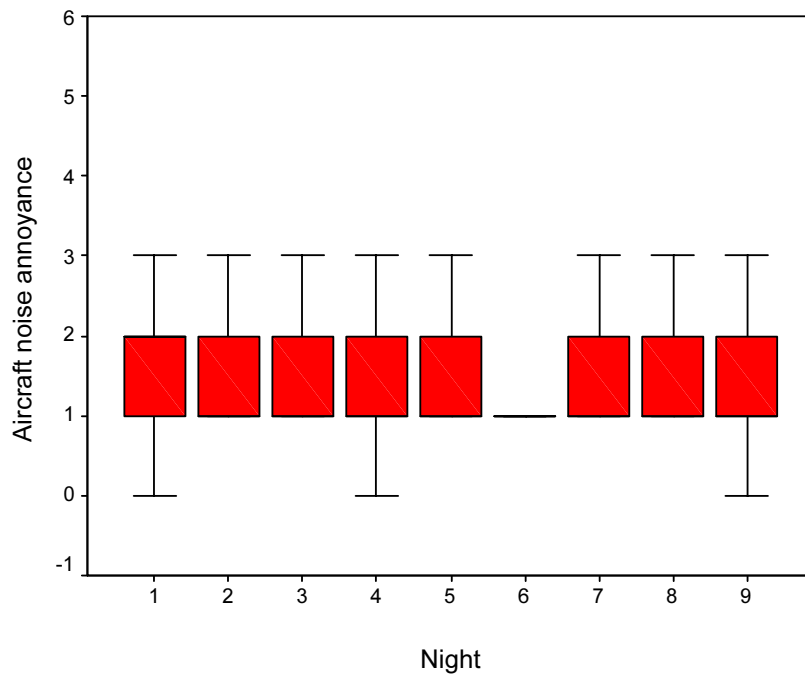


Figure 49: Box-plot of the field subjects' (N = 64) aircraft noise annoyance evaluation ("1 = not" to "5 = very") in the course of the field study.

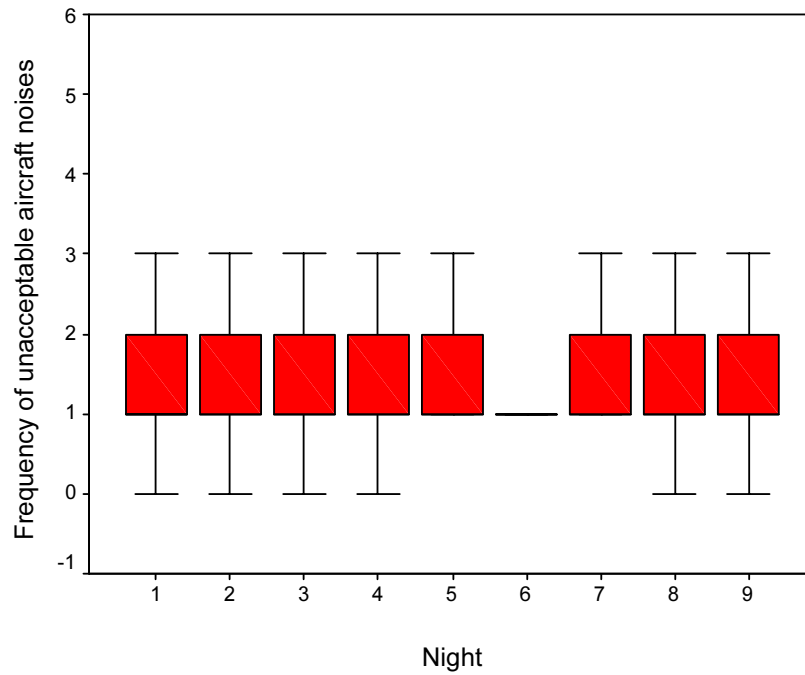


Figure 50: Box-plot of the field subjects' (N = 64) evaluation of the frequency of unacceptable aircraft noises ("1 = never" to "5 = always") in the course of the field study.

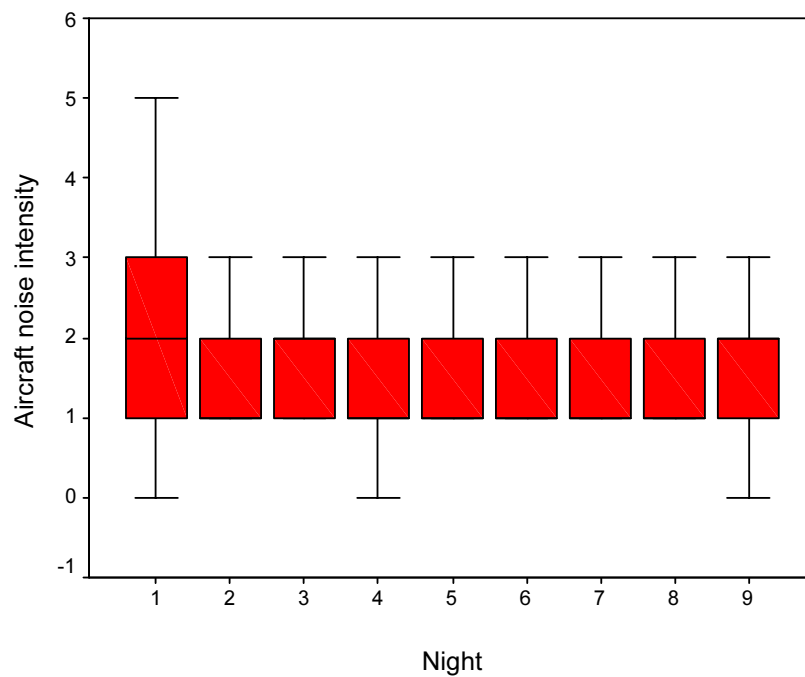


Figure 51: Box-plot of the field subjects' (N = 64) aircraft noise intensity evaluation ("1 = not" to "5 = very") in the course of the field study.

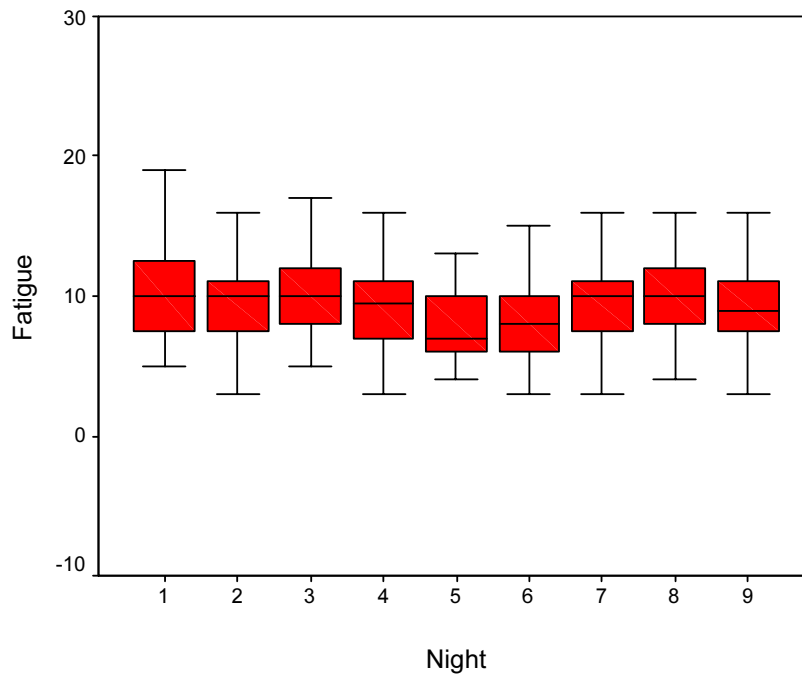


Figure 52: Box-plot of the field subjects' (N = 64) fatigue evaluation ("0 = wide awake" to "20 = extremely tired") in the course of the field study.

### 1.9.1.3 Dose-response curves

The laboratory *dose-response curves for aircraft noise annoyance*, which were developed by means of random effects logistic regression, were *validated by the field study data*. The modelling was based on the same iterative processes as for the laboratory data (cp. *chapter 1.8.2.3*). Solely the physical influence parameters varied, i.e., only the number of aircraft noise events and the  $L_{AS,eq}$  were taken into account. A specific regression model was then developed for each of the parameters. The maximum noise level could not be included, since, unlike the laboratory study, it was inconsistent under real field conditions. The  $NAT70_{outside}$ , which Kastka [2001a, 2001b] developed in order to describe the annoyance near airports (cp. *chapter 1.4.1*), proved to be unsuitable in the descriptive analysis regarding interactions between independent and dependent variables. Thus, a significant dose-response relationship was not identifiable. Tables 15 and 16 describe *the regression models F1 (number of events) and F2 ( $L_{AS,eq}$ ) with the respective significant psychological moderators (F1: age, adaptation to aircraft noise; F2: adaptation to aircraft noise)*, which deviate from those in the

laboratory models (*gender, pre-annoyance due to aircraft noise and necessity of air traffic*).

	<b>Value</b>	<b>DF</b>	<b>p-value</b>
<b>Deviance</b>	333,4987	552	
<b>Parameter Estimates</b>			
	<b>Coefficient</b>	<b>Std.Error</b>	<b>p-value</b>
<b>Intercept</b>	-3,9162	1,2623	0,0019
<b>Age</b>	0,0510	0,0206	0,0134
<b>Number of events</b>	0,0371	0,0079	< 0,001
<b>Adaptation to aircraft noise</b>	-0,9334	0,2516	< 0,001
<b>Variance component random eff.</b>	1,2113	0,2995	

Table 15: Logistic regression model F1 with regard to the aircraft noise parameter number of events and significant psychological moderators ( $p \leq .050$ ).

	<b>Value</b>	<b>DF</b>	<b>p-value</b>
<b>Deviance</b>	346,4440	553	
<b>Parameter Estimates</b>			
<b>Terms</b>	<b>Coefficient</b>	<b>Std.Error</b>	<b>p-value</b>
<b>Intercept</b>	-2,4460	0,9170	0,0076
<b>LAS,eq</b>	0,0989	0,0261	< 0,001
<b>Adaptation to aircraft noise</b>	-1,1381	0,2788	< 0,001
<b>Variance component random eff.</b>	1,5386	0,3623	

Table 16: Logistic regression model F2 with regard to the aircraft noise parameter energy equivalent noise level LAS,eq and significant psychological moderators ( $p \leq .050$ ).

The ratio value/degree of freedom DF, which constitutes .604 for F1 and .626 for F2, indicates an even better fit of the field models than for the laboratory data.

Figure 53 shows the group of persons highly and moderately annoyed by aircraft noise (categories  $\geq 3$ , i.e., moderately and highly annoyed) depending on the number of nocturnal aircraft noise events, as predicted by regression model F1. The psychological parameters considered in the model correspond to the median of the field subjects (age = 37.5 years, noise adaptation = 3). Obviously, the *number of flight situations has a significant influence*: the extent of annoyance increases with growing frequency. 138 aircraft noise events per night cause the highest proportion of annoyed persons (approximately 55%).

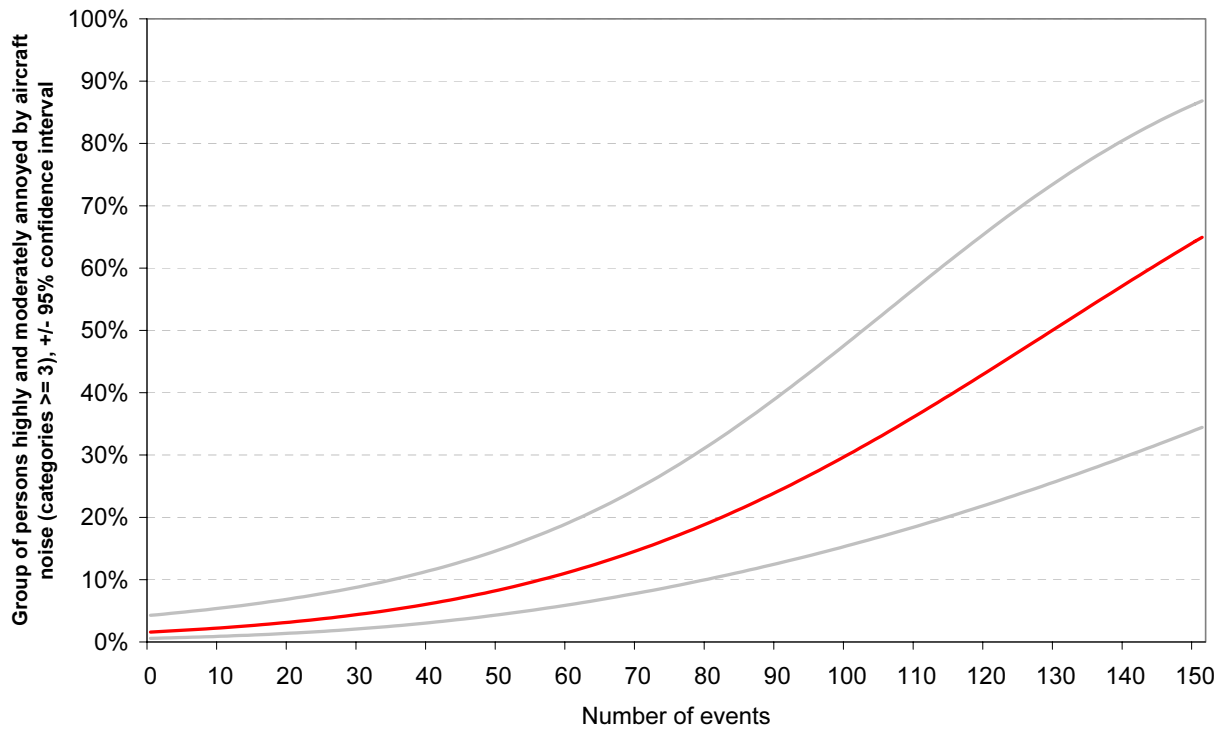


Figure 53: Group of people highly and moderately annoyed by aircraft noise (categories  $\geq 3$ ) depending on the number of aircraft events predicted by the regression model F1.

Figure 54 depicts the percentage of aircraft noise annoyed persons (categories  $\geq 3$ ) in dependence on the energy equivalent noise level  $L_{AS,eq}$ , as predicted by the model F2. The moderator in the model corresponds to the median of the subjects (see above). There is a *significant increase of the proportion of aircraft noise annoyance with growing  $L_{AS,eq}$* , which ranges up to approximately 30% at 47.3 dB(A).

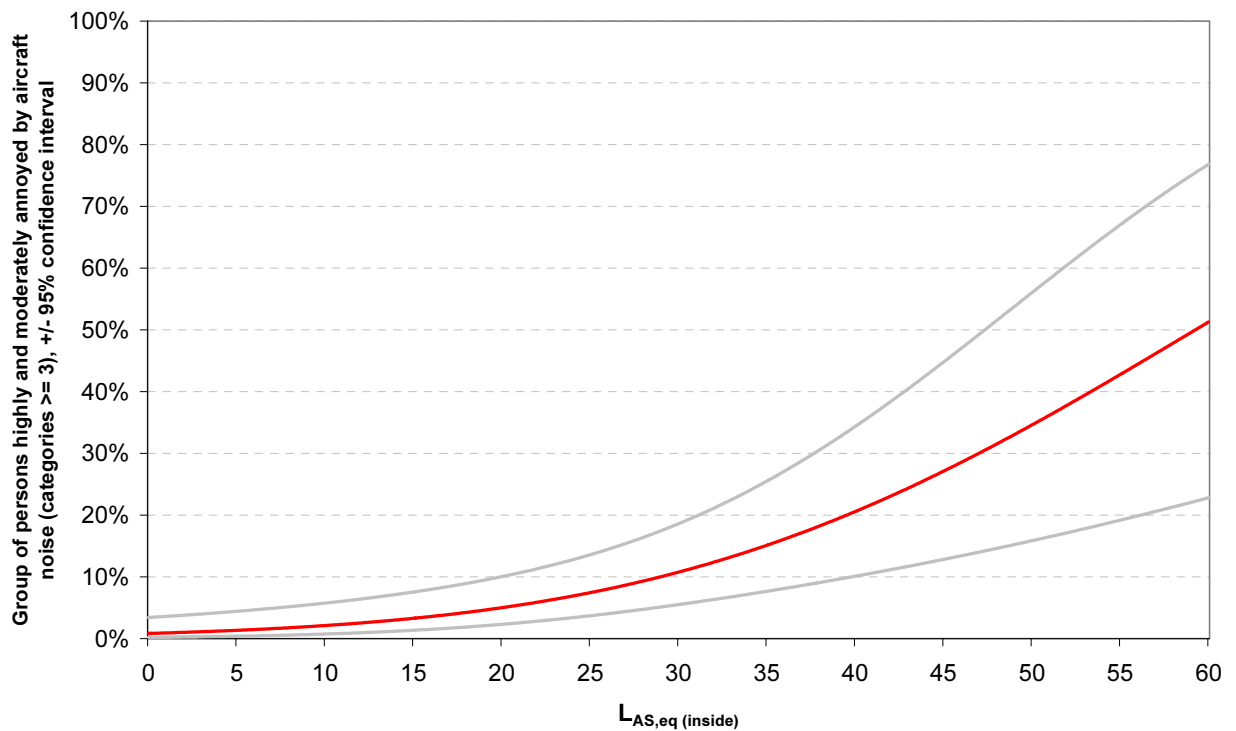


Figure 54: Group of people highly and moderately annoyed by aircraft noise (categories  $\geq 3$ ) depending on the energy equivalent noise level  $L_{AS,eq}$  predicted by the regression model F2.

In figures 55 to 57, the influence of the contributing psychological moderators is summarized regarding both regression models, whereas the median is applied for the *non-illustrated* parameters. It is noticeable that the extent of aircraft noise annoyed persons, which is predicted by F1, is *higher for older than for younger people*. The expected proportion is also *higher for persons with no adaptation to aircraft noise than for those with a very high adaptation*. For a better understanding, aside from the extreme value comparison for both moderators, the expected percentage for the median is given.

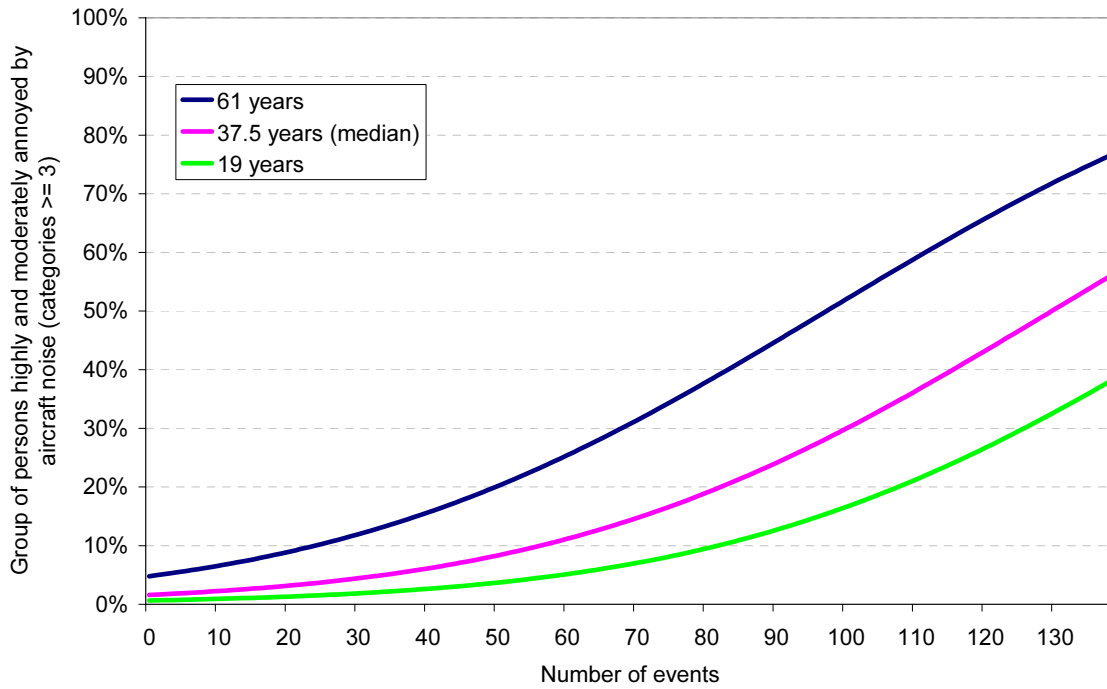


Figure 55: Group of people highly and moderately annoyed by aircraft noise (categories  $\geq 3$ ) depending on the number of aircraft events and the age predicted by the regression model F1.

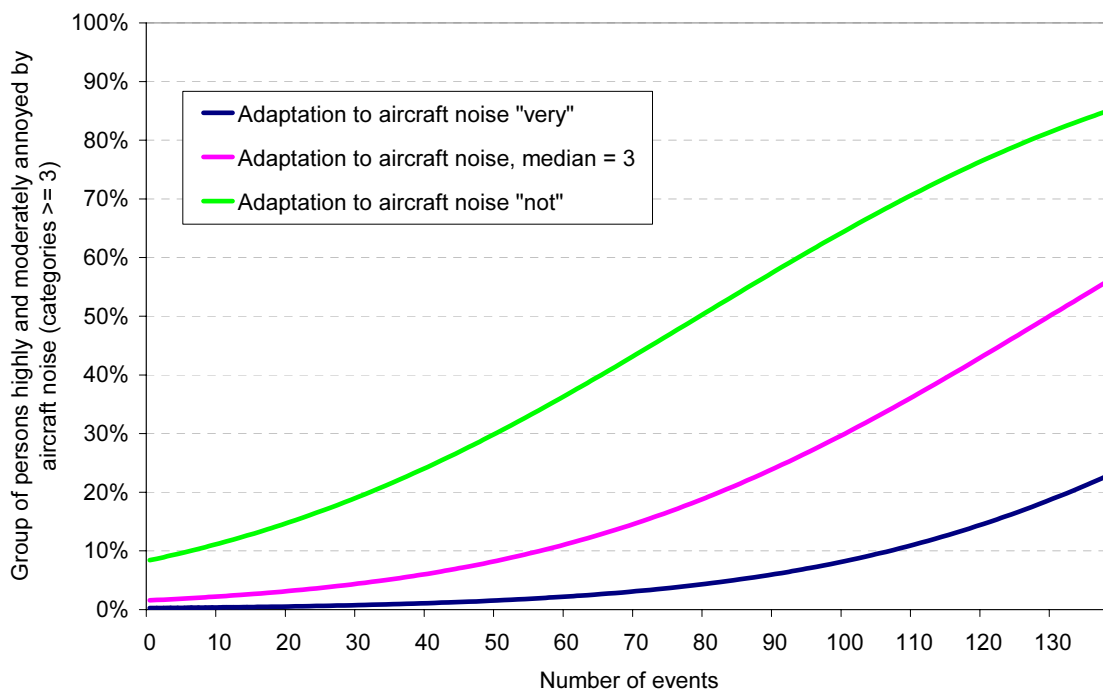


Figure 56: Group of people highly and moderately annoyed by aircraft noise (categories  $\geq 3$ ) depending on the number of aircraft events and the adaptation to aircraft noise ("not", median, "very") predicted by the regression model F1.

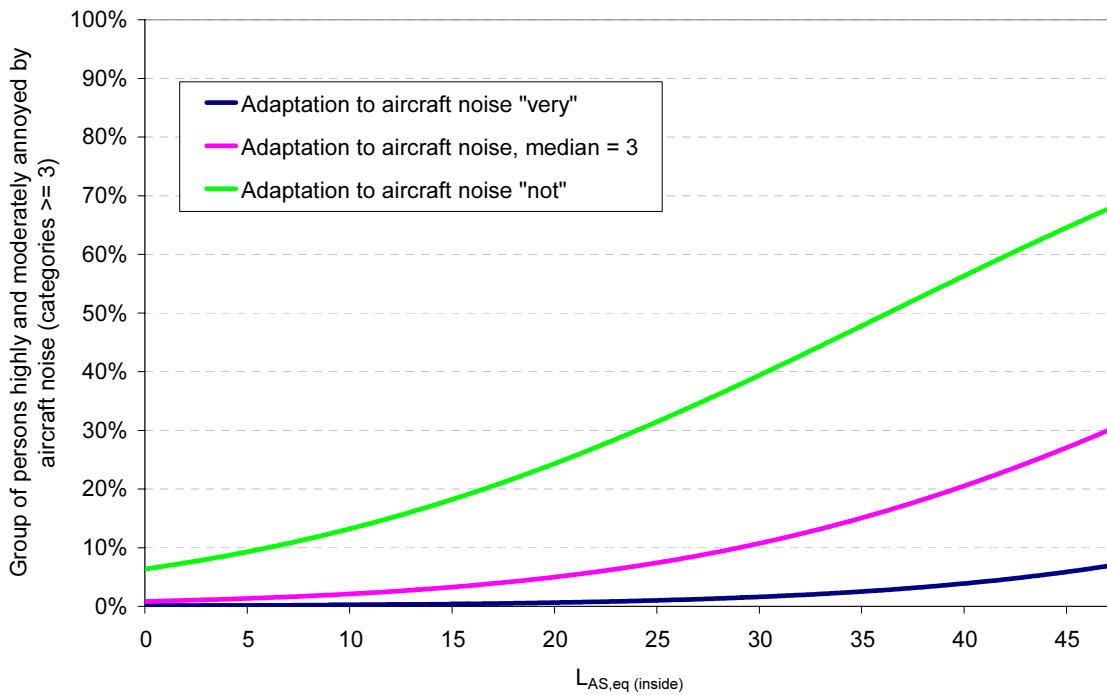


Figure 57: Group of people highly and moderately annoyed by aircraft noise (categories  $\geq 3$ ) depending on the energy equivalent noise level  $L_{AS,eq}$  and the adaptation to aircraft noise ("not", median, "very") predicted by the regression model F2.

In order to *compare the laboratory- and field-specific dose-response relationships*, the curves showing common values of the independent variables number of events and  $L_{AS,eq}$ , as derived from the respective regression models, are compared in figures 58 and 59. It should be noticed, that different psychological moderators are integrated into both the field and the laboratory models. Therefore the laboratory dose-response relationship only applies to females with a pre-annoyance degree of 2 ("little") and an evaluation of the "necessity of air traffic" of 4 ("quite"). To enable the consideration of all level frequencies, the laboratory curve only concerns to a maximum noise level of 55 dB(A). The field-specific curve only applies to persons aged 37.5 years, who have a medium degree of adaptation to aircraft noise. Under consideration of these limitations, it is evident that the laboratory curve lies clearly above the field curve (approximately 20% to 40% difference). Regarding 4 events per night, the predicted group of aircraft noise annoyed persons in the field amounts to 2%, compared to 20% in the laboratory. For 128 events per night, the percentage is 50% in the field, compared to 80% in the laboratory.

Figure 59 depicts the annoyance depending on the energy equivalent noise level. The laboratory-specific dose-response curve only applies to females with a pre-annoyance of 2 ("little") and an assessment of the "necessity of air traffic" of 4 ("quite"). The field curve only concerns people with a medium adaptation to aircraft noise. Taking these limitations into account, it is apparent that the laboratory curve again lies above the field curve (approximately up to 40% difference). The predicted proportion of noise annoyed persons in both the field and the laboratory is still relatively similar (12% to 15%) at 30 dB(A). At 47.3 dB(A), the percentage is 30% in the field compared to 70% in the laboratory.

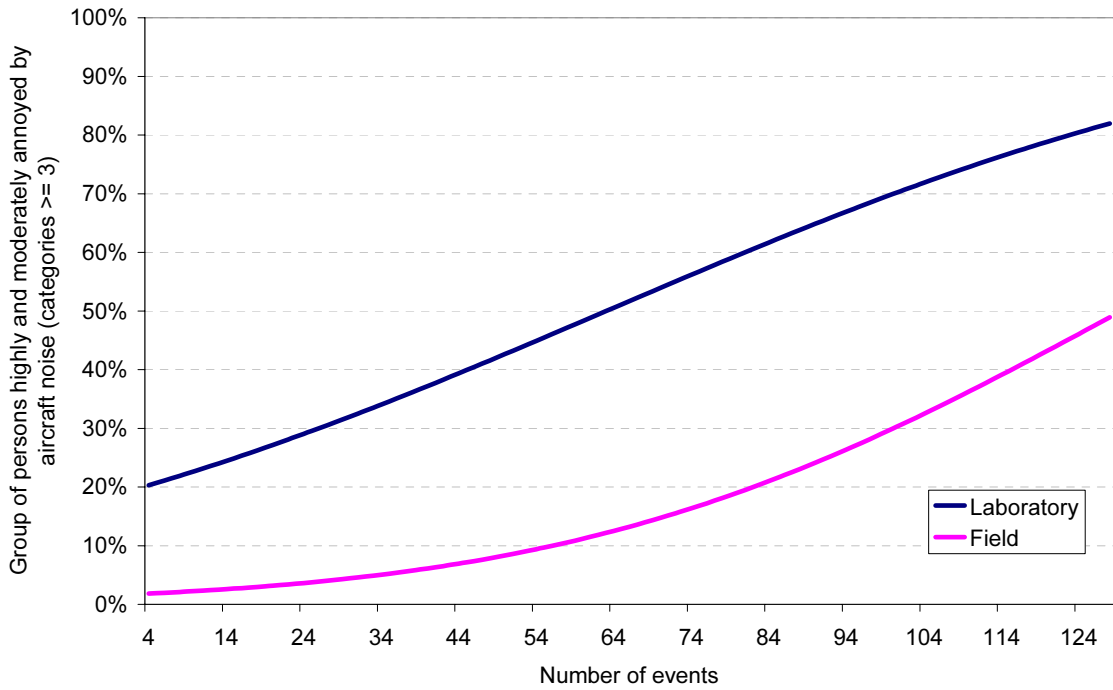


Figure 58: Group of people highly and moderately annoyed by aircraft noise (categories  $\geq 3$ ) depending on the number of events predicted by the laboratory- and field-specific regression models L1 and F1.

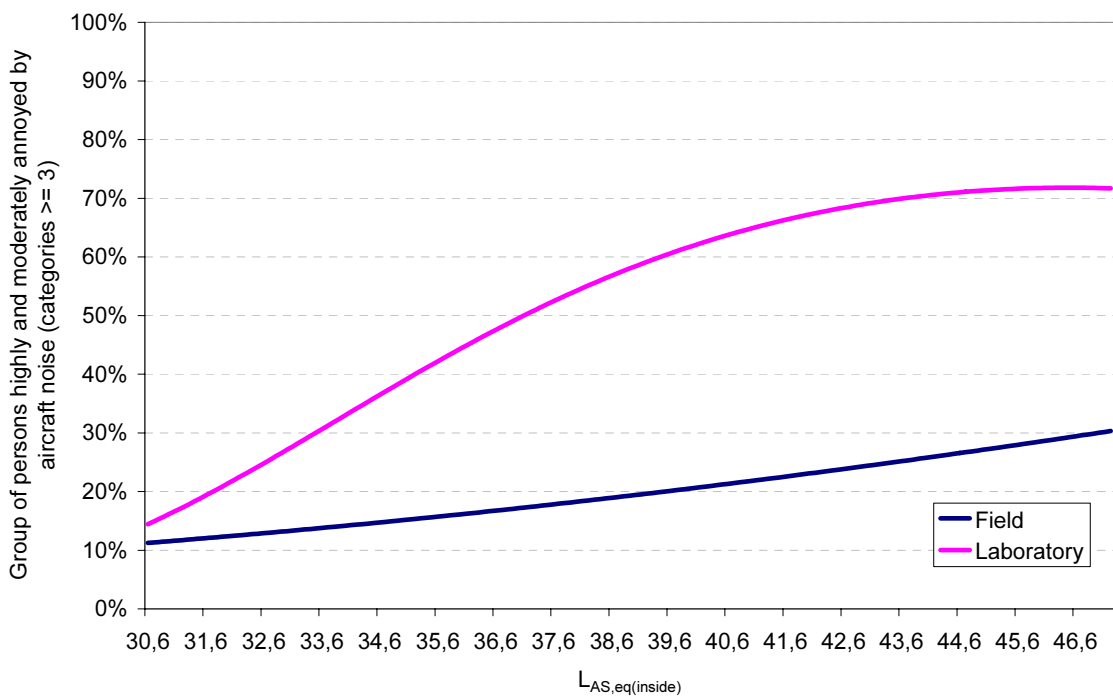


Figure 59: Group of people highly and moderately annoyed by aircraft noise (categories  $\geq 3$ ) depending on the energy equivalent noise level  $L_{AS,eq}$  predicted by the laboratory- and field-specific regression models L2 and F2.

## 1.9.2 Annoyance due to aircraft noise before the field study

The following chapter addresses the aircraft noise annoyance at home *before* the field study (in terms of an aircraft noise *pre-annoyance*, cp. *chapter 1.8.3*). For this purpose, data from the general questionnaire is analyzed, that had been posted before the study began.

### 1.9.2.1 *Semantic analysis of aircraft noise pre-annoyance*

In order to verify the meaning of the term “aircraft noise annoyance”, a varimax-rotated principle component analysis (PCA) was conducted according to the Kaiser criteria. For the purpose of interpreting the first three factors, which together explain 47.7% of the total variance, only items with loadings  $>.50$  were regarded. The results in table 17 confirm that *the concept of aircraft noise annoyance corresponds closely to aircraft noise-induced disturbances of activities such as communication, recuperation and sleep* [cp. Guski et al. 1999; Kastka 2001a]. The factor structure, which resulted from the analysis of the laboratory data, is largely verified.

The main component (approximately 31% variance explanation) combines the experienced disturbances of the mentioned activities, as well as the related emotions and cognitions, caused by aircraft noise in one’s residence. Additionally, items regarding the description of unacceptable aircraft noises during the day and night are found. Unlike the laboratory investigation, the first factor also combines image variables concerning the social assessment of air traffic (e.g., its “necessity” and “health-hazardous effect”, as well as “possibilities of avoiding it”), and the adaptation to aircraft noise, which together constitute the second component in the laboratory study. Unlike the laboratory findings, all items describing the aircraft noise intensity in the residential area, which are united in the second component (approximately 9% variance explanation), are absent.

As in the laboratory survey, the third factor (approximately 8% variance explanation) contains aspects concerning the (dis-)contentment with characteristics of the residential area (e.g., air quality, outer appearance) in terms of the so-called "environmental aesthetic" [Booth 1999; Guski 1987; Oliva 1998].

**Rotated component matrix**

	Component		
	1 (31,2%)	2 (8,5%)	3 (8%)
disturbance of relaxation and leisure time	.815	.264	-.051
lack of pleasure in recreational time	.800	.150	-.035
individual health hazard caused by aircraft noise	.769	.130	.187
adaptation to aircraft noise	-.761	-.073	-.149
health hazard caused by air traffic	.743	-.036	-.163
frequency of unacceptable aircraft noises during night	.711	.371	.156
prevention of reading/thinking	.701	.256	-.257
to do without visitors	.695	.187	-.313
petulance	.694	.211	.272
being reluctant to come home	.660	.231	.014
prevention of falling asleep	.655	.319	.097
general health hazard caused by aircraft noise	.643	.047	.027
being reluctant to spend time outside	.622	.262	-.119
avoidability of air traffic	.619	-.198	-.252
disturbance of conversations	.613	.411	-.270
general attitude towards air traffic	-.607	.117	.324
frequency of unacceptable aircraft noises during day	.600	.352	-.032
to do without open the windows	.570	.283	.132
afraid	.553	-.004	-.027
necessity of air traffic	-.500	.111	.396
insecurity of air traffic	.425	-.086	-.318
to do without telephone calls	.419	.279	-.075
eco friendliness of air traffic	-.319	-.123	.168
aircraft noise intensity, outside	.056	.798	-.033
aircraft noise intensity, tilted bedroom window	.253	.766	-.076
aircraft noise intensity, tilted window	.222	.743	-.005
aircraft noise intensity, closed bedroom window	.232	.706	-.243
aircraft noise intensity, closed window	.120	.698	-.271
contentment with public transportation system	-.010	.500	.098
contentment with shopping possibilities	.055	.408	.110
contentment with air quality	-.037	-.048	.725
contentment with outer appearance	.048	-.138	.622
contentment with proximity to work place	.218	.179	.567
overall residential contentment	-.022	-.191	.554
trembling of walls and clinking of windows	.396	.313	-.453
contentment with recreation possibilities	.298	.259	.453
increasing the volume of the radio/TV	.390	.328	-.403
reliability of air traffic	-.213	-.046	-.246

method of extraction: principal component analysis according to the Kaiser criteria

Table 17: Varimax-rotated principal component analysis of aspects regarding aircraft noise pre-annoyance. Data from the general questionnaire of the field sample (N = 64) are considered. For the factor interpretation items with loadings > .50 (grey-shaded) have been taken into account.

### 1.9.2.2 The influence of psychological moderators on aircraft noise pre-annoyance

Figure 60 illustrates the percentile frequency distribution of the annoyance ratings before the field study. There are the quartiles  $Q_1 = 2$  ("little" annoyed),  $Q_2 = 3$  ("moderately" annoyed) and  $Q_3 = 4$  ("rather" annoyed). Unlike the laboratory sample, "only" 64% of the ratings are distributed among the first three categories (laboratory sample: 87%). 36% are "rather" or "highly" annoyed (laboratory sample: 13%).

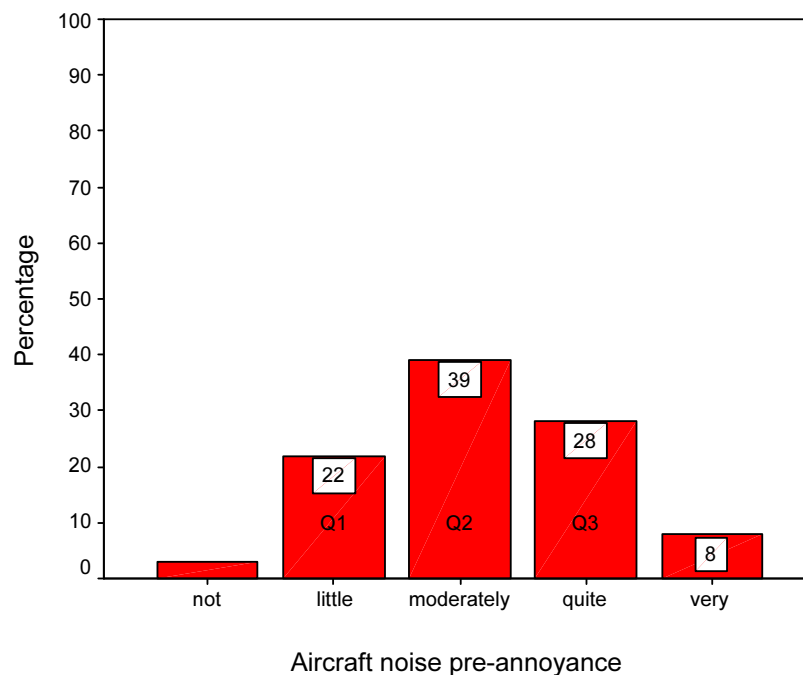


Figure 60: Percentile distribution of the annoyance evaluation ("How much are you annoyed by aircraft noise?") before the field study (N = 64).

On average, the field study participants remember nearly double as many unacceptable aircraft noises as the subjects of the laboratory sample: during the day (from 6 am to 10 pm) 5.70 (standard deviation = 8.78) and during the night (from 10 pm to 6 am) 4.61 noises (standard deviation = 8.45).

Based on the qualitative analysis, more than half (55%) of the subjects are highly annoyed by aircraft noise before the study (laboratory sample: 37%). This is favourable for the representation of the chosen collective with regard to the examined objectives. Similar to the studied sleep laboratory subjects, aircraft noise events when falling asleep, during the night and early in

the morning (22 namings) were complained about. The level (12 namings) is named as main reason for the considerable annoyance. In contrast to the laboratory subjects, the number of aircraft noises, as well as noise-induced disturbances of communication and sleep, also play an important role (7 namings each). 44% of the subjects are of the opinion that these especially annoying flight situations should be avoided (laboratory sample: 20%).

The influence of non-acoustic moderators on aircraft noise pre-annoyance was tested by means of Kruskal-Wallis one-way analysis of variance. For this purpose, median splits of the field sample (N = 64) were carried out (cp. *chapter 1.8.3.2*).

#### **a) Situational or contextual moderators**

Positively judged residential variables often decrease noise effects in terms of the "environmental aesthetic" [Booth 1999; Guski 1987; Oliva 1998]. The importance of the contentment with the residential area was examined with regard to the:

- *outer appearance* (median = 4.0),
- *air quality* (median = 4.0),
- *access to the public transportation system* (median = 4.0)
- *proximity to the work place* (median = 4.0)
- *shopping possibilities* (median 4.0)
- *recuperation and relaxation possibilities* (median = 4.0)

In addition, the effect of the *overall residential contentment* (median = 4.0) on aircraft noise pre-annoyance was tested. As in the laboratory inquiry, no significant differences between satisfied and less satisfied subjects (cp. *chapter 1.8.3.2*) can be found for the individual aspects of the residential area. However, concerning *overall residential contentment* ( $\chi^2_{(1, .033)} = 4.527$ ) there is a significant finding in terms of a positive moderating impact of the surroundings (high residential contentment).

A significant influence of the *time of residence* (median = 8.00 years) on aircraft noise pre-annoyance does not exist.

88% report having double window glazing in their residence. 8% have single and the remaining 4% have threefold window glazing (laboratory study: 10%, respectively 2%). 55% of the subjects are “rather” or “very” satisfied with the available sound insulation of the closed windows (laboratory study: 64%), while 36% are “moderately” and 9% are “not” or a “little” satisfied. About 64% of the subjects would like to have better noise control in their homes (laboratory study: 51%). Unlike the laboratory study, *different window glazing does not accompany significant differences in the aircraft noise pre-annoyance* (figure 61). Therefore, different noise controls do not have a systematic effect on the annoyance reaction of the field study participants [cp. Kastka 1990; Paulsen et al. 1992].

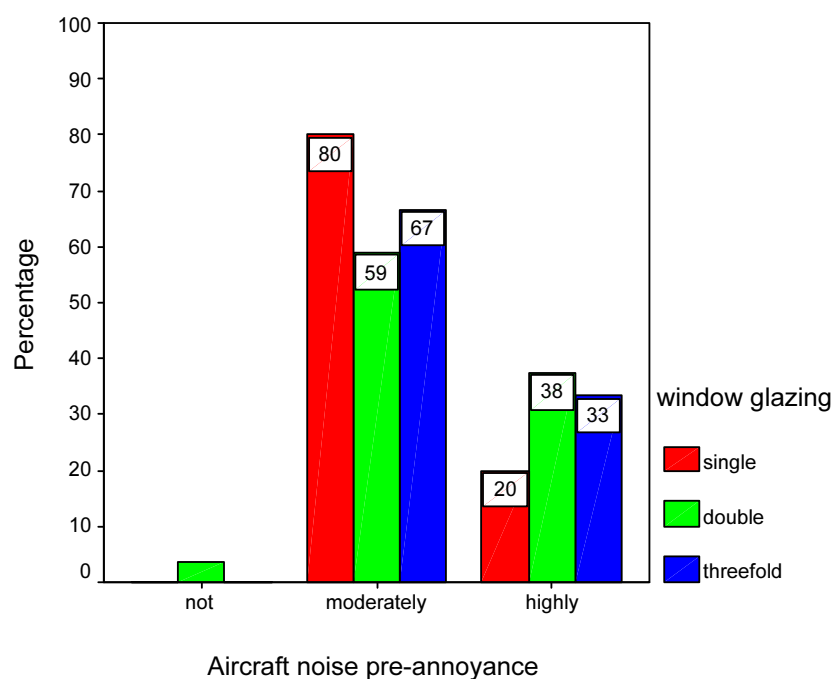


Figure 61: Aircraft noise pre-annoyance depending on domestic noise control (window glazing) *before* the field study (N = 64).

As in the laboratory inquiry, significant differences between the assessed *aircraft noise intensity* ( $\chi^2_{(4, .000)} = 197.370$ ) and the *pre-annoyance* ( $\chi^2_{(4, .000)} = 156.478$ ) are shown by means of the Friedman-test, depending on different *room-acoustic conditions* at home (figures 62 and 63). Wilcoxon paired

comparisons exhibit significant differences between the respective room-acoustic conditions (without table). Only the conditions "bedroom window closed" vs. "window closed", and "bedroom window tilted" vs. "window tilted" do not differ significantly in respect to both variables. The conditions which are most sensitive are the "tilted-window-situations" and "outside", where the outside condition for the rated aircraft noise intensity is more sensitive than the "tilted-window-situations" [cp. Kastka 1990, 1999, 2001a]. In comparison to the laboratory data, corresponding to a stronger classification, the borders of the 1<sup>st</sup> and 3<sup>rd</sup> quartile for the different conditions are almost always displaced one or two categories higher.

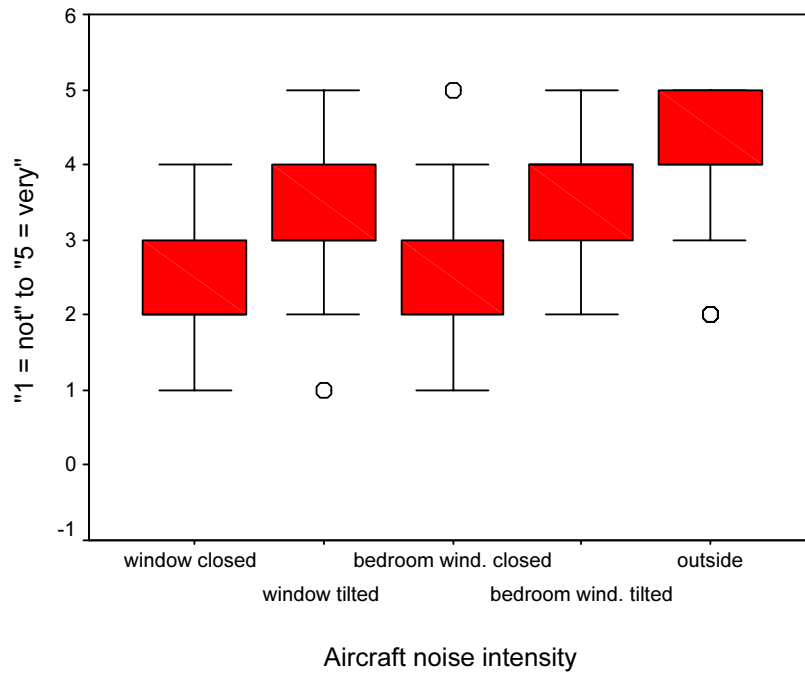


Figure 62: Aircraft noise intensity under different room-acoustic conditions at home (*"How much do you hear the aircraft noise...?"*) before the field study (N = 64).

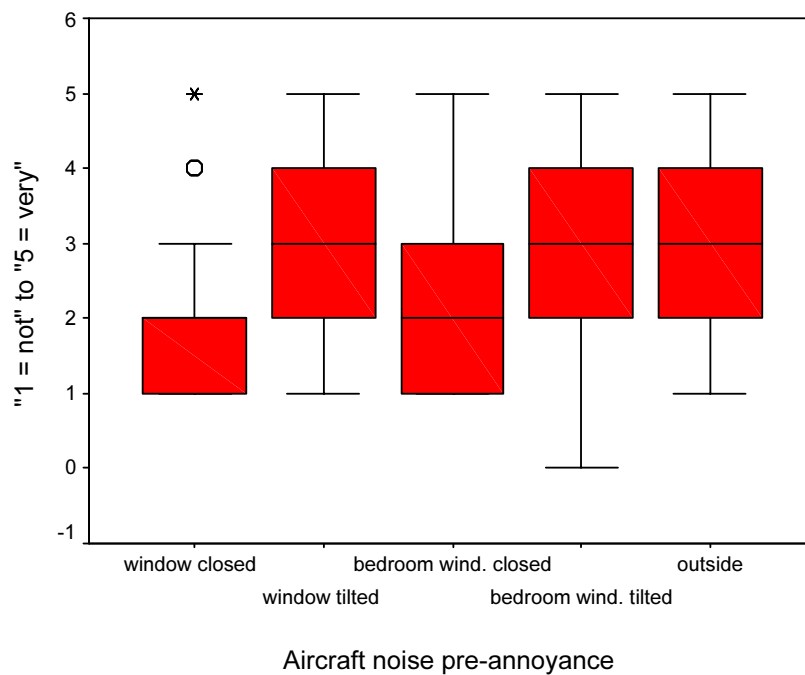


Figure 63: Aircraft noise pre-annoyance under different room-acoustic conditions at home (*"How much are you annoyed by aircraft noise...?"*) before the field study (N = 64).

## **b) Social moderators**

A Friedman-test concerning *general attitudes towards the main traffic modes road, railway and air traffic* proves significant differences ( $\chi^2_{(2, .000)} = 21.804$ ), whereas in the Wilcoxon paired comparison, railway traffic has again a significant bonus compared to road and air traffic. However, attitudes towards road and air traffic again do not differ (figure 64). With regard to traffic *noise annoyance*, there are also no significant differences between the three main traffic modes ( $\chi^2_{(2, .000)} = 90.028$ ). Wilcoxon paired comparisons confirm the railway bonus in respect to road and air traffic (noise). In the field study, air traffic is evaluated as significantly more annoying than road traffic (figure 65). Contrary to the laboratory subjects, no significant differences can be found concerning *noise adaptation* (figure 66).

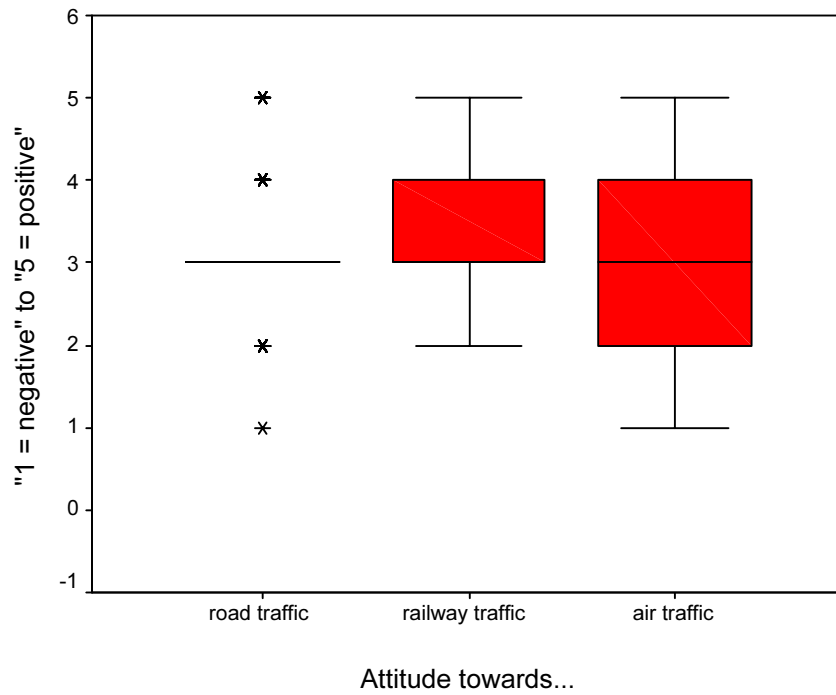


Figure 64: Attitudes towards the three main traffic modes (*"What is your overall attitude towards the following traffic modes?"*) before the field study (N = 64).

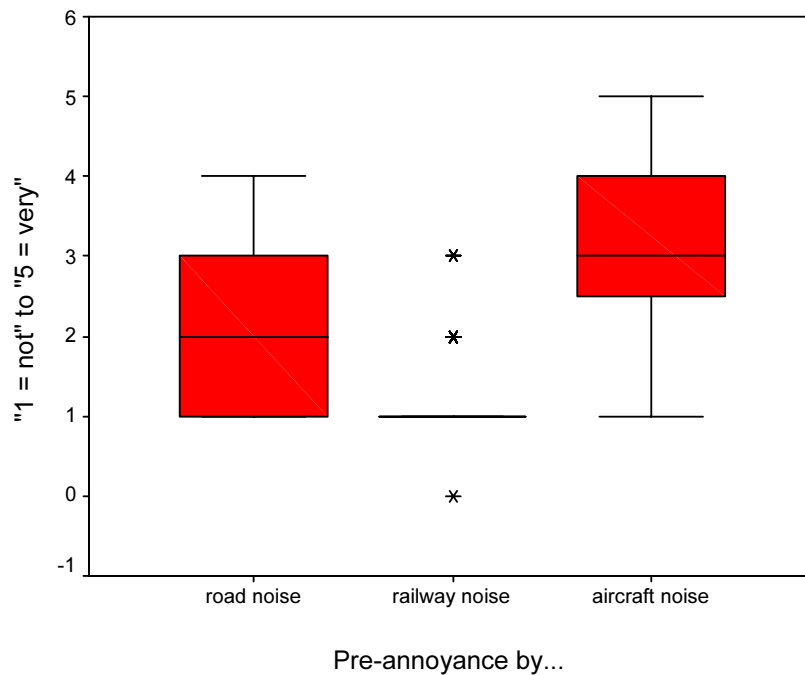


Figure 65: Traffic noise pre-annoyance (*"How much are you annoyed by the following kinds of noise...?"*) before the field study (N = 64).

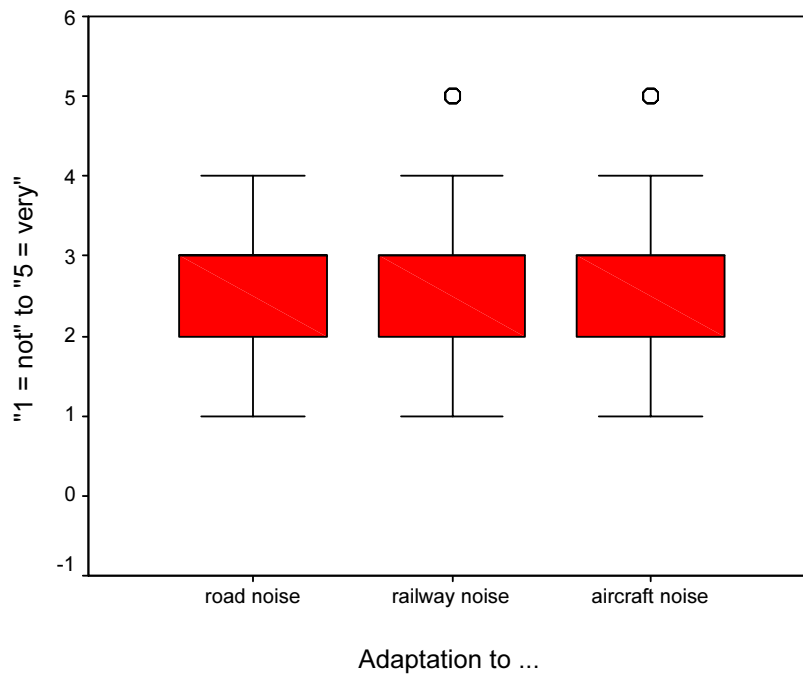


Figure 66: Traffic noise adaptation (*"How good can you generally adapt with the following kinds of noise ...?"*) before the field study (N = 64).

With respect to the so-called image variables, which provide an important (psychological) contribution to the explanation of noise effects [Guski 1987], the source of aircraft noise- air traffic- has the image to be "quite necessary", "moderately harmful", "little eco friendly" and "little avoidable" (figure 67). Compared to the laboratory data, the borders of the first and third quartile are one to two categories lower.

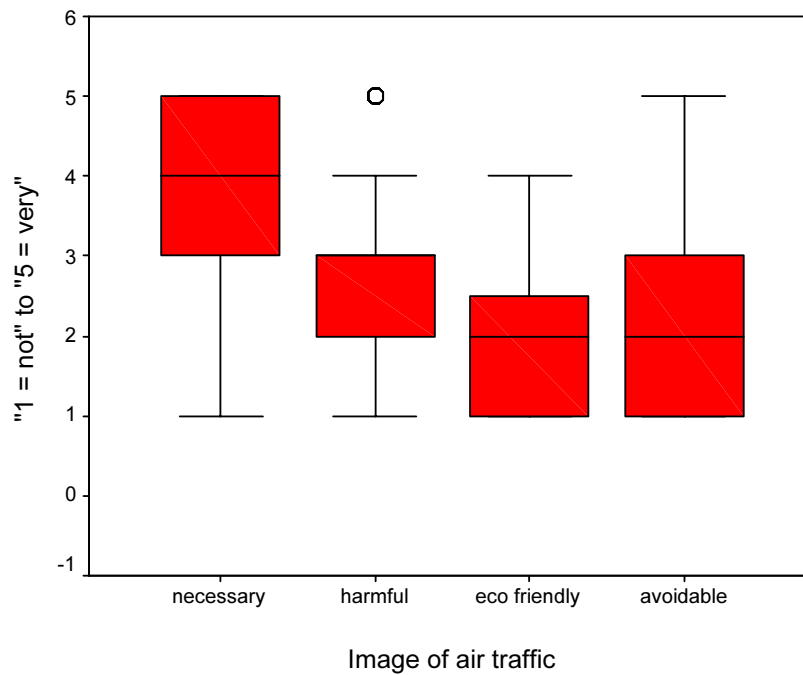


Figure 67: Image of air traffic (“In general, do you regard air traffic as...?”) before the field study (N = 64).

The *image-variables* perceived “health hazard” ( $\chi^2_{(1, .000)} = 13.765$ ; median = 3.0), “eco friendliness” ( $\chi^2_{(1, .006)} = 7.504$ ; median = 2.0) and “avoidance possibilities” ( $\chi^2_{(1, .013)} = 6.235$ ; median = 4.0) of air traffic, have a statistically significant influence on the aircraft noise pre-annoyance. The latter variable does not have a significant effect in the laboratory inquiry. There is again a significant moderating impact of the assessment of the *health hazard caused by aircraft noise* ( $\chi^2_{(1, .026)} = 4.989$ ; median = 3.0). The “general health hazard caused by aircraft noise” is also seen as significantly higher than the “individual hazard” is rated on part of the field subjects (Wilcoxon-test:  $Z_{(p \leq .000)} = -5.361$ ) (figure 68). In addition to this, the results again show a significant influence of the *general attitude* towards air traffic on the annoying effect of aircraft noise ( $\chi^2_{(1, .000)} = 14.942$ ; median = 3.0). Unlike the laboratory study, the “necessity of air traffic” (median = 4.0) is not significant.

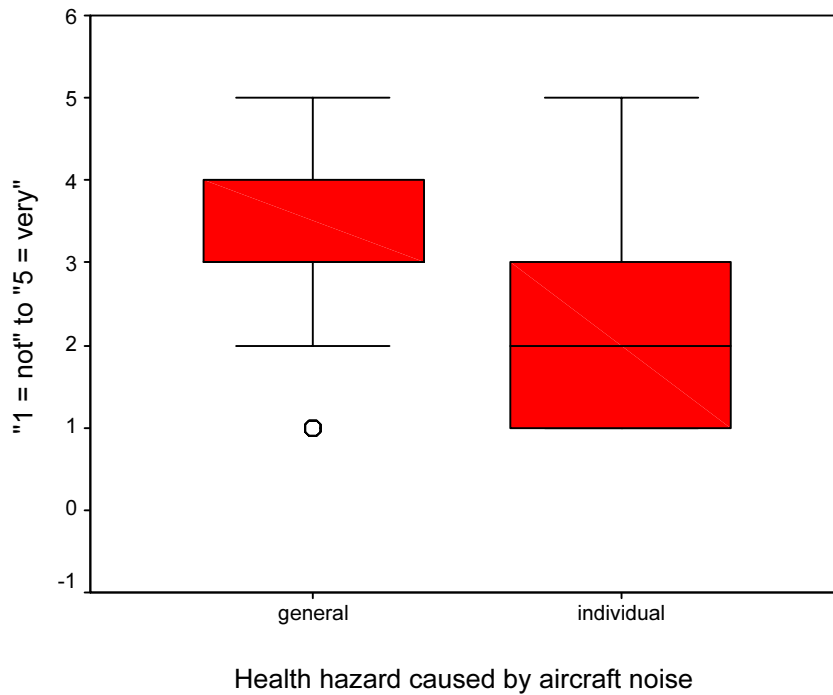


Figure 68: Health hazard caused by aircraft noise (*“How much aircraft noise generally harms the health?”* and *“How much aircraft noise harms your own health?”*) before the field study (N = 64).

Figure 69 describes the extent of confidence that the field study participants have towards persons and institutions potentially responsible for causing aircraft noise. As in the laboratory inquiry, the “aircraft manufacturers” and “communities and cities” dominate.

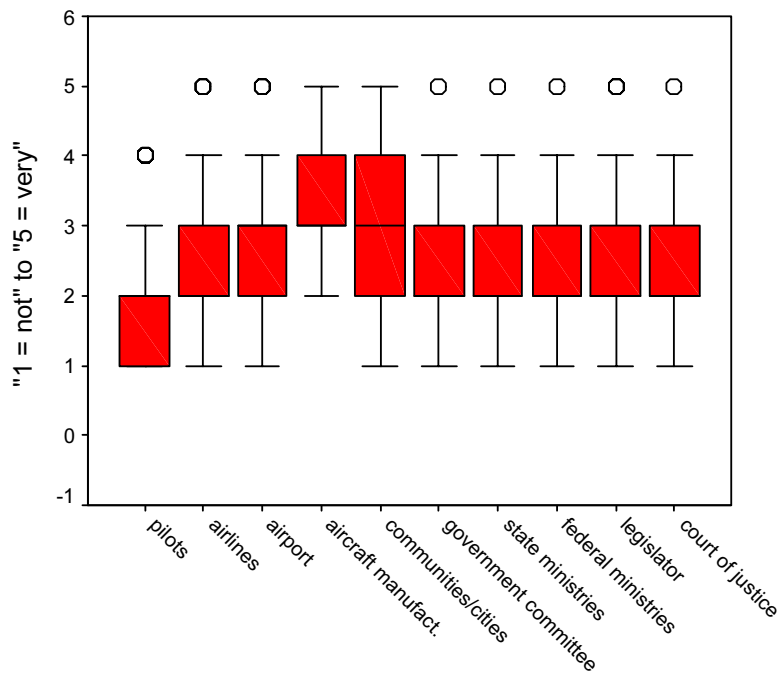


Figure 69: Confidence in people and institutions perceived as responsible for reducing aircraft noise (“To your mind, how much lobby the following persons and institutions for an aircraft noise reduction?”) before the field study (N = 64).

The confidence in *aircraft noise responsables* “communities and cities” ( $\chi^2_{(1, .011)} = 6.489$ ; median = 3.0), “government committees” ( $\chi^2_{(1, .028)} = 4.818$ ; median = 2.0) and “state ministries” ( $\chi^2_{(1, .026)} = 4.997$ ; median = 2.0), has a systematic influence on the aircraft noise pre-annoyance. A moderating effect of confidence on the remaining noise-responsible persons, as well as on the belief in the successful *chance of aircraft noise reduction* does not exist. 47% of the collective are of the opinion that the chances of noise reduction are “bad” or “very bad” (32% of the laboratory sample). 14% believe that “good” to “very good” chances exist (20% of the laboratory sample) (figure 70). Economic interests are once again stated as the main reason against a successful aircraft noise reduction.

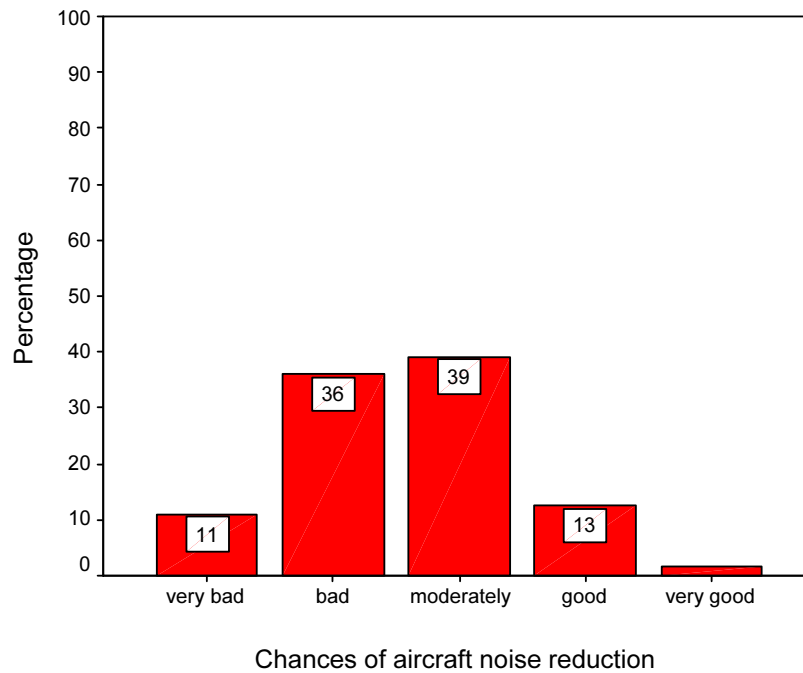


Figure 70: Chances of aircraft noise reduction (“To your mind, how good are the chances of a successful aircraft noise reduction?”) before the field study (N = 64).

### c) Personal moderators

As for the laboratory sample, the inferential statistics prove significant effects for *individual noise sensitivity* ( $\chi^2_{(1, .043)} = 4.084$ ; media = 3.0) and *subjective noise adaptation* ( $\chi^2_{(1, .001)} = 11.124$ ; median = 3.0). The *participation in activities against aircraft noise* (active vs. non-active) also has a statistical influence ( $\chi^2_{(1, .003)} = 8.986$ ). 12.5% of the subjects report having taken part in activities against aircraft noise (participation in the form of demonstrations, public events, and written complaints). The personal noise affection is given again as the main reason for the participation. Just like the laboratory study, a moderating impact of *travelling experiences on aircrafts* (flyers vs. non-flyers) and of *residential status* (owner vs. renter) cannot be found.

## PART 2: MOOD, STRESS AND RECUPERATION

### 2.1 Introduction

Changes of mood, stress and recuperation following a night of noise exposure also belong to the group of noise-induced *secondary reactions* (cp. *chapter 1.1*). Thus, the examination of the human-specific psychological effects of nocturnal aircraft noise also included inquiries of these secondary disturbances. Two standardized questionnaires were used to measure them: the multi-dimensional mood questionnaire (MDMQ) by Steyer et al. [1997], and the recuperation and load questionnaire (RLQ) by Kallus [1995].

The MDMQ registers three bipolar dimensions of the current psychical mood: (1) good – bad mood, (2) alertness – fatigue, and (3) ease – unease. Each dimension contains eight items (adjectives), based on which the *current mood* (“*At the moment I feel...*”) is assessed by means of 5-point category scales (1 = “not at all” to 5 = “very”). The values of the respective items of a dimension are combined to a sum or scale value (values from 0 to 40):

1. *Good – bad mood (GB)*: a high scale value implies a positive mood: the person feels well, is happy and content. Low values signify a negative state of feeling: the person feels unwell and ill, is distempered and discontent.
2. *Alertness – fatigue (AF)*: a high scale value denotes alert and rested persons; they feel wide awake. A low value denotes that the person is tired, drowsy and nerveless.
3. *Ease – unease (EU)*: high scale values indicate that the person feels inwardly calm and composed. A low value implies a tense, nervous and inwardly uneasy person.

The MDMQ was filled out in the morning after waking up and in the evening.

The RLQ characterizes the current stress status of a person, i.e., it describes the current “stress-recuperation-balance”. It is assumed, that an accumulation of load from different spheres, in connection to insufficient recuperation possibilities, leads to a changed psycho-physical overall condition [Kallus 1995]. The EFB determines the degree of stress and recuperation over a certain period of time as a retrospective assessment. In the original questionnaire the intended time period comprises three days. Within the framework of the conducted aircraft noise effects studies, this time period was shortened to one day, in order to enable an inquiry concerning an entire day following an aircraft noise-exposed night. For this purpose, the EFB was completed every evening. Stress is generally understood as psychological stress, whereas aspects of mental and physical stress are also considered. The measurement of stress contains a total of seven sub-scales, from which the *total stress score* (STRESS-T) is calculated:

1. *General load – depressiveness (LOAD-GEN)*: persons with high scale values are mentally burdened, depressed, unbalanced, and lethargic.
2. *Emotional load (LOAD-EMO)*: the experience of persons with high scale values is characterized by the occurrence of aggravation, aggression, fear, and inhibition.
3. *Social tensions (LOAD-SOC)*: high scale values denote persons, who have frequent altercations and arguments, feel aggravated about others and often feel offended.
4. *Unresolved conflicts – failure (CONFL)*: high values are reached when conflicts remain unresolved, unpleasant things have to be taken care of, goals are not reached, and certain thoughts cannot be disengaged from.

5. *Fatigue – time pressure (FATIG)*: high scale values signify time pressure, a high degree of fatigue, excessive demands, and a lack of sleep.
6. *Lack of energy and concentration (LACK-EC)*: high values indicate ineffective performance and a lack of concentration.
7. *Somatic complaints (LOAD-SOM)*: high scale values denote somatic illness and somatic complaints.

The *total recuperation score (REC-T)* is derived from five sub-scales:

1. *Success – efficiency (SUCCESS)*: high values stand for success and the enjoyment of one's work.
2. *Recuperation in the social domain (REC-SOC)*: high values are achieved by frequent enjoyable social contacts in connection with relaxation and amusement.
3. *Somatic recuperation (REC-SOM)*: high values indicate somatic recuperation and fitness.
4. *General recuperation – well-being (REC-GEN)*: high scale values signify a frequent good mood, positive well-being, general relaxation, and contentment.
5. *Restorative sleep (SLEEP)*: high values characterize a well rested wake up, as well as the lack of disturbances while falling asleep and during sleep.

Each stress and recuperation scale includes six items, which describe the frequency of circumstances (e.g., "... *I have read the newspaper*") over a defined period of time (one day), by means of 7-point category scales (0 = "never" to 6 = "always").

An extensive, theoretical description of mood, stress and recuperation, their scaling methods and related empirical results of noise effects research is given by Rey [2002].

## 2.2 Objectives

For the examination of the human-specific effect of nocturnal aircraft noise on the *psychical mood* in the morning and night of the subsequent day, the following hypothesis was tested:

*The mood is impaired by nocturnal aircraft noise exposure, which is denoted by the decrease of the scale values of the MDMQ. An impairment of the mood exists when there is a significant decline of the scale values in at least one of the three dimensions of the MDMQ:*

- *GB*: the subjects feel unwell, ill and distempered rather than they are in a good mood, happy and content.
- *AF*: the subjects are tired, drowsy and nerveless rather than wide awake.
- *EU*: the subjects are inwardly tense, nervous and uneasy, rather than calm and composed.

Furthermore, an analysis concerning whether the *stress and recuperation processes* change due to an impairment of sleep by nocturnal aircraft noise, was conducted. The noise-induced psychological reactions on the evening following an aircraft noise-exposed night were tested by means of two hypotheses:

- *The degree of stress increases in correspondence with the extent of aircraft noise exposure. The scale values for stress (total score, as well as single scales of the RLQ) rise with an increasing noise exposure. Increased stress exists if a significant augmentation of the scale values*

occurs for the total stress (STRESS-T), or for at least one of the seven sub-scales: general load (LOAD-GEN), emotional load (LOAD-EMO), fatigue – time pressure (FATIG), social tensions (LOAD-SOC), somatic complaints (LOAD-SOM), unresolved conflicts – failure (CONFL), and lack of energy and concentration (LACK-EC).

- *The degree of recuperation is reduced corresponding to the extent of noise exposure. The scale values for recuperation (total score and single scales of the RLQ) decline with increasing aircraft noise exposure. A deterioration of recuperation exists when a significant decline of the scale values occurs for the total recuperation (REC-T), or for at least one of the five dimensions: general recuperation – well-being (REC-GEN), somatic recuperation (REC-SOM), recuperation in the social domain (REC-SOC), success – efficiency (SUCCESS), and restorative sleep (SLEEP).*

The hypotheses were tested by means of both descriptive (*chapter 2.3.1.1*) as well as inferential (*chapter 2.3.1.2*) inter-individual comparisons between the control groups (N = 16) and experimental groups (N = 112) from the sleep laboratory study. This enabled the deduction of the general influence of aircraft noise on the examined reaction parameters regardless of its extent. Furthermore, the experimental groups' data of various examination days in the laboratory were compared (*chapter 2.3.2.1.1*). Kruskal-Wallis one-way analysis of variance for testing the main effects for the aircraft noise parameters  $L_{AS,max}$ ,  $L_{AS,eq}$  and of the number of aircraft noise was conducted (*chapter 2.3.2.1.2*). Potential dose-response relationships between the three physical aircraft noise variables and the psychological variables were tested (*chapter 2.3.2.2*).

The *validation of the laboratory results* was conducted by means of the performed *field study* (N = 64) (*chapter 2.4*).

## 2.3 Results of the sleep laboratory study<sup>28</sup>

### 2.3.1 Inter-individual comparison of control and experimental groups

#### 2.3.1.1 Descriptive statistics

Tables 18 to 21 list the measures of the central tendency (median and mode) and the dispersion (range) of the dependent variables for the control and experimental groups in correspondence to the non-metric of scale level. Only the measurements after the baseline night and the 9 consecutive aircraft noise-exposed nights were taken into account.<sup>29</sup>

Statistics

		GB evenings	AF evenings	EU evenings	GB mornings	AF mornings	EU mornings
N	Valid	1115	1115	1115	1112	1112	1112
	Missing	5	5	5	8	8	8
Median		34	30	33	32	26	32
Mode		36	36	36	36	28	36
Range		32	32	32	32	32	32

Table 18: Measures of central tendency (median and mode) and dispersion (range) regarding the experimental groups' mood (N = 112) (abbreviations: GB = good – bad mood, AF = alertness – fatigue, EU = ease – unease).

<sup>28</sup>Due to the non-metric scale level and the insufficient normal distribution of data which appeared in the Kolmogorov-Smirnov-test of the laboratory data, non-parametric procedures were chosen. In all analyses, the probability of rejecting the null hypothesis according to Bonferoni was corrected to  $\alpha/n$ , dependent on the number of conducted individual tests.

<sup>29</sup>The aircraft noise presented in the laboratory included starting as well as landing airplanes, since the results of a Mann-Whitney-U-test comparing the effect of starting and landing noises only proved significant differences for the parameters "AF mornings" (middle rank<sub>landing</sub> = 457.25; middle rank<sub>starting</sub> = 548.29; Z = -4.981; p < .001) and "EU evenings" (middle rank<sub>landing</sub> = 537.87; middle rank<sub>starting</sub> = 465.19; Z = -3.981; p < .001). With to the mood, this signifies that after a night of aircraft noise exposure from starting planes, the subjects feel significantly more alert and rested in the mornings, while in the evenings they felt significantly more tense and nervous than after nights of exposure from landing airplanes. With regard to stress and recuperation, significant differences between starting and landing planes can be observed for the dimensions "REC-SOC" (middle rank<sub>landing</sub> = 537.84; middle rank<sub>starting</sub> = 469.14; Z = -3.751; p < .001), "REC-SOM" (middle rank<sub>landing</sub> = 543.86; middle rank<sub>starting</sub> = 462.93; Z = -4.420; p < .001) and "REC-GEN" (middle rank<sub>landing</sub> = 541.94; middle rank<sub>starting</sub> = 464.91; Z = -4.207; p < .001). This implies, that the subjects classify themselves as significantly more recuperated on the nights following exposure to landing planes than following exposure to starting planes.

**Statistics**

		GB evenings	AF evenings	EU evenings	GB mornings	AF mornings	EU mornings
N	Valid	160	160	160	160	160	160
	Missing	0	0	0	0	0	0
Median		36	31	33	33	29	32
Mode		36	36	34	36	32	32
Range		25	23	23	18	26	17

Table 19: Measures of central tendency (median and mode) and dispersion (range) regarding the control groups' mood (N = 16) (abbreviations: GB = good – bad mood, AF = alertness – fatigue, EU = ease – unease).

**Statistics**

	LOAD-GEN	LOAD-EMO	LOAD-SOC	CONFL	FATIG	LACK-EC	LOAD-SOM	SUCCESS	REC-SOC	REC-SOM	REC-GEN	SLEEP	STRESS-T	REC-T
N	1119	1119	1119	1119	1119	1119	1119	1119	1119	1119	1119	1119	1119	1119
Valid	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Missing														
Median	,33	,33	,17	,67	1,17	,83	,67	2,17	1,83	2,83	3,50	3,33	,67	2,80
Mode	,00	,00	,00	,00	,67 <sup>a</sup>	,00	,50	1,83	1,83	2,67	4,00	2,83	,33	2,60
Range	5,17	4,33	5,17	4,00	5,33	4,33	4,67	5,00	5,83	5,83	6,00	6,00	3,71	5,23

a. More than on mode, the smallest value is denoted.

Table 20: Measures of central tendency (median and mode) and dispersion (range) regarding the experimental groups' stress and recuperation (N = 112) (abbreviations: LOAD-GEN = general load, LOAD-EMO = emotional load, LOAD-SOC = social tensions, CONFL = unresolved conflicts – failure, FATIG = Fatigue – time pressure, LACK-EC = lack of energy and concentration, LOAD-SOM = somatic complaints, SUCCESS = success – efficiency, REC-SOC = recuperation in the social domain; REC-SOM = somatic recuperation, REC-GEN = general recuperation – well-being, SLEEP = restorative sleep, STRESS-T = total stress, REC-T = total recuperation).

**Statistics**

	LOAD-GEN	LOAD-EMO	LOAD-SOC	CONFL	FATIG	LACK-EC	LOAD-SOM	SUCCESS	REC-SOC	REC-SOM	REC-GEN	SLEEP	STRESS-T	REC-T
N	160	160	160	160	160	160	160	160	160	160	160	160	160	160
Valid	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Missing														
Median	,17	,33	,33	,67	1,00	,83	,67	2,17	2,00	3,00	3,67	3,67	,69	2,93
Mode	,00	,00	,00	,83	1,00	,83 <sup>a</sup>	,67	2,33	1,33	3,00	3,33	4,33	,26 <sup>a</sup>	2,93 <sup>a</sup>
Range	2,33	2,83	2,83	2,67	3,83	2,83	3,17	4,83	4,16	4,84	4,66	4,66	2,07	3,43

a. More than on mode, the smallest value is denoted.

Table 21: Measures of central tendency (median and mode) and dispersion (range) regarding the control groups' stress and recuperation (N = 16) (abbreviations see table 20).

### 2.3.1.2 Inferential statistics

The inter-individual comparison between the control and experimental groups regarding their mood following nights 3 to 11 (aircraft noise-exposed nights for all experimental groups) was conducted by means of Mann-Whitney U-tests. The results are listed in table 22:

	<b>GB evenings</b>	<b>AF evenings</b>	<b>EU evenings</b>	<b>GB mornings</b>	<b>AF mornings</b>	<b>EU mornings</b>
Mean rank.....Ex	565.51	565.12	578.53	558.18	548.82	571.65
.....Co	633.16	635.84	542.44	684.18	749.37	590.34
Z	-2.300	-2.399	-1.225	<b>-4.282</b>	-6.800	-.634
Asymptotic Sign.	.021	.016	.221	<b>.000**</b>	<b>.000**</b>	.526

Table 22: Results of Mann-Whitney U-test (test statistic Z) regarding the comparison between the control and experimental groups' mood following nights 3 to 11. According to the Bonferoni correction ( $\alpha/6 = .008$ ) significant (\*) and very significant differences (\*\*) are denoted (abbreviations: GB = good – bad mood, AF = alertness – fatigue, EU = ease – unease).

For the purpose of verifying inter-individual differences between control and experimental groups, which may have existed before the introduction of aircraft noise, table 23 lists the results of the U-tests, in which the evening and morning values following the baseline night (night 2) were compared.

	<b>GB evenings</b>	<b>AF evenings</b>	<b>EU evenings</b>	<b>GB mornings</b>	<b>AF mornings</b>	<b>EU mornings</b>
Mean rank.....Ex	64.20	64.63	63.85	62.81	61.69	63.34
.....Co	66.59	63.59	69.03	64.28	71.94	60.69
Z	-.242	-.105	-.524	<b>-.152</b>	-1.058	-.274
Asymptotic Sign.	.808	.917	.600	<b>.879</b>	.290	.784

Table 23: Results of Mann-Whitney U-test (test statistic Z) regarding the comparison between the control and experimental groups' mood following the baseline night (night 2). According to the Bonferoni correction ( $\alpha/6 = .008$ ) significant (\*) and very significant differences (\*\*) are denoted (abbreviations: GB = good – bad mood, AF = alertness – fatigue, EU = ease – unease).

The experimental groups have significantly lower scale values than the control groups concerning ratings of “GB mornings” and “AF mornings” (i.e., worse mood, more pronounced fatigue). Significant differences between control and experimental groups cannot be found for any of the other mood scales. There are no significant differences following the baseline night (night 2).

The results of the inter-individual comparison between the control and experimental groups regarding stress and recuperation are summarized in tables 24 and 25. With respect to the recuperation dimension "restorative sleep", there are significantly higher scale values only for the control groups, but not for the experimental groups, following the nights 3 to 11. Further significant differences cannot be proven after the aircraft noise-exposed nights, nor following the baseline night.

Combined, there is general *significant influence of aircraft noise* on the mood variables "GB mornings" and "AF mornings", and on the recuperation subscale "restorative sleep". Thus, the following inferential statistics regarding *aircraft noise-induced secondary reactions of the experimental groups* are limited to these psychological variables.

	LOAD-GEN	LOAD-EMO	LOAD-SOC	CON FL	FATIG	LACK-EC	LOAD-SOM	SUC-CESS	REC-SOC	REC-SOM	REC-GEN	SLEEP	STRES S-T	REC-T
Mean Rank.....Ex	579.01	573.85	569.60	576.04	583.04	581.59	578.47	575.40	573.32	572.09	572.93	563.82	578.38	569.89
.....Co	554.94	591.02	620.74	575.75	526.79	536.94	558.71	580.16	594.71	603.38	597.48	661.17	559.35	618.73
Z	-.832	-.592	-1.788	-.010	-1.903	-1.513	-.670	-.161	-.723	-1.058	-.830	-3.290	-.643	-1.649
Asymptotic Sign.	.405	.554	.074	.992	.057	.130	.503	.872	.470	.290	.407	.001**	.520	.099

Table 24: Results of Mann-Whitney U-test (test statistic Z) regarding the comparison between the control and experimental groups' stress and recuperation following nights 3 to 11. According to the Bonferoni correction ( $\alpha/14 = .004$ ) significant (\*) and very significant differences (\*\*) are denoted (abbreviations: LOAD-GEN = general load, LOAD-EMO = emotional load, LOAD-SOC = social tensions, CONFL = unresolved conflicts – failure, FATIG = Fatigue – time pressure, LACK-EC = lack of energy and concentration, LOAD-SOM = somatic complaints, SUCCESS = success – efficiency, REC-SOC = recuperation in the social domain; REC-SOM = somatic recuperation, REC-GEN = general recuperation – well-being, SLEEP = restorative sleep, STRESS-T = total stress, REC-T = total recuperation).

	LOAD-GEN	LOAD-EMO	LOAD-SOC	CON FL	FATIG	LACK-EC	LOAD-SOM	SUC-CESS	REC-SOC	REC-SOM	REC-GEN	SLEEP	STRES S-T	REC-T
Mean Rank.....Ex	65.88	63.89	64.23	65.37	64.83	64.98	64.29	65.94	64.21	64.44	63.67	64.42	65.12	64.30
.....Co	54.88	68.78	66.38	58.44	62.16	61.13	65.94	54.41	66.56	64.94	70.31	65.06	60.19	65.91
Z	-1.135	-.502	-.223	-.701	-.271	-.391	-.167	-1.166	-.238	-.051	-.671	-.065	-.497	-.162
Asymptotic Sign.	.256	.616	.823	.483	.786	.696	.868	.244	.812	.960	.502	.948	.619	.871

Table 25: Results of Mann-Whitney U-test (test statistic Z) regarding the comparison between the control and experimental groups' stress and recuperation following the baseline night (night 2). According to the Bonferoni correction ( $\alpha/14 = .004$ ) significant (\*) and very significant differences (\*\*) are denoted (abbreviations see table 24).

## 2.3.2 Aircraft noise-induced secondary reactions of the experimental groups

### 2.3.2.1 *Inferential statistics*

#### **2.3.2.1.1 Measurement value progress in the course of time**

In order to determine a general influence of aircraft noise, the data of various measurement days in the laboratory are compared with each other by means of Wilcoxon-tests (table 26). The values of the mood scales "GB mornings" and "AF mornings", as well as of the recuperation sub-scale "restorative sleep", are compared after the following measurement days in the laboratory:

- a) first night vs. second night in the laboratory (i.e., adaptation and baseline nights): "first night effect"
- b) baseline night vs. first aircraft noise-exposed night (nights 2 and 3)
- c) first night vs. last aircraft noise-exposed night (nights 3 and 11)
- d) last aircraft noise-exposed night vs. the subsequent noise-free night (nights 11 and 12)
- e) final two noise-free nights (nights 12 and 13): "last night effect"

Since aircraft noise was also presented in nights 12 and 13 in the last laboratory study section (STRAIN IV), only the comparisons a) and b) refer to the entire experimental sample (N = 112). Comparisons c) and d) only refer to the subjects from STRAIN I to III (N = 80).

A "first night effect" exists for both mood aspects "GB mornings" and "AF mornings", and for the sub-scale "restorative sleep", i.e., the subjects experience the second night as significantly more restorative than the first night, and they are in a significantly better mood and more rested on the second morning. According to the comparison between the baseline and the first

noise exposure nights, there is a significant “aircraft noise effect” for all three dependent variables, i.e., the subjects sleep significantly worse in the first noise-exposed night and are more fatigued and in a worse mood the subsequent morning. The comparison between the first and last aircraft noise-exposed nights only exhibits significant differences regarding “restorative sleep”, i.e., the subjects are more rested after the last noise-exposed night. After the first noise-free night following the noise-exposed nights, a significant “improvement” of all psychological parameters takes place, i.e., the scale values are reversed with regard to the comparison of the baseline night with the first noise-exposed night (see above). A “last night effect” does not exist.

	1 <sup>st</sup> vs. 2 <sup>nd</sup> night (first night effect)	2 <sup>nd</sup> vs. 3 <sup>th</sup> night	3 <sup>th</sup> vs. 11 <sup>th</sup> night	11 <sup>th</sup> vs. 12 <sup>th</sup> night	12 <sup>th</sup> vs. 13 <sup>th</sup> night (last night effect)
Z	GBm2 - GBm1 (27NR, 64PR, 16B)	GBm3 - GBm2 (67NR, 31PR, 10B)	GBm11 - GBm3 (30NR, 35PR, 13B)	GBm12 - GBm11 (7NR, 60PR, 12B)	GBm13 - GBm12 (21NR, 34PR, 24B)
Sign	-3.612 .000**	-4.546 .000**	-.111 .911	-6.300 .000**	-2.014 .044
Z	AFm2 - AFm1 (32NR, 67PR, 8B)	AFm3 - AFm2 (73NR, 26PR, 9B)	AFm11 - AFm3 (35NR, 37PR, 6B)	AFm12 - AFm11 (13NR, 60PR, 6B)	AFm13 - AFm12 (24NR, 40PR, 15B)
Sign	-3.145 .002**	-4.798 .000**	-.298 .766	-5.514 .000**	-1.568 .117
Z	SL2 - SL1 (27NR, 73PR, 10B)	SL3 - SL2 (80NR, 28PR, 4B)	SL11 - SL3 (24NR, 52PR, 4B)	SL12 - SL11 (23NR, 49PR, 8B)	SL13 - SL12 (34NR, 39PR, 7B)
Sign	-5.285 .000**	-5.769 .000**	-3.263 .001**	-3.785 .000**	-.572 .567

Table 26: Results of Wilcoxon-test (test statistic Z) regarding the comparison between the experimental groups’ mood and restorative sleep following different measurement days in the laboratory. According to the Bonferoni correction ( $\alpha/4 = .01$ ) significant (\*) and very significant differences (\*\*) are denoted (abbreviations: GBm = good – bad mood mornings, AFm = alertness – fatigue mornings, SL = restorative sleep; NR = negative ranks, PR = positive ranks, B = links).

The measurement value progress of the mood aspects “GB mornings” and “AF mornings” and of the “restorative sleep” of *all* experimental groups (N = 112) during the course of the laboratory study (13 nights) will be shown by the following box-plots (figures 71 to 73). It should be kept in mind that the data apply to inquiries in the mornings, respectively evenings *after* the nights 1 to 13.

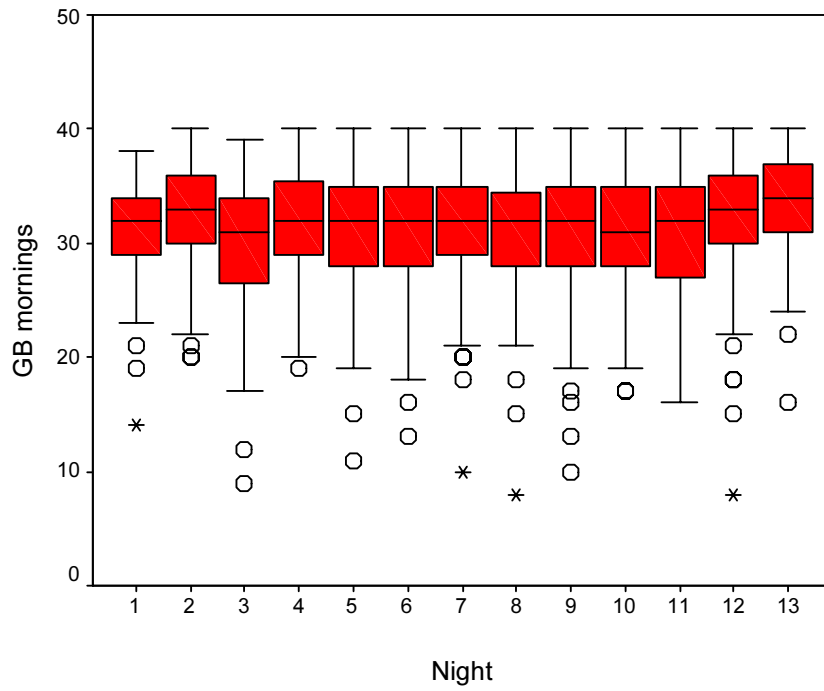


Figure 71: “Good – bad mood mornings” of the experimental groups (N = 112) in the course of the sleep laboratory study.

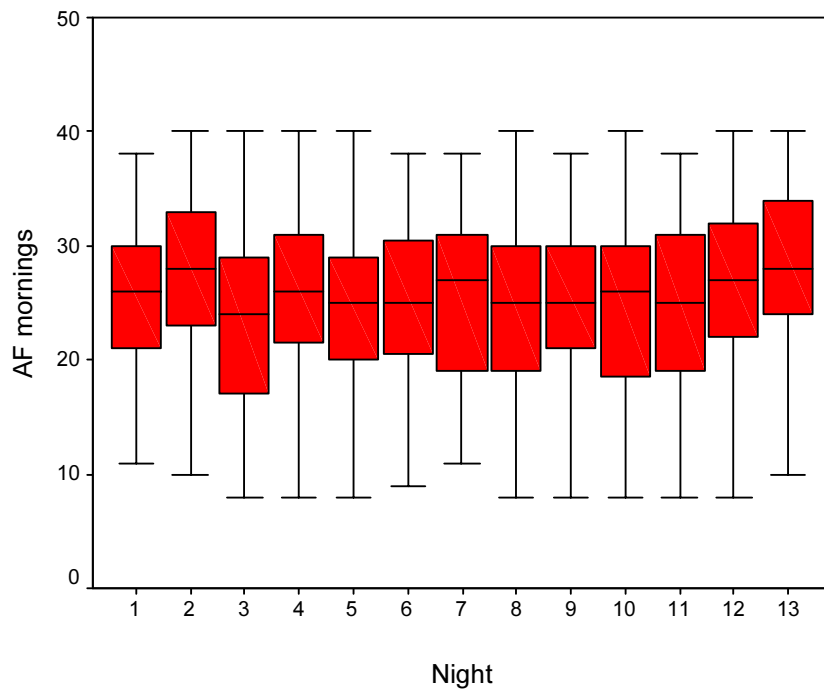


Figure 72: “Alertness – fatigue mornings” of the experimental groups (N = 112) in the course of the sleep laboratory study.

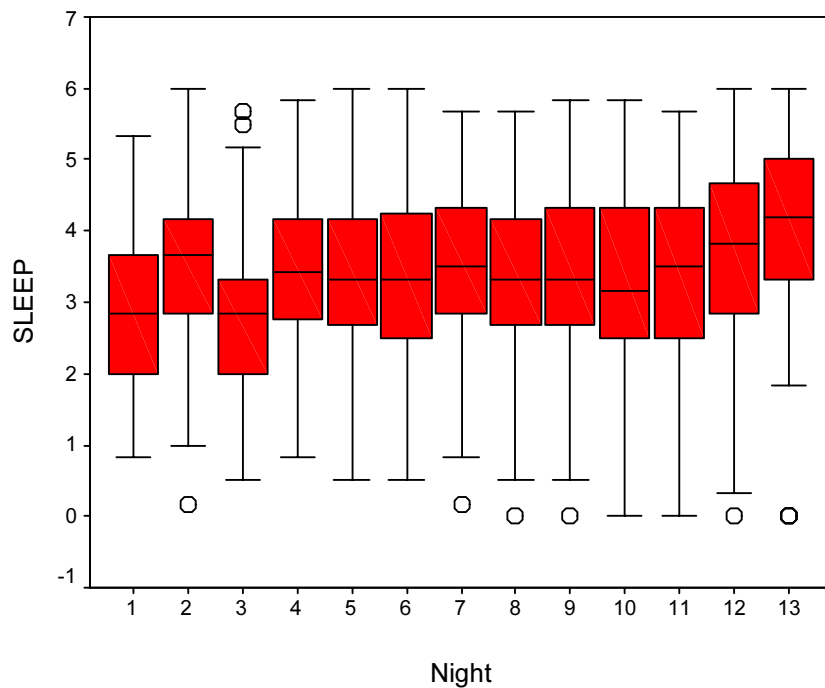


Figure 73: “Restorative sleep” of the experimental groups (N = 112) in the course of the sleep laboratory study.

### 2.3.2.1.2 Physical aircraft noise parameters

The assumption, that an *increasing nocturnal aircraft noise exposure* (operationalized by means of the independent variables  $L_{AS,max}$ ,  $L_{AS,eq}$  and level frequency) leads to an *impairment* of:

- *mood*, i.e., decreasing scale values of “GB mornings” and “AF mornings” (MDMQ)
- *recuperation*, i.e., decreasing scale values of “restorative sleep” (EFB)

was verified by means of inferential statistics.

Kruskal-Wallis one-way analysis of variance shows no *significant effects for the three aircraft noise parameters* with regard to the mentioned *mood aspects and restorative sleep* of the experimental groups (table 27). Thus, single comparisons of the factor stages of the physical parameters by means of U-tests were refrained from.

		<b>GB mornings</b>	<b>AF mornings</b>	<b>SL</b>
<b>L<sub>AS,max</sub></b>	Chi-Quadrat	17.806	15.58	12.900
	Df	8	8	8
	Asymptot. Sign.	.023	.044	.115
<b>L<sub>AS,eq</sub></b>	Chi-Quadrat	12.499	17.949	19.720
	Df	9	9	9
	Asymptot. Sign.	.187	.036	.020
<b>Level frequency</b>	Chi-Quadrat	14.735	10.667	15.385
	Df	6	6	6
	Asymptot. Sign.	.022	.099	.017

Table 27: Results of Kruskal-Wallis one-way analysis of variance regarding the influence of L<sub>AS,max</sub>, L<sub>AS,eq</sub> und level frequency on the experimental groups' mood and "restorative sleep" (N = 112). According to the Bonferoni correction ( $\alpha/3 = .016$ ) significant (\*) and very significant differences (\*\*) are denoted (abbreviations: GB = good – bad mood, AF = alertness – fatigue, SL = restorative sleep).

### 2.3.2.2 Dose-response curves

As for the aircraft noise annoyance, the *logistic regression* can be used to deduce *dose-response curves* between independent physical aircraft noise variables (applied by means of the L<sub>AS,max</sub>, L<sub>AS,eq</sub> and the number of flight events) and dependent mood and recuperation variables (cp. *chapter 1.8.2.3*). Before conducting the regression analysis, it is wise to descriptively illustrate the interrelation between dependent and independent parameters. This enables the finding of possible interactions, based on which it can be decided, which factors are relevant for the regression model. Only the aircraft noise-exposed nights 3 to 11 of the experimental groups (N = 112) were considered for the descriptive analysis.

For the purpose of describing possible interactions, it was necessary to convert the assessments on the MDMQ and the RLQ into *dichotomous dependent variables*, in order to be able to illustrate the probability of a "positive mood" (GB), "alertness" (AF), "ease" (EU), and of "restorative sleep" (SLEEP) in connection to the applied independent variables. For its generation, median splits were conducted and the corresponding gradations of the original sum and scale values were summed up. Regarding "GB mornings" (median = 32), all sum values < 32 indicate a bad mood (value = 0), while all values  $\geq 32$  describe a positive mood (value = 1). Similar results apply to "AF mornings"

(median = 26; value 0 = fatigue, value 1 = alertness). Concerning “restorative sleep”, less restorative sleep corresponds to  $< 3.33$  (value = 0), while restorative sleep occurs at  $\geq 3.33$  (value = 1).

Based on the figures 74 to 82, it becomes apparent that the examined mood aspects “GB mornings”, “AF mornings” and the scale “restorative sleep” *do not exhibit systematic interactions with the physical aircraft noise parameters*. The illustrated interactions do not show a definite trend; the probabilities solely vary in the range of  $P = 0.40$  to  $0.60$ . Accordingly, *none of the logistic regression analyses show significant dose-response relationships for mood and recuperation*. At this point, an explicit description of the results will be refrained from.

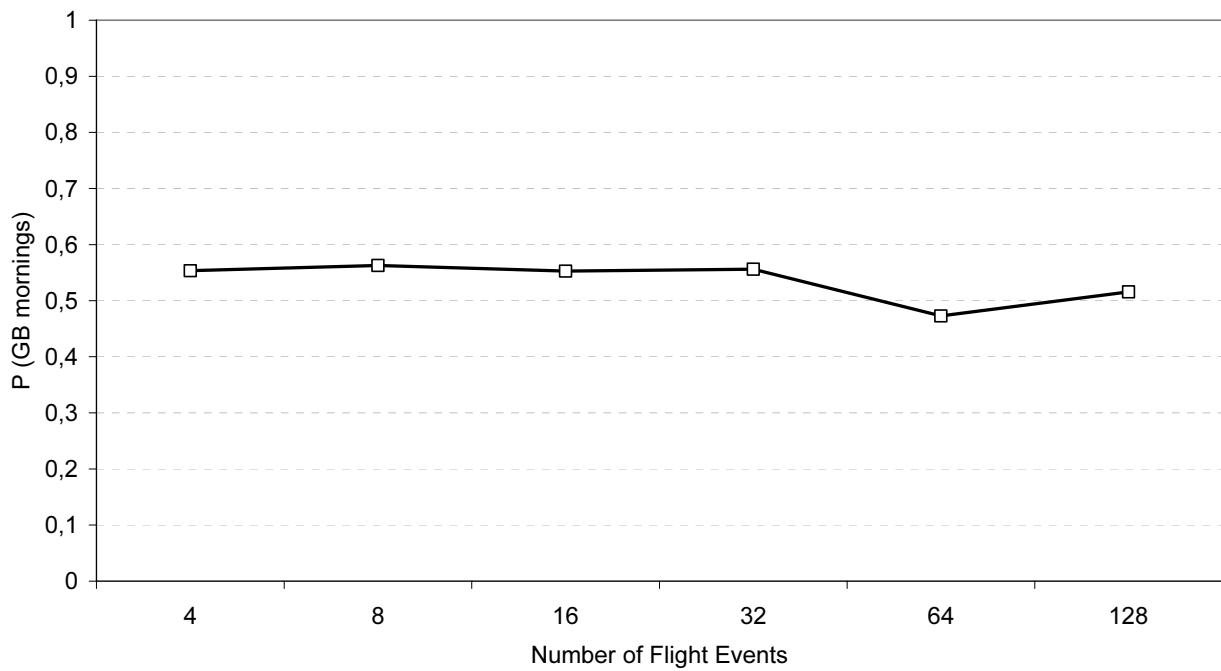


Figure 74: "Good – bad mood mornings" of the experimental groups (N = 112) depending on the number of events.

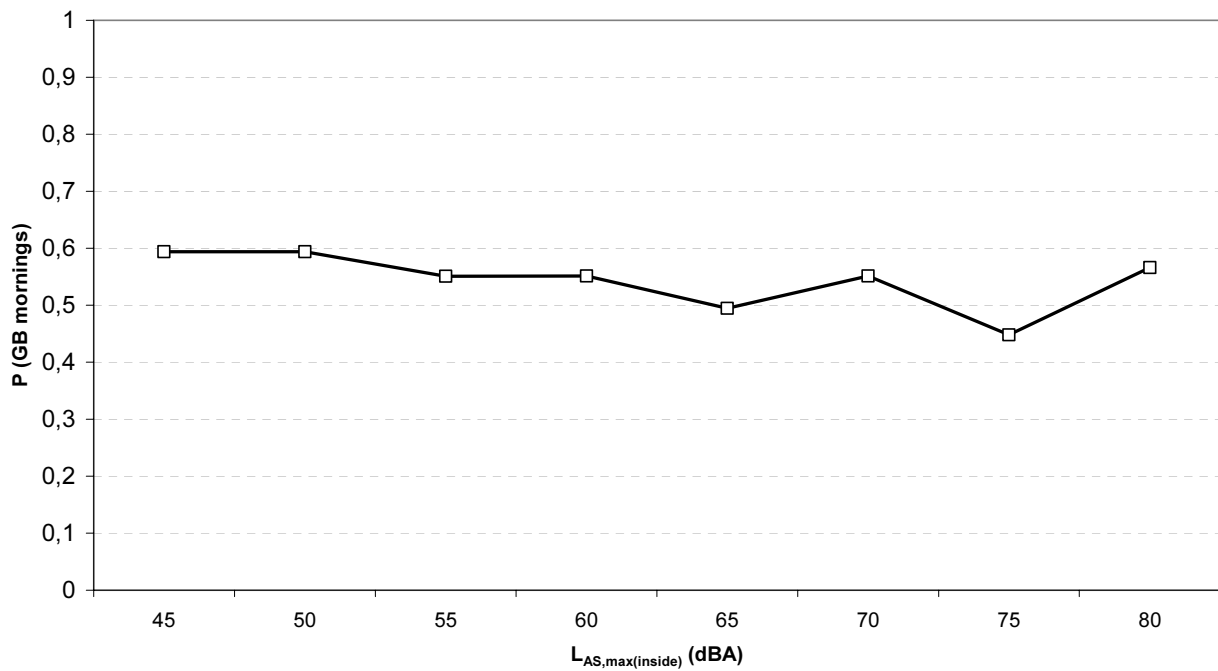


Figure 75: "Good – bad mood mornings" of the experimental groups (N = 112) depending on the maximum noise level  $L_{AS,max}$ .

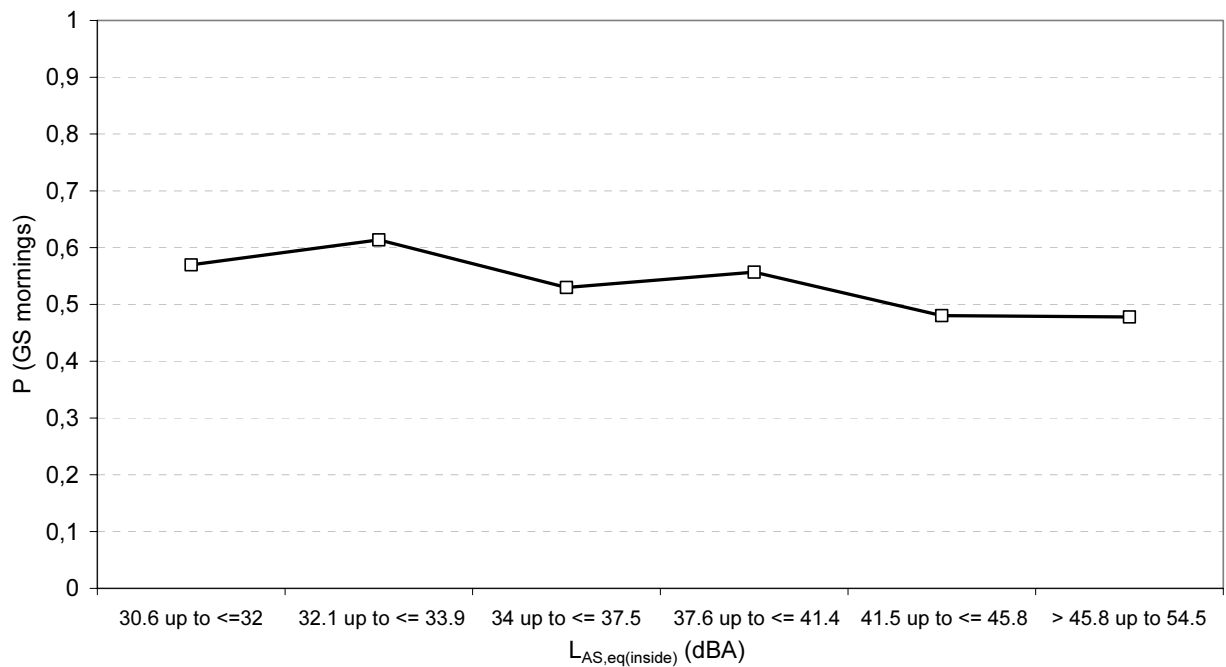


Figure 76: "Good – bad mood mornings" of the experimental groups (N = 112) depending on the energy equivalent noise level  $L_{AS,eq}$ .

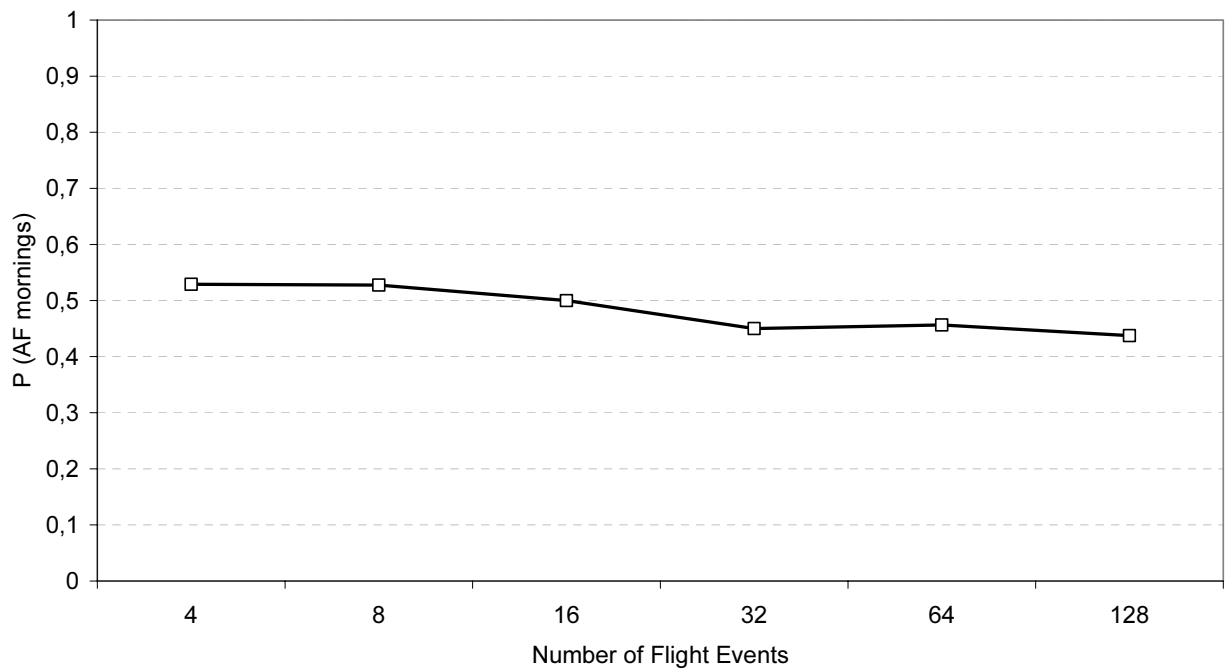


Figure 77: "Alertness – fatigue mornings" of the experimental groups (N = 112) depending on the number of flight events.

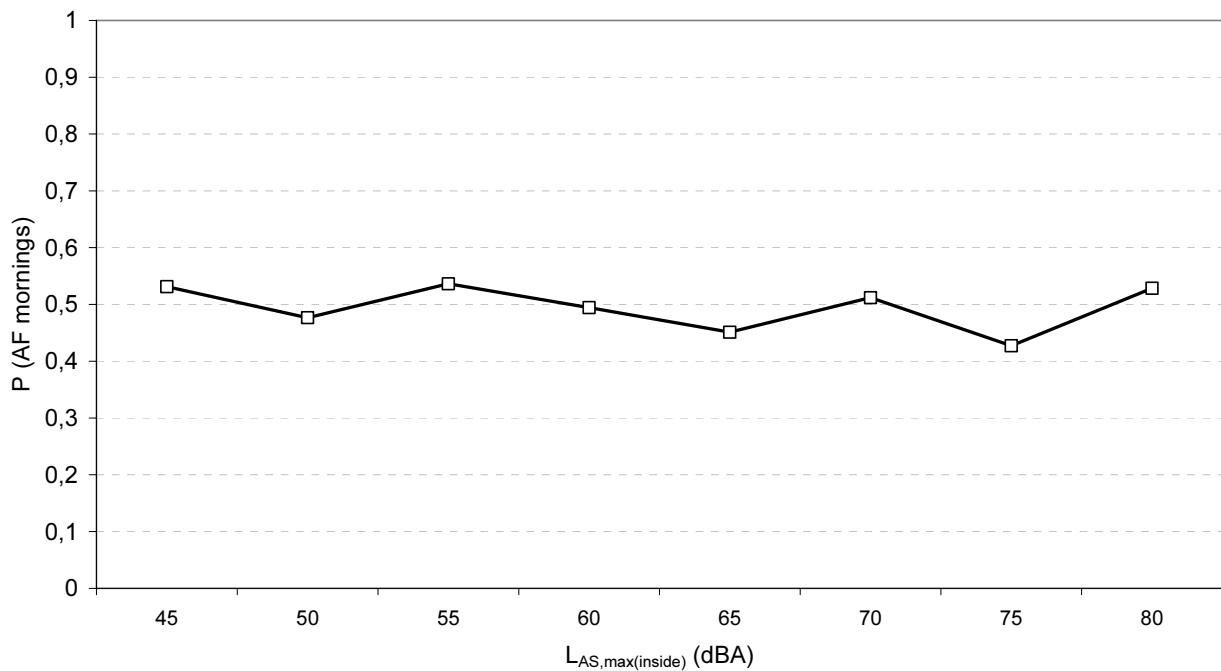


Figure 78: "Alertness – fatigue mornings" of the experimental groups (N = 112) depending on the maximum noise level  $L_{AS,max}$ .

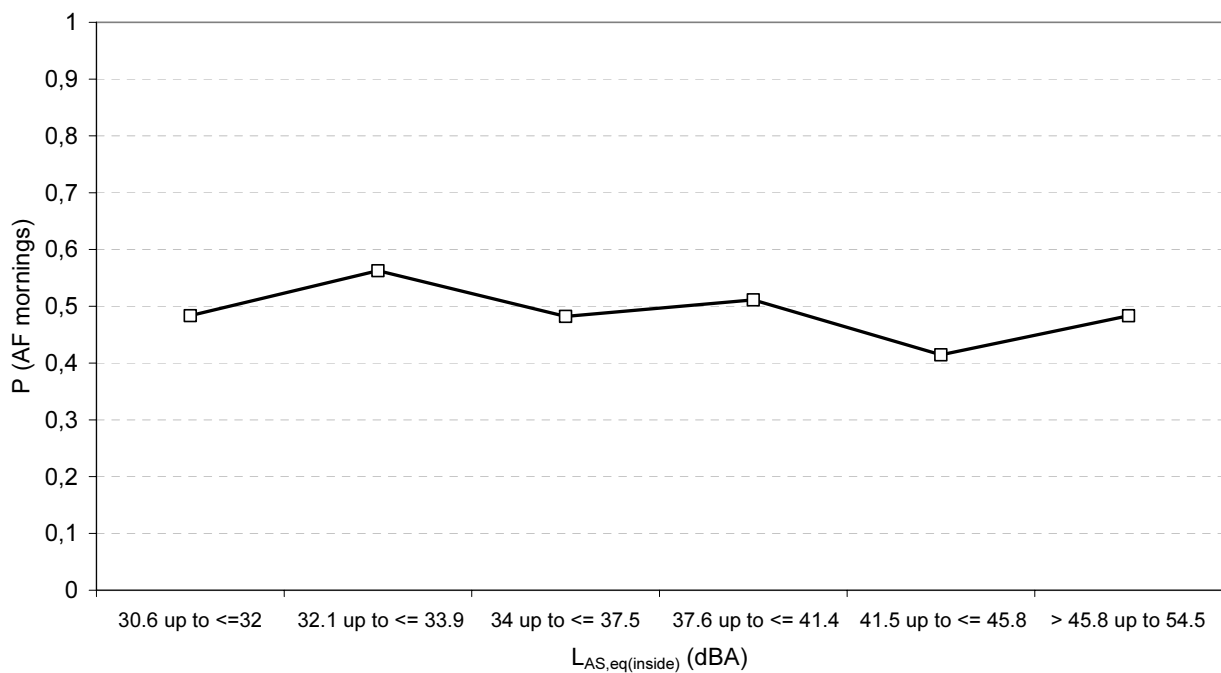


Figure 79: "Alertness – fatigue mornings" of the experimental groups (N = 112) depending on the energy equivalent noise level  $L_{AS,eq}$ .

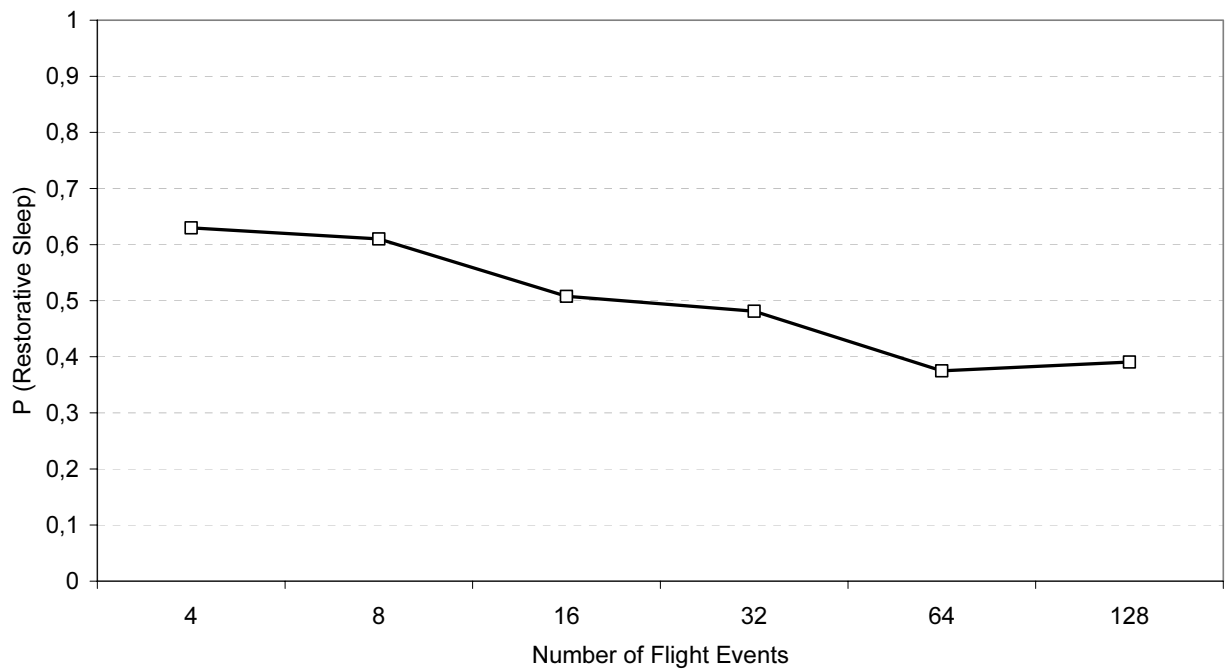


Figure 80: "Restorative sleep" of the experimental groups (N = 112) depending on the number of flight events.

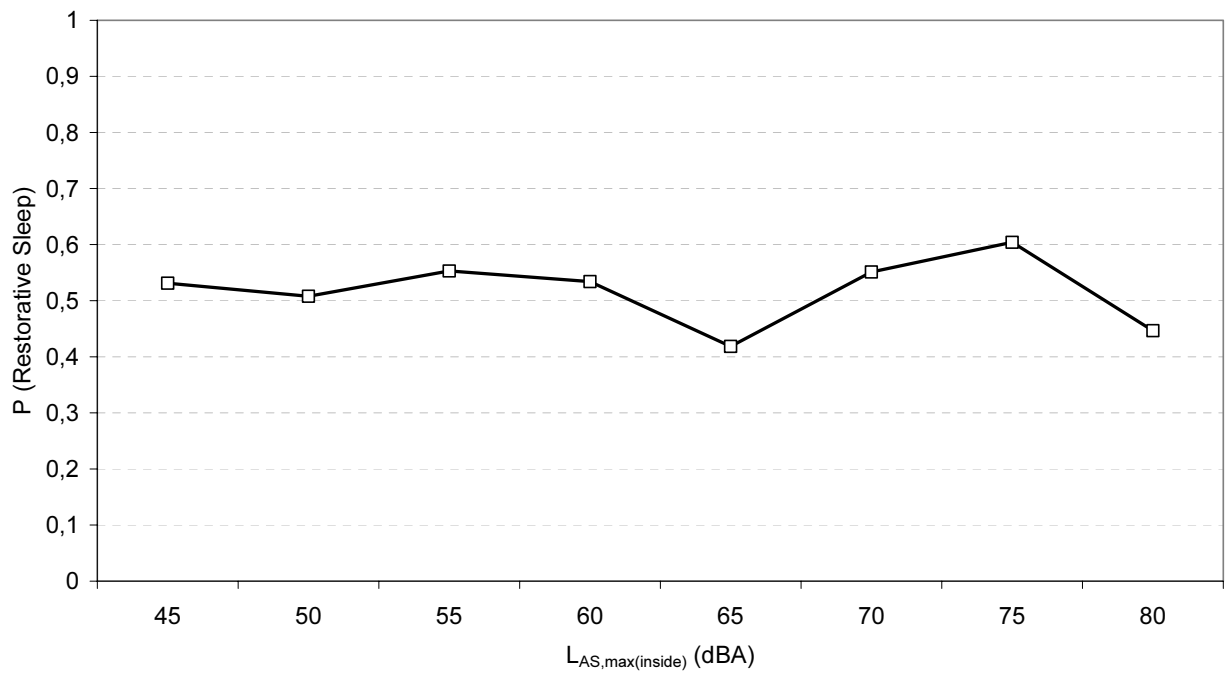


Figure 81: "Restorative sleep" of the experimental groups (N = 112) depending on the maximum noise level  $L_{AS,max}$ .

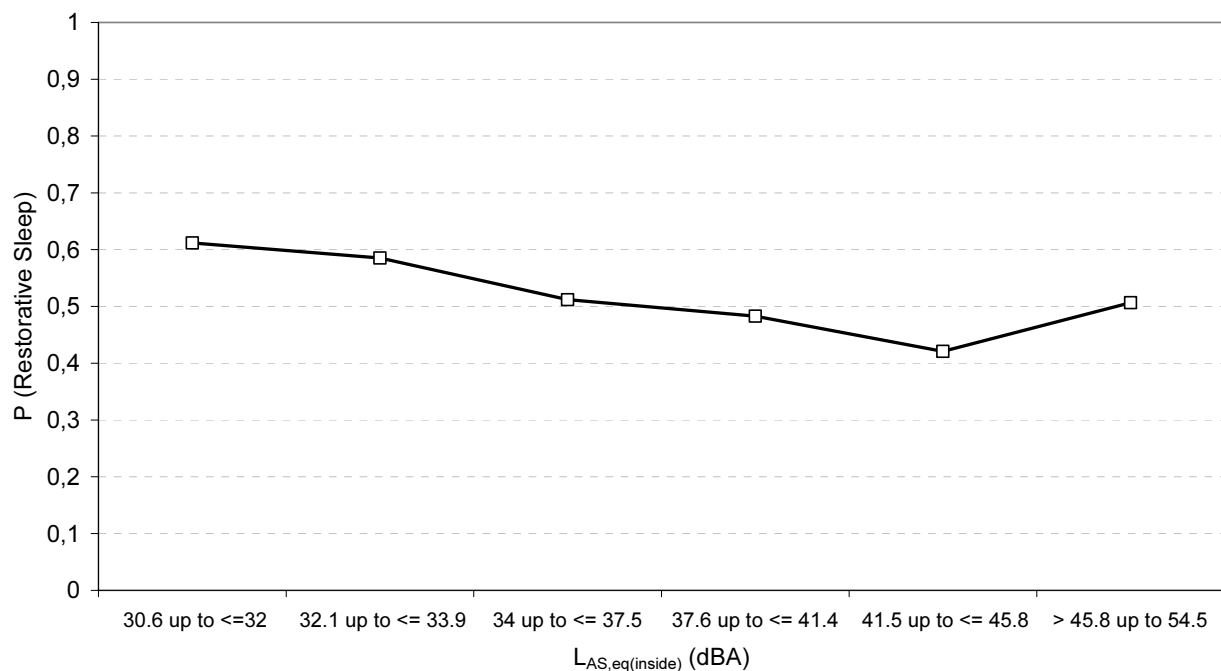


Figure 82: "Restorative sleep" of the experimental groups (N = 112) depending on the energy equivalent noise level  $L_{AS,eq}$ .

## 2.4 Results of the field study<sup>30</sup>

### 2.4.1 Aircraft noise-induced secondary reactions of the field subjects

#### 2.4.1.1 Descriptive statistics

Tables 28 and 29 list the measures of the central tendency (median and mode) and the dispersion (range) of the field subjects' mood, stress and recuperation according to the non-metric scale level of the data. All 9 consecutive nights of the field study were considered.

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<sup>30</sup>Due to the non-metric scale level and the insufficient normal distribution of data which appeared in the Kolmogorov-Smirnov-test of the field data, non-parametric procedures were chosen. In all analyses, the probability of rejecting the null hypothesis according to Bonferoni was corrected to  $\alpha/n$ , dependent on the number of conducted individual tests.

**Statistics**

		GB evenings	AF evenings	EU evenings	GB mornings	AF mornings	EU mornings
N	Valid	510	510	510	570	570	570
	Missing	66	66	66	6	6	6
Median		35	26	33	33	26	33
Mode		36	28	36	36	26	36
Range		26	32	27	30	32	24

Table 28: Measures of central tendency (median and mode) and dispersion (range) regarding the field subjects' mood (N = 64) (abbreviations: GB = good – bad mood, AF = alertness – fatigue, EU = ease – unease).

**Statistics**

	LOAD-GEN	LOAD-EMO	LOAD-SOC	CONFL	FATIG	LACK-EC	LOAD-SOM	SUCCESS	REC-SOC	REC-SOM	REC-GEN	SLEEP	STRESS-T	REC-T
N	512	512	512	512	512	512	512	512	512	512	512	512	512	512
Valid	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Missing	,17	,33	,33	,67	1,17	,83	,67	2,33	2,00	3,00	3,67	3,67	,62	3,00
Median	,00	,00	,00	,00	,50	,67	,17 <sup>a</sup>	1,67	1,17	3,17 <sup>a</sup>	3,67	3,17	,38	3,27
Mode	5,50	5,00	5,67	5,67	5,83	4,67	3,83	5,00	5,83	5,50	6,00	6,00	4,45	4,83

a. More than on mode, the smallest value is denoted.

Table 29: Measures of central tendency (median and mode) and dispersion (range) regarding the field subjects' stress and recuperation (N = 64) (abbreviations: LOAD-GEN = general load, LOAD-EMO = emotional load, LOAD-SOC = social tensions, CONFL = unresolved conflicts – failure, FATIG = Fatigue – time pressure, LACK-EC = lack of energy and concentration, LOAD-SOM = somatic complaints, SUCCESS = success – efficiency, REC-SOC = recuperation in the social domain; REC-SOM = somatic recuperation, REC-GEN = general recuperation – well-being, SLEEP = restorative sleep, STRESS-T = total stress, REC-T = total recuperation).

#### *2.4.1.2 Inferential statistics concerning the measurement value progress in the course of time*

In order to determine a general influence of aircraft noise, the data of various measurement days in the field are compared with each other by means of Wilcoxon-tests (tables 30 and 31). The psychological reaction parameters regarding mood, stress and recuperation are compared after the following days at home:

- a) first night vs. second night: "first night effect"
- b) second night vs. sixth night: "weekend effect"
- c) eighth night and ninth night: "last night effect"

Only the morning values of the MDMQ could be used for the comparison of the eighth and ninth nights ("last night effect"), since no evening values were inquired neither for the MDMQ nor the RLQ on the last study day. At home, there is a "first night effect" for the morning values concerning mood ("GB mornings") and alertness ("AF mornings"), i.e., similar to the laboratory study, the subjects feel significantly better and more rested in the second study night. With respect to the stress and recuperation parameters, a "first night effect" exists for the variables "FATIG" (fatigue – time pressure), "LOAD-SOM" (somatic complaints), "CONFL" (unresolved conflicts – failure), restorative "SLEEP", "STRESS-T" (total stress), and "REC-T" (total recuperation). This signifies that the subjects are less stressed and significantly more recuperated (especially with regard to "restorative sleep") on the evening after the second night than after the first study night. A "weekend effect" can be observed for almost all mood, stress and recuperation parameters. The mood in the mornings ("GB mornings"), "LOAD-SOC" (social tensions) and the "restorative sleep" are exceptions. Overall, this finding indicates that the subjects are significantly less impaired regarding their mood at the weekends and that they associate the weekend with a higher recuperation value (i.e., less stress). However, the "restorative sleep" is not affected. Unlike in the

laboratory data, a “last night effect” exists for all morning values of the mood, i.e., on the last study morning the subjects are significantly more content, alert and composed than on the previous morning, due to the prospect that the study would soon end.

	1 <sup>st</sup> vs. 2 <sup>nd</sup> night (first night effect)	2 <sup>nd</sup> vs. 6 <sup>th</sup> night (weekend effect)	8 <sup>th</sup> vs. 9 <sup>th</sup> night (last night effect)
Z Sign	GBe2 – GBe1 (26NR, 31PR, 7B) -.112 .911	GBe6 - GBe2 (18NR, 36PR, 10B) -2.912 .004**	--
Z Sign	AFe2 – AFe1 (28NR, 34PR, 2B) -1.542 .123	AFe6 - AFe2 (19NR, 42PR, 3B) -4.290 .000**	--
Z Sign	EUE2 - EUE1 (29NR, 27PR, 8B) -.106 .915	EUE6 - EUE2 (13NR, 43PR, 8B) -4.466 .000**	--
Z Sign	GBm2 – GBm1 (18NR, 36PR, 8B) -2.657 .008*	GBm6 – GBm2 (19NR, 36PR, 7B) -2.246 .025	GBm9 – GBm8 (13NR, 38PR, 13B) -3.247 .001**
Z Sign	AFm2 – AFm1 (18NR, 38PR, 6B) -2.863 .004**	AFm6 - AFm2 (20NR, 38PR, 4B) -2.852 .004**	AFm9 – AFm8 (20NR, 39PR, 5B) -2.427 .015*
Z Sign	EUm2 - EUm1 (20NR, 30PR, 12B) -1.454 .146	EUm6 – EUm2 (16NR, 36PR, 10B) -3.024 .002**	EUm9 – EUm8 (16NR, 35PR, 13B) -2.580 .010*

Table 30: Results of Wilcoxon-test (test statistic Z) regarding the comparison between the field subjects’ mood following different measurement days in the field. According to the Bonferoni correction ( $\alpha/3 = .02$ ) significant (\*) and very significant differences (\*\*) are denoted (abbreviations: GBm = good – bad mood mornings, AFm = alertness –fatigue mornings, EUm = ease – unease mornings, GBe = good – bad mood evenings, AFe = alertness –fatigue evenings, EUE = ease – unease evenings; NR = negative ranks, PR = positive ranks, B = links).

	1 <sup>st</sup> vs. 2 <sup>nd</sup> night (first night effect)	2 <sup>nd</sup> vs. 6 <sup>th</sup> night (weekend effect)
Z Sign	LOAD-GEN2 – LOAD-GEN1 (27NR, 22PR, 15B) -.913 .361	LOAD-GEN6 – LOAD-GEN2 (35NR, 11PR, 18B) -3.318 .001**
Z Sign	LOA-EMO2 – LOAD-EMO1 (23NR, 22PR, 19B) -.628 .530	LOA-EMO6 – LOAD-EMO2 (33NR, 15PR, 16B) -2.544 .011*
Z Sign	LOAD-SOC2 – LOAD-SOC1 (24NR, 20PR, 20B) -1.032 .302	LOAD-SOC6 – LOAD-SOC2 (27NR, 15PR, 22B) -2.157 .031
Z Sign	CONFL2 – CONFL1 (36NR, 13PR, 15B) -2.838 .005*	CONFL6 – CONFL2 (54NR, 4PR, 6B) -6.323 .000**
Z Sign	FATIG2 – FATIG1 (40NR, 15PR, 9B) -4.117 .000**	FATIG6 – FATIG2 (54NR, 9PR, 1B) -5.508 .000**
Z Sign	LACK-EC2 - LACK-EC1 (38NR, 21PR, 5B) -2.143 .032	LACK-EC6 – LACK-EC2 (53NR, 8PR, 3B) -5.420 .000**
Z Sign	LOA-SOM2 – LOAD-SOM1 (38NR, 20PR, 6B) -2.862 .004**	LOA-SOM6 – LOAD-SOM2 (32NR, 19PR, 13B) -2.9.05 .004**
Z Sign	SUCCESS2 - SUCCESS1 (26NR, 33PR, 5B) -1.326 .185	SUCCESS6 – SUCCESS2 (52NR, 10PR, 2B) -5.362 .000**
Z Sign	REC-SOC2 – REC-SOC1 (22NR, 35PR, 7B) -2.152 .031	REC-SOC6 – REC-SOC2 (13NR, 48PR, 3B) -4.282 .000**

Table 31: Results of Wilcoxon-test (test statistic Z) regarding the comparison between the field subjects' stress and recuperation following different measurement days in the field. According to the Bonferoni correction ( $\alpha/2 = .025$ ) significant (\*) and very significant differences (\*\*) are denoted (abbreviations: LOAD-GEN = general load, LOAD-EMO = emotional load, LOAD-SOC = social tensions, CONFL = unresolved conflicts – failure, FATIG = Fatigue – time pressure, LACK-EC = lack of energy and concentration, LOAD-SOM = somatic complaints, SUCCESS = success – efficiency, REC-SOC = recuperation in the social domain; REC-SOM = somatic recuperation, REC-GEN = general recuperation – well-being, SLEEP = restorative sleep, STRESS-T = total stress, REC-T = total recuperation; NR = negative ranks, PR = positive ranks, B = links).

	1 <sup>st</sup> vs. 2 <sup>nd</sup> night (first night effect)	2 <sup>nd</sup> vs. 6 <sup>th</sup> night (weekend effect)
Z Sign	REC-SOM2 – REC-SOM1 (27NR, 33PR, 4B) -.719 .472	REC-SOM6 – REC-SOM2 (13NR, 46PR, 5B) -4.790 .000**
Z Sign	REC-GEN2 – REC-GEN1 (28NR, 33PR, 3B) -.715 .474	REC-GEN6 – REC-GEN2 (13NR, 47PR, 4B) -4.421 .000**
Z Sign	SLEEP2 – SLEEP1 (10NR, 50PR, 4B) -5.051 .000**	SLEEP6 – SLEEP2 (22NR, 35PR, 7B) -1.921 .055
Z Sign	STRESS-T2 – STRESS-T1 (41NR, 20PR, 3B) -2.608 .009*	STRESS-T6 – STRESS-T2 (57NR, 7PR, 0B) -6.083 .000**
Z Sign	REC-T2 – REC-T1 (22NR, 40PR, 2B) -2.984 .003**	REC-T6 – REC-T2 (18NR, 46PR, 0B) -3.187 .001**

Continuation of table 31

The measurement value progress of all mood, stress and recuperation variables during the entire period of the field study (9 nights for the morning values, 8 nights for the evening values) are depicted by the following box-plots (figures 83 to 102).

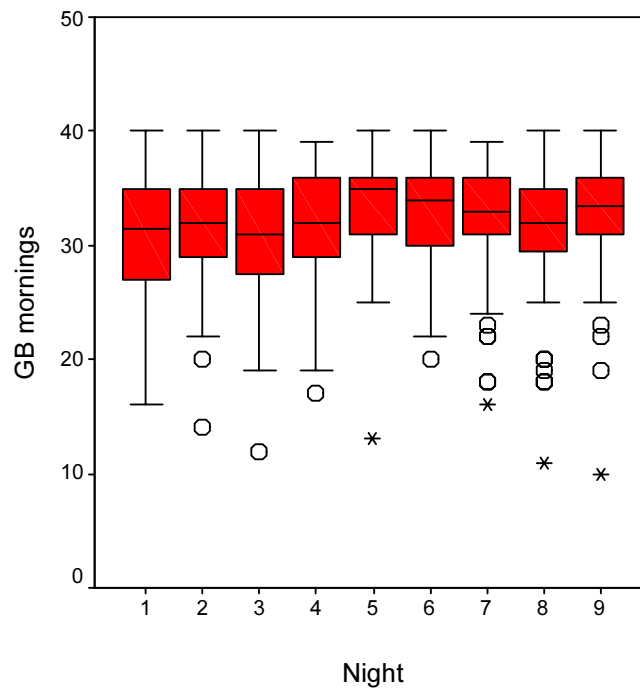


Figure 83: “Good – bad mood mornings” of the field subjects (N = 64) in the course of the field study.

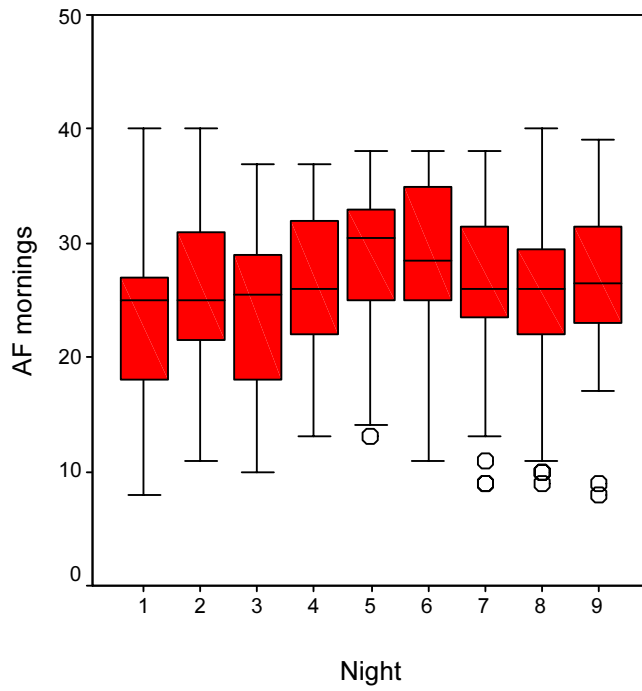


Figure 84: "Alertness – fatigue mornings" of the field subjects (N = 64) in the course of the field study.

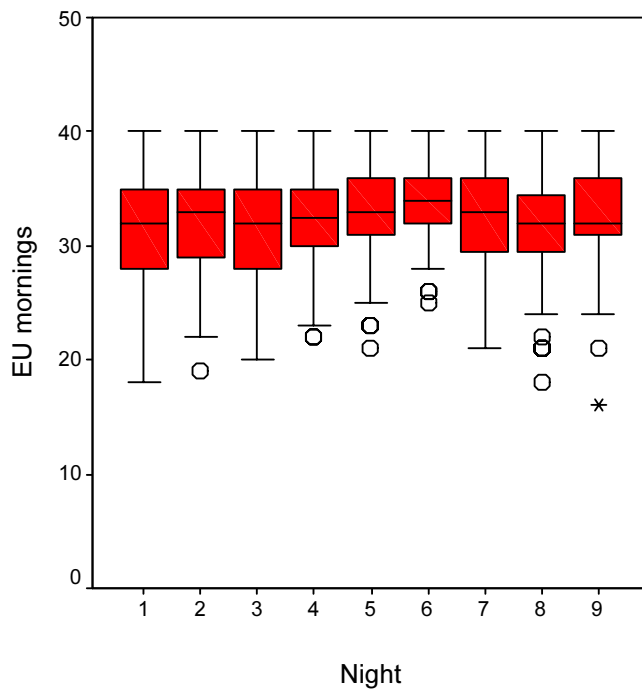


Figure 85: "Ease – unease mornings" of the field subjects (N = 64) in the course of the field study.

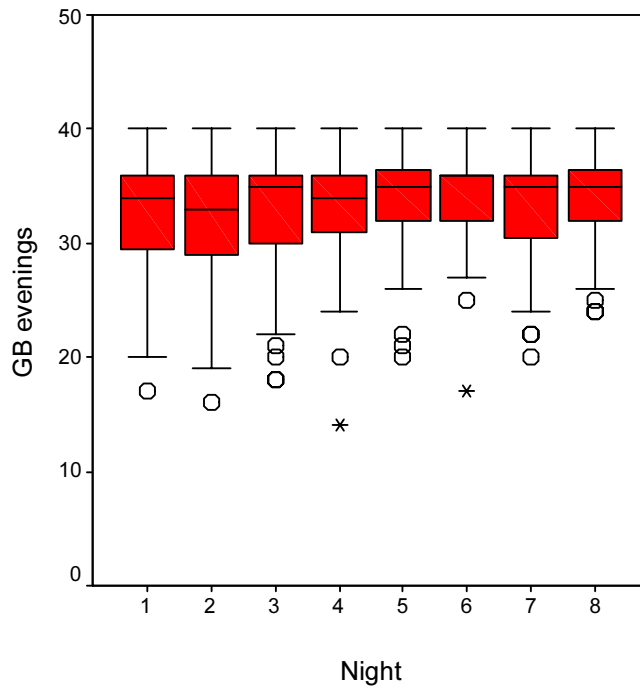


Figure 86: "Good - bad mood evenings" of the field subjects (N = 64) in the course of the field study.

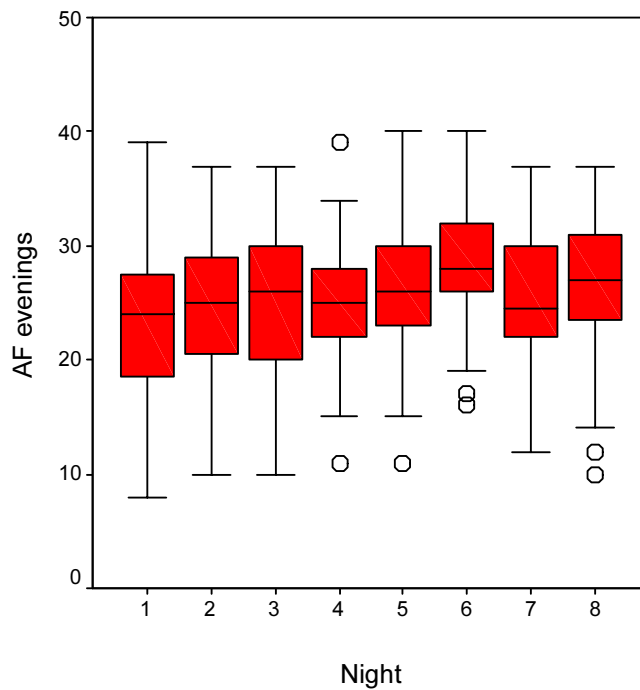


Figure 87: "Alertness - fatigue evenings" of the field subjects (N = 64) in the course of the field study.

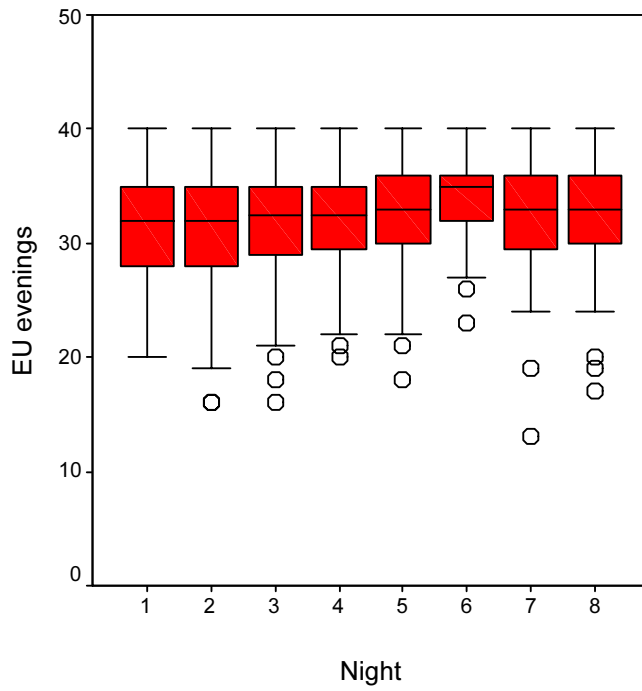


Figure 88: "Ease - unease evenings" of the field subjects (N = 64) in the course of the field study.

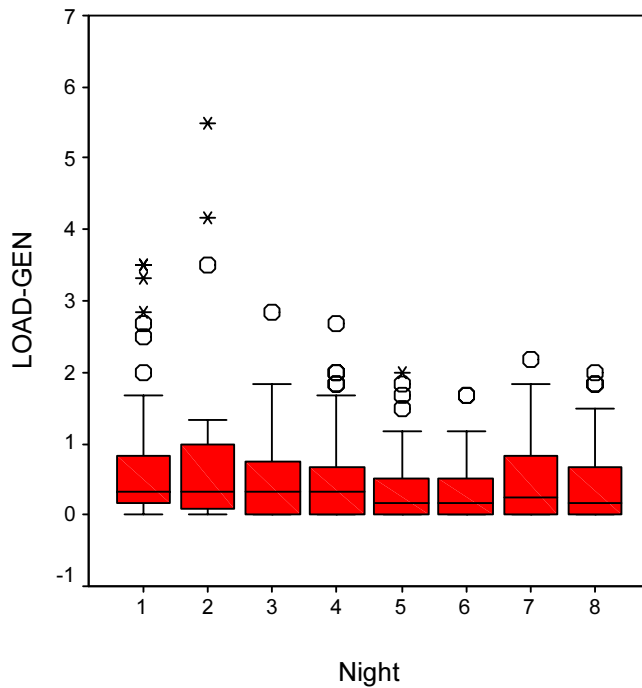


Figure 89: "General load" of the field subjects (N = 64) in the course of the field study.

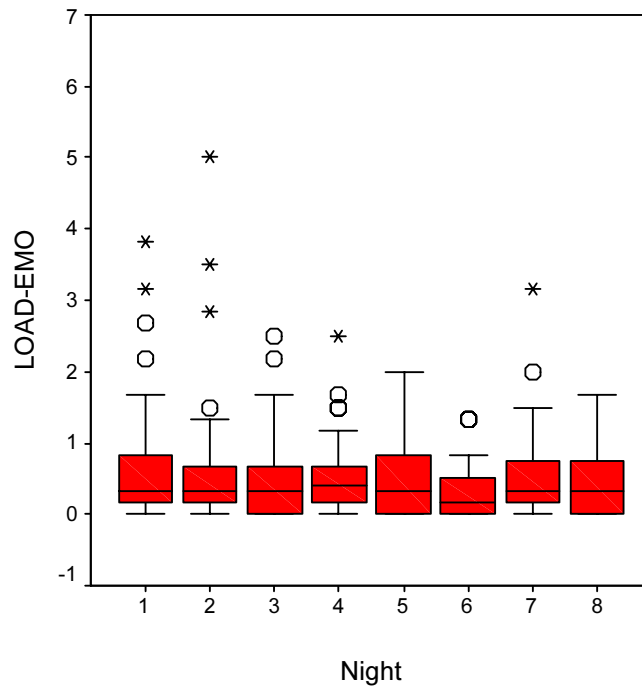


Figure 90: "Emotional load" of the field subjects (N = 64) in the course of the field study.

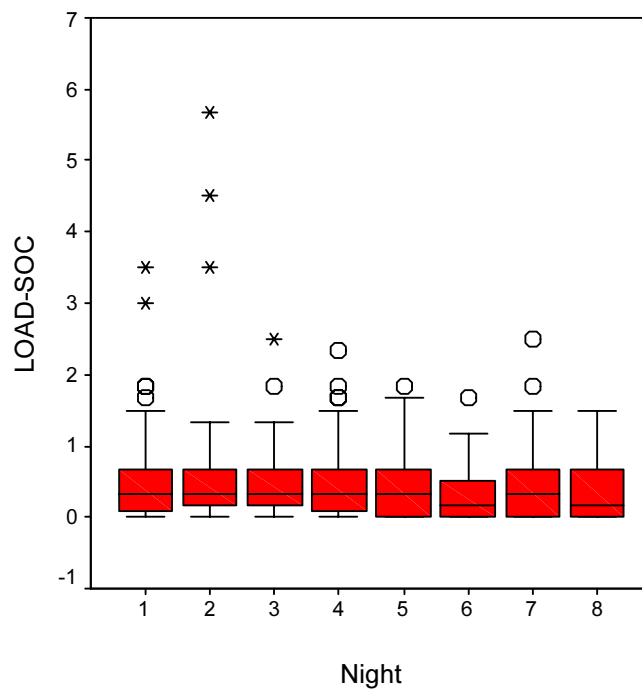


Figure 91: "Social tensions" of the field subjects (N = 64) in the course of the field study.

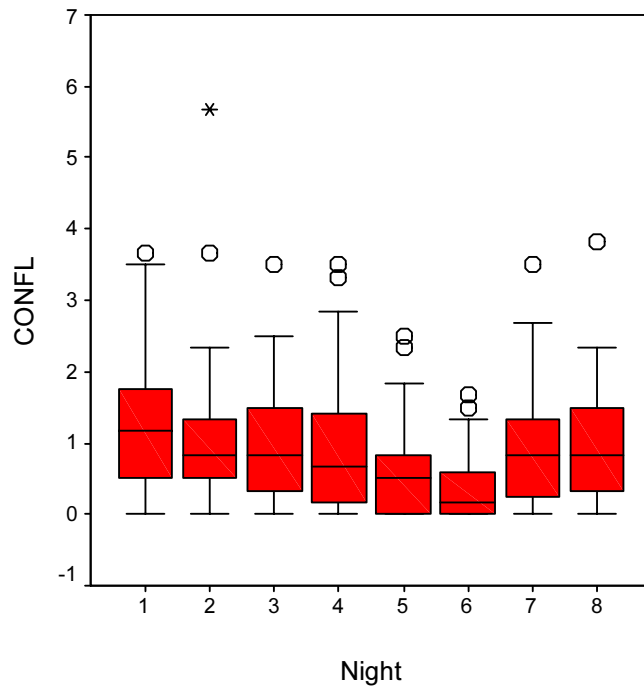


Figure 92: "Unresolved conflicts – failure" of the field subjects (N = 64) in the course of the field study.

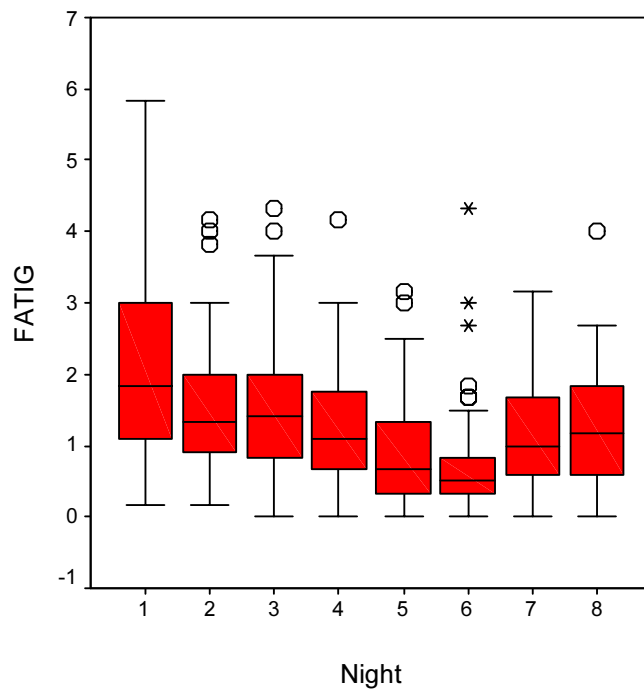


Figure 93: "Fatigue – time pressure" of the field subjects (N = 64) in the course of the field study.

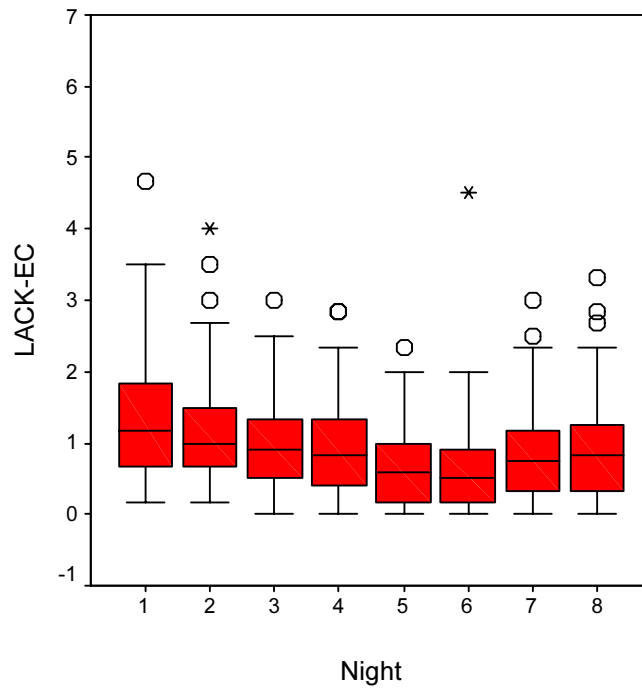


Figure 94: "Lack of energy and concentration" of the field subjects (N = 64) in the course of the field study.

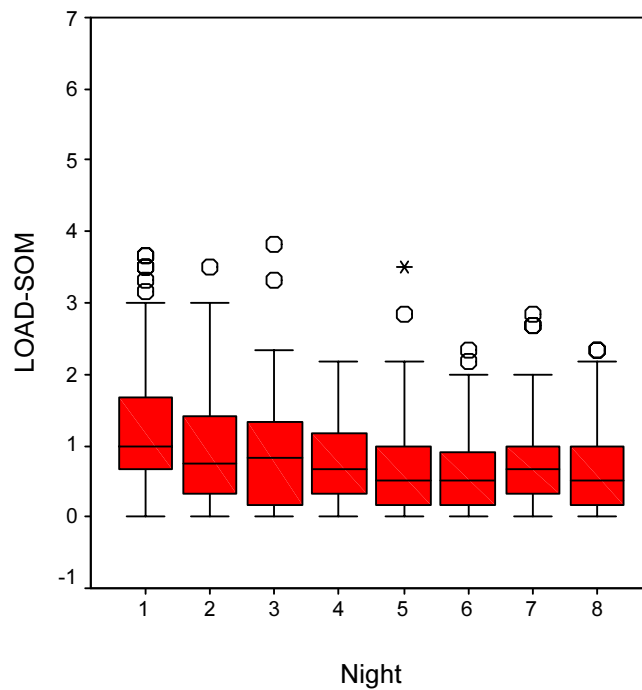


Figure 95: "Somatic complaints" of the field subjects (N = 64) in the course of the field study.

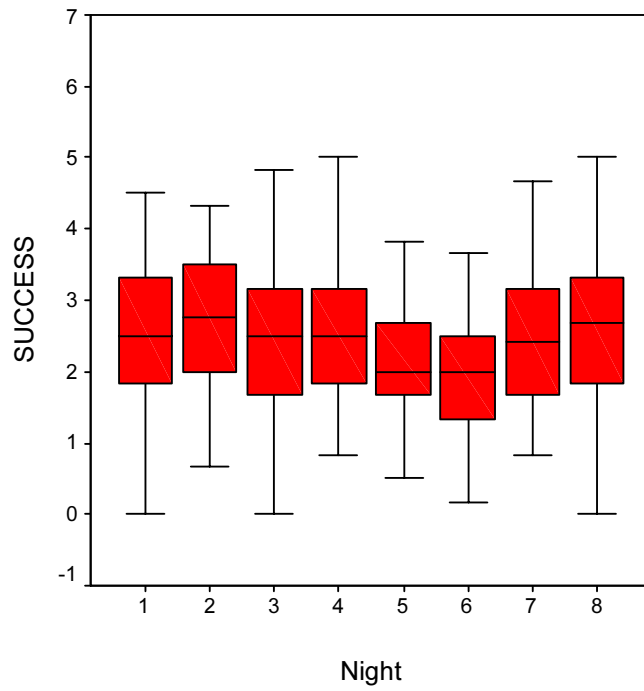


Figure 96: "Success – efficiency" of the field subjects (N = 64) in the course of the field study.

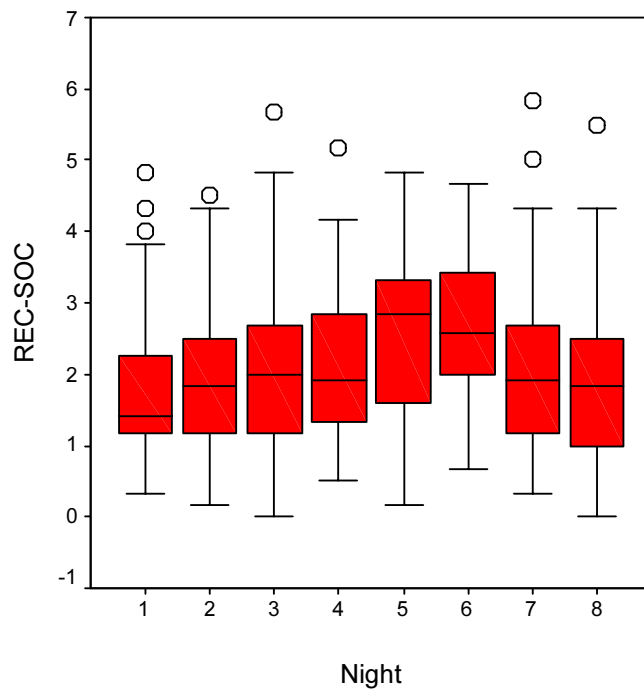


Figure 97: "Recuperation in the social domain" of the field subjects (N = 64) in the course of the field study.

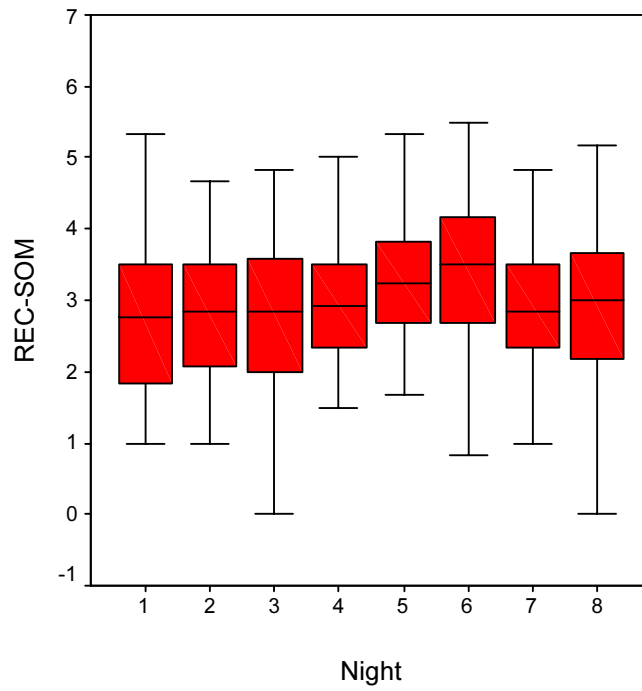


Figure 98: "Somatic recuperation" of the field subjects (N = 64) in the course of the field study.

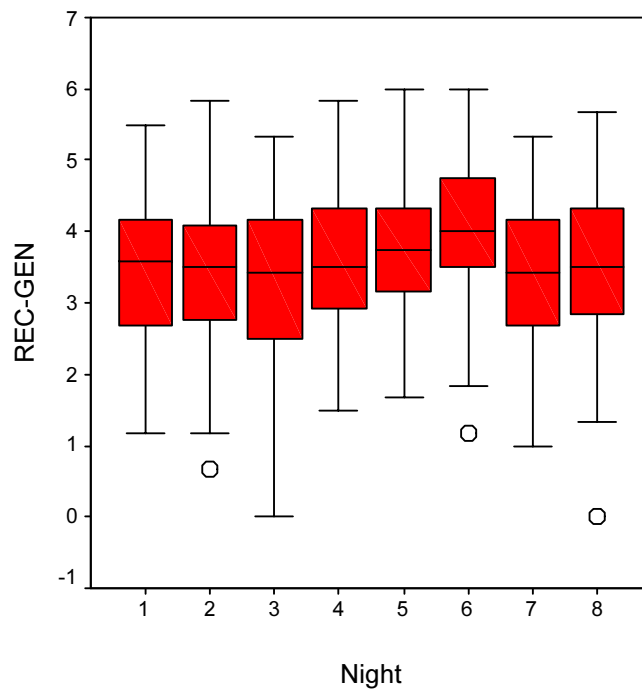


Figure 99: "General recuperation – well-being" of the field subjects (N = 64) in the course of the field study.

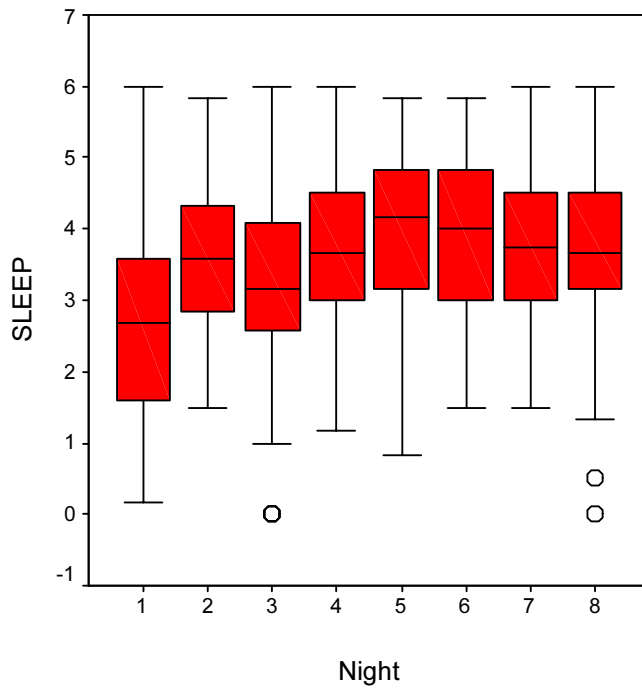


Figure 100: "Restorative sleep" of the field subjects (N = 64) in the course of the field study.

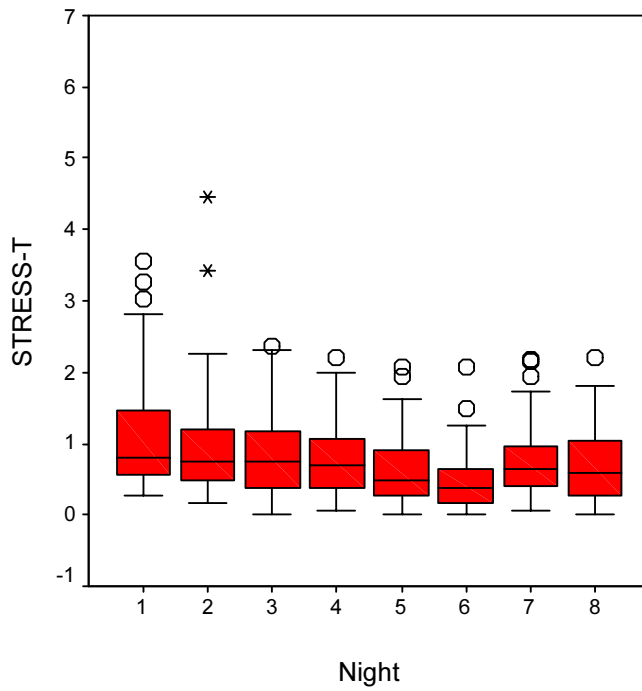


Figure 101: "Total stress" of the field subjects (N = 64) in the course of the field study.

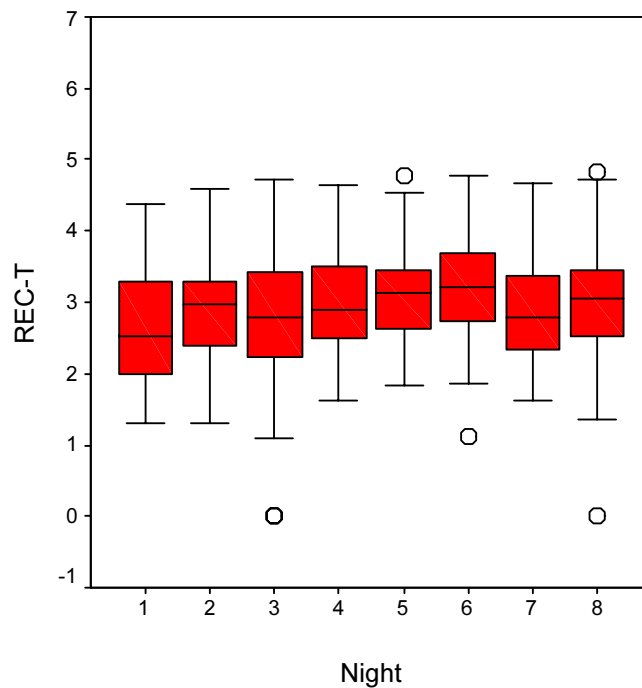


Figure 102: "Total recuperation" of the field subjects (N = 64) in the course of the field study.

#### 2.4.1.3 Dose-response curves

In order to deduce *dose-response curves* between independent physical aircraft noise parameters ( $L_{AS,eq}$ , number of flight events) and dependent psychological reaction parameters, the interrelation between independent and dependent variables was descriptively verified (figures 103 to 108 for the morning values of the MDMQ, figures 109 to 114 for the RLQ). All 9 field study nights were considered. The results for the RLQ are exemplarily illustrated for the dimensions "total stress" (STRESS-T), "total recuperation" (REC-T) and "restorative sleep". Similar to the laboratory study, it can be shown that mood, stress and recuperation do not exhibit systematic interactions with the physical aircraft noise parameters; the probabilities solely vary in the range of  $P = 0.40$  to  $0.60$ . Accordingly, *none of the logistic regression analyses yield significant dose-response relationships for mood, stress and recuperation*. At this point, an explicit description of the findings will be refrained from.

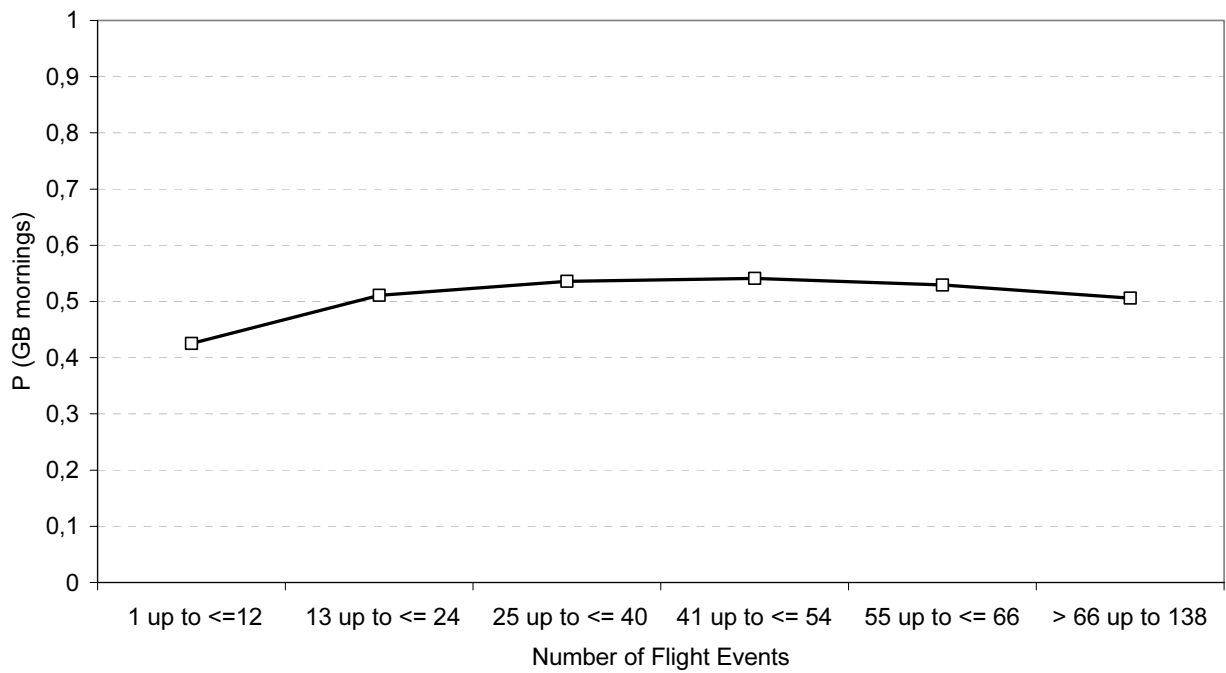


Figure 103: "Good – bad mood mornings" of the field subjects (N = 64) depending on number of flight events.

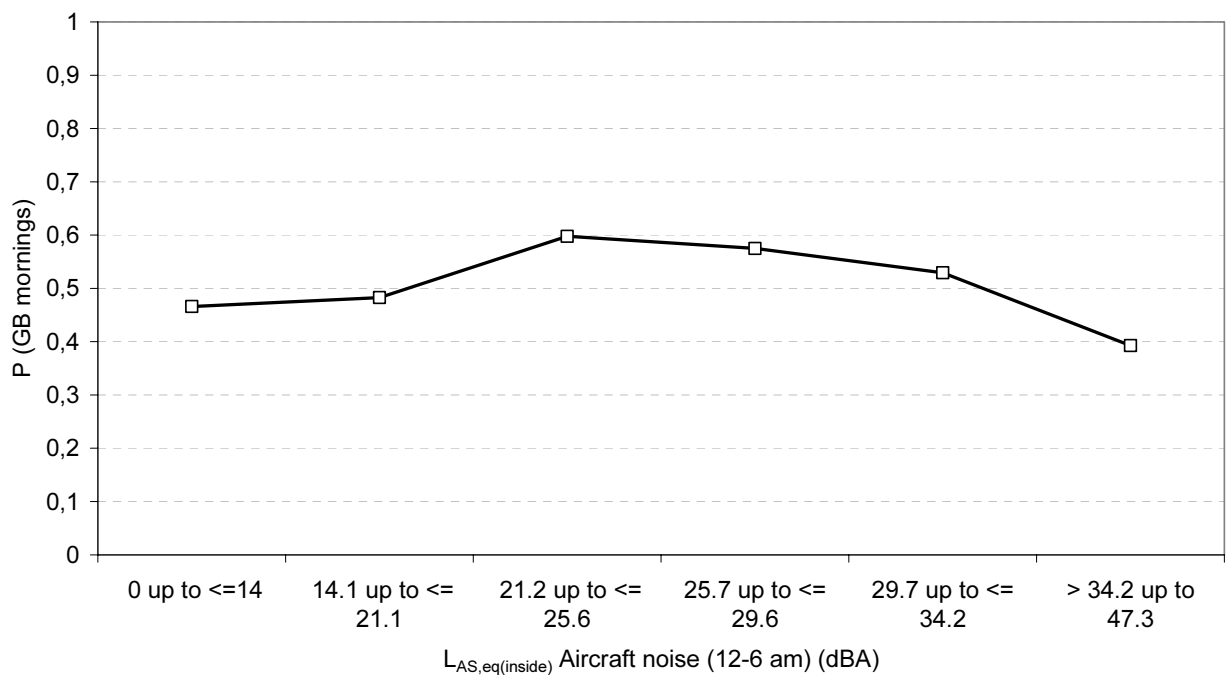


Figure 104: "Good – bad mood mornings" of the field subjects (N = 64) depending on the energy equivalent noise level L<sub>AS,eq</sub>.

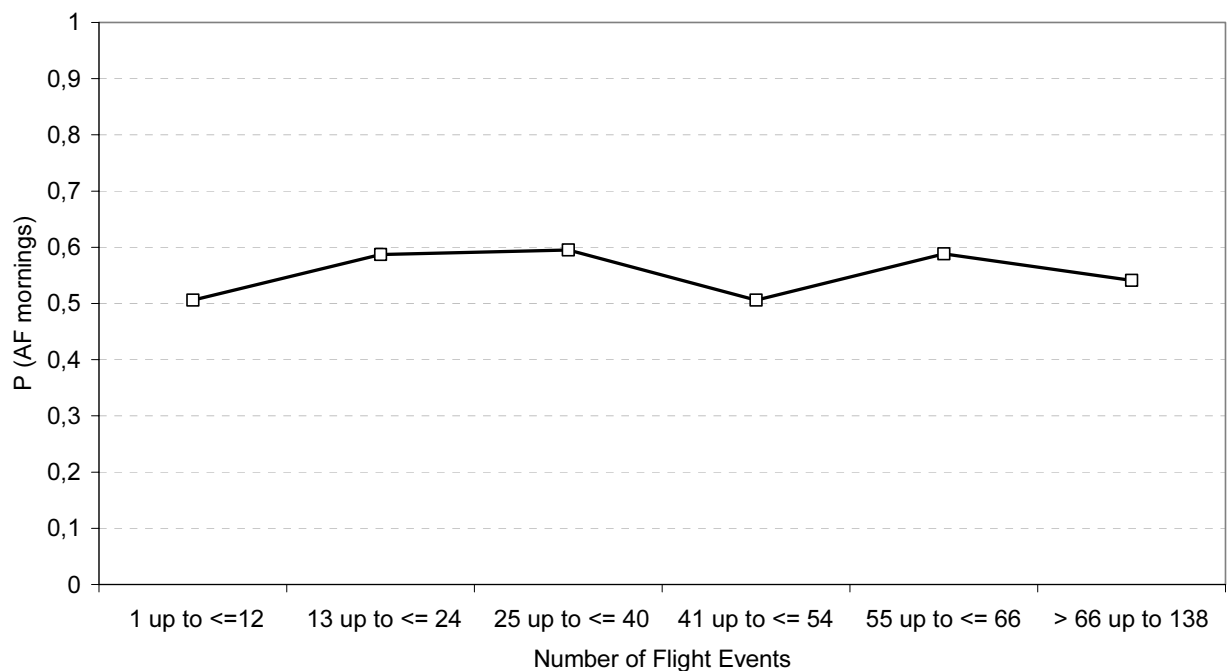


Figure 105: "Alertness – fatigue mornings" of the field subjects (N = 64) depending on number of flight events.

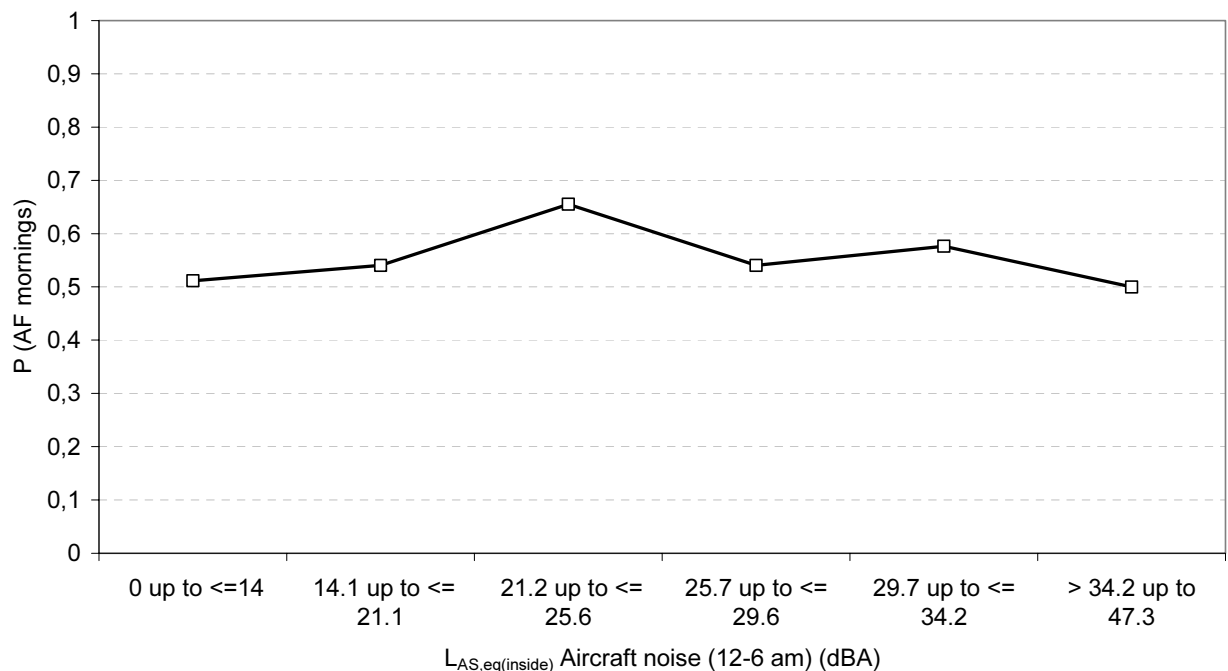


Figure 106: "Alertness – fatigue mornings" of the field subjects (N = 64) depending on the energy equivalent noise level L<sub>AS,eq</sub>.

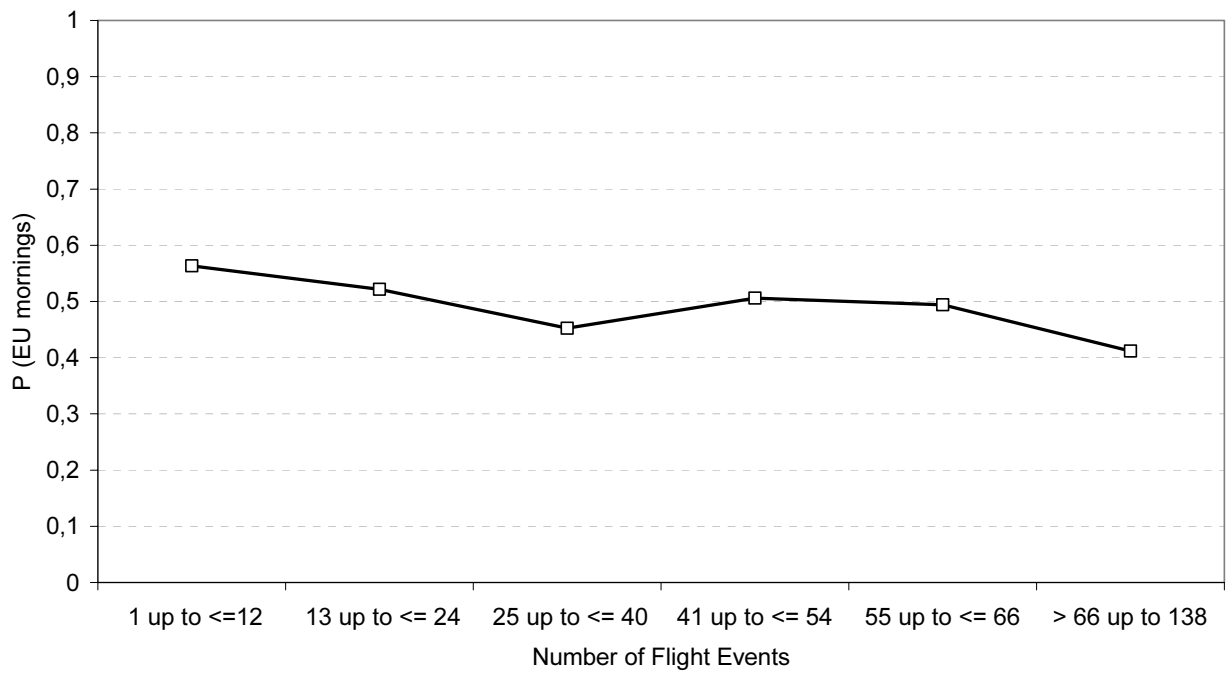


Figure 107: "Ease – unease mornings" of the field subjects (N = 64) depending on number of flight events.

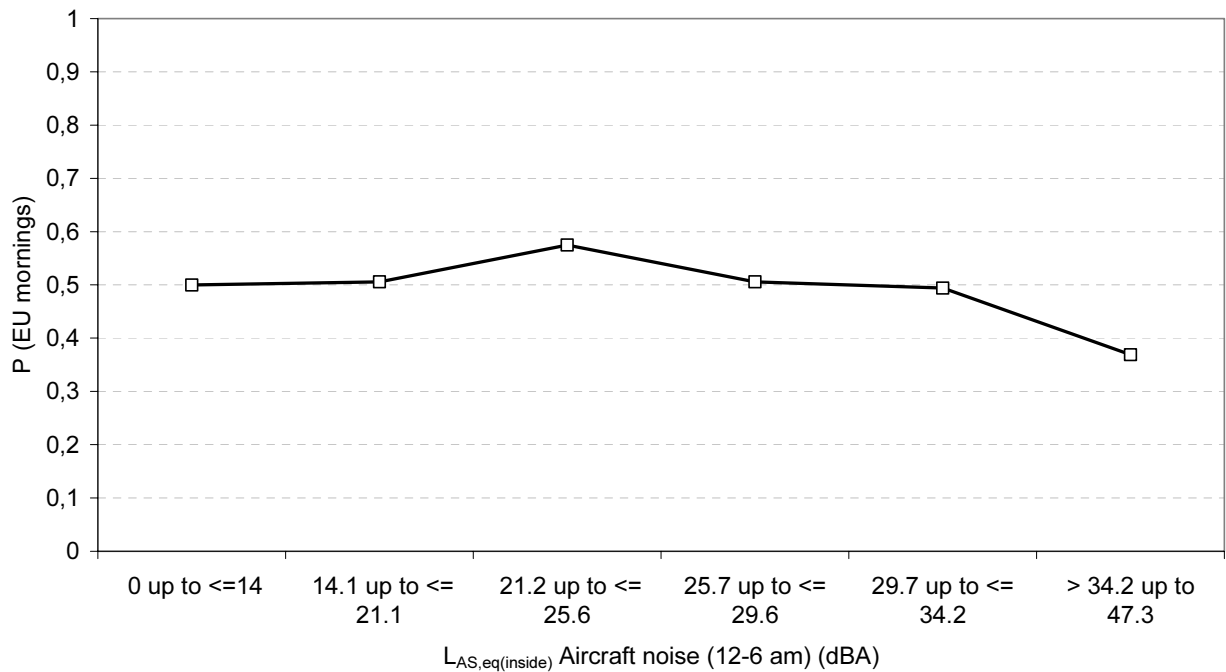


Figure 108: "Ease – unease mornings" of the field subjects (N = 64) depending on the energy equivalent noise level L<sub>AS,eq</sub>.

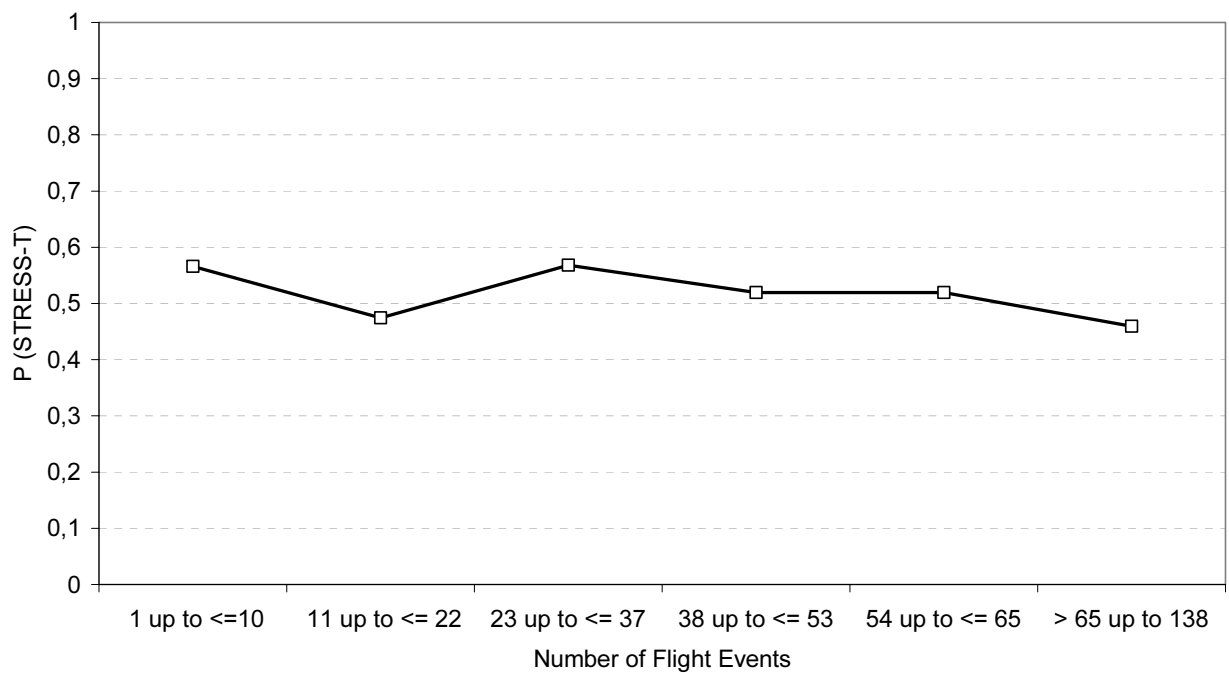


Figure 109: "Total stress" of the field subjects (N = 64) depending on number of flight events.

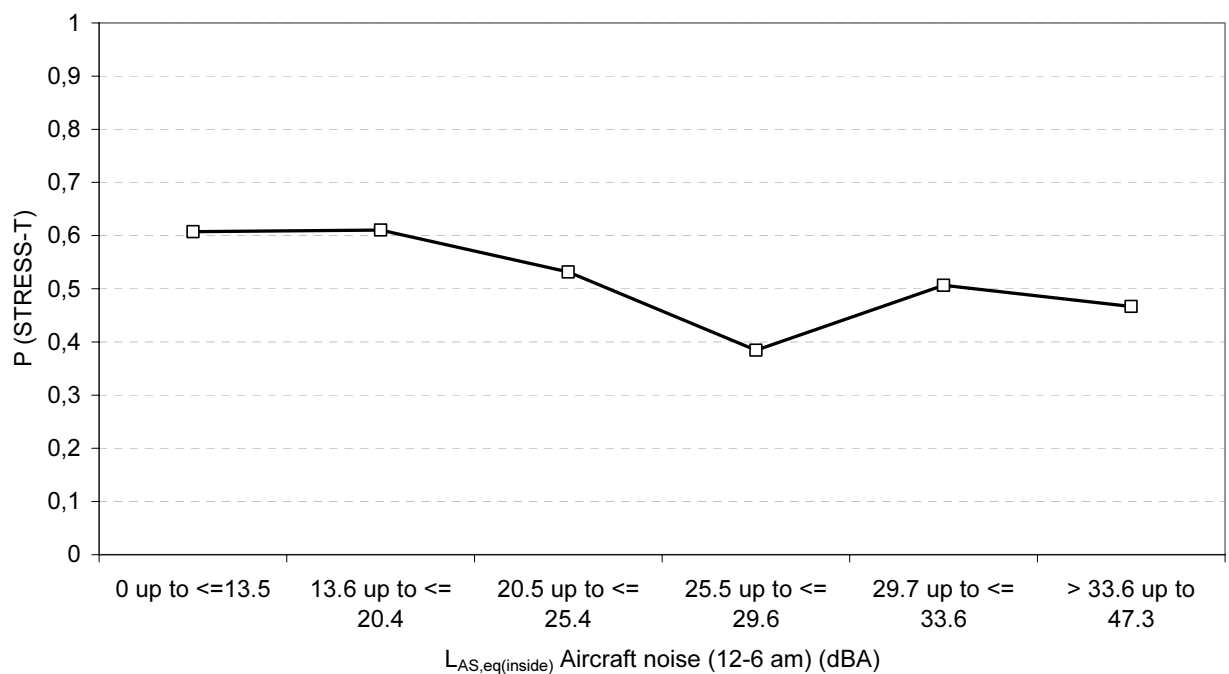


Figure 110: "Total stress" of the field subjects (N = 64) depending on the energy equivalent noise level L<sub>AS,eq</sub>.

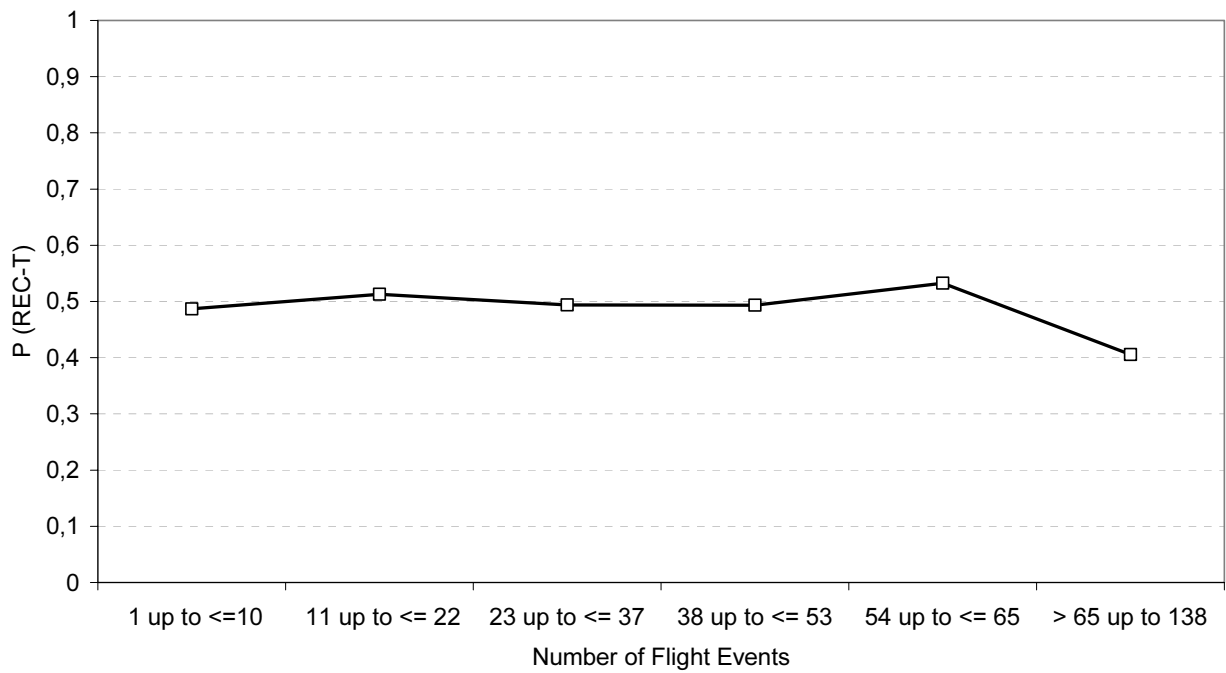


Figure 111: "Total recuperation" of the field subjects (N = 64) depending on number of flight events.

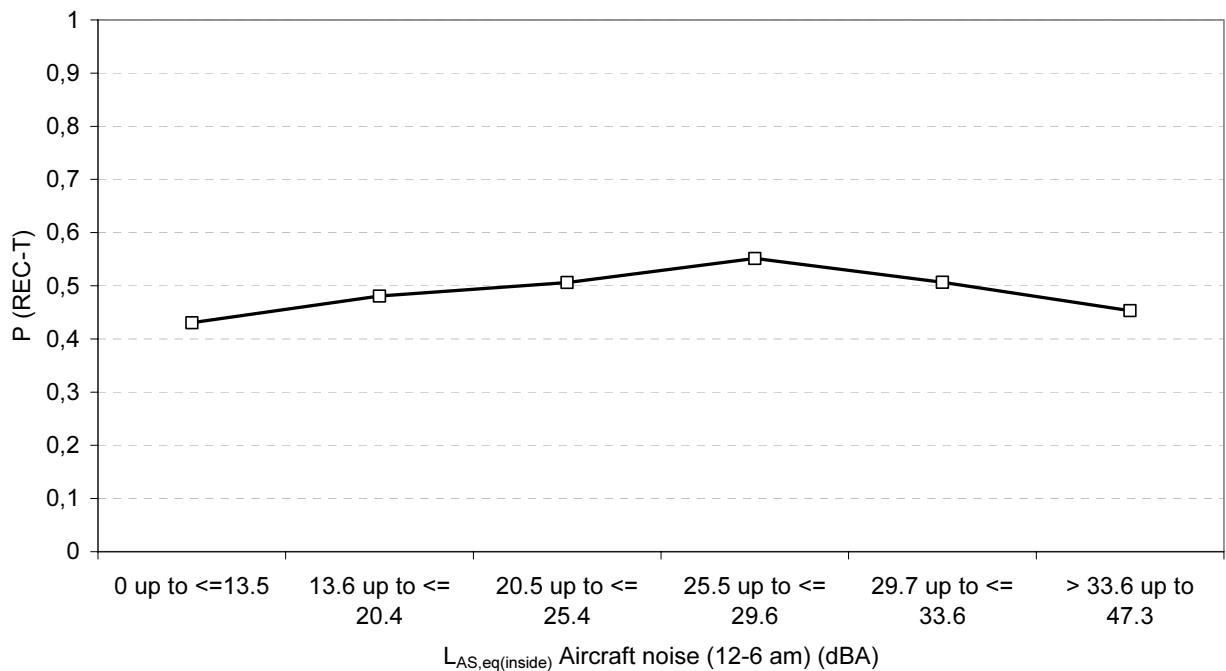


Figure 112: "Total recuperation" of the field subjects (N = 64) depending on the energy equivalent noise level L<sub>AS,eq</sub>.

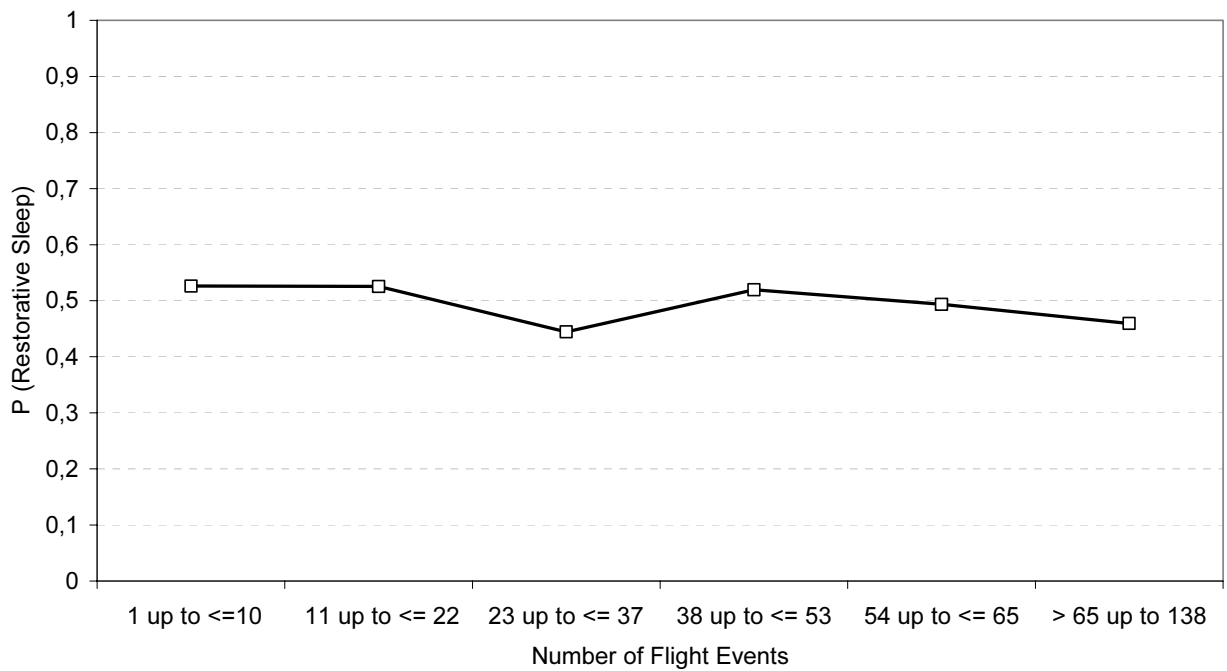


Figure 113: "Restorative sleep" of the field subjects (N = 64) depending on number of flight events.

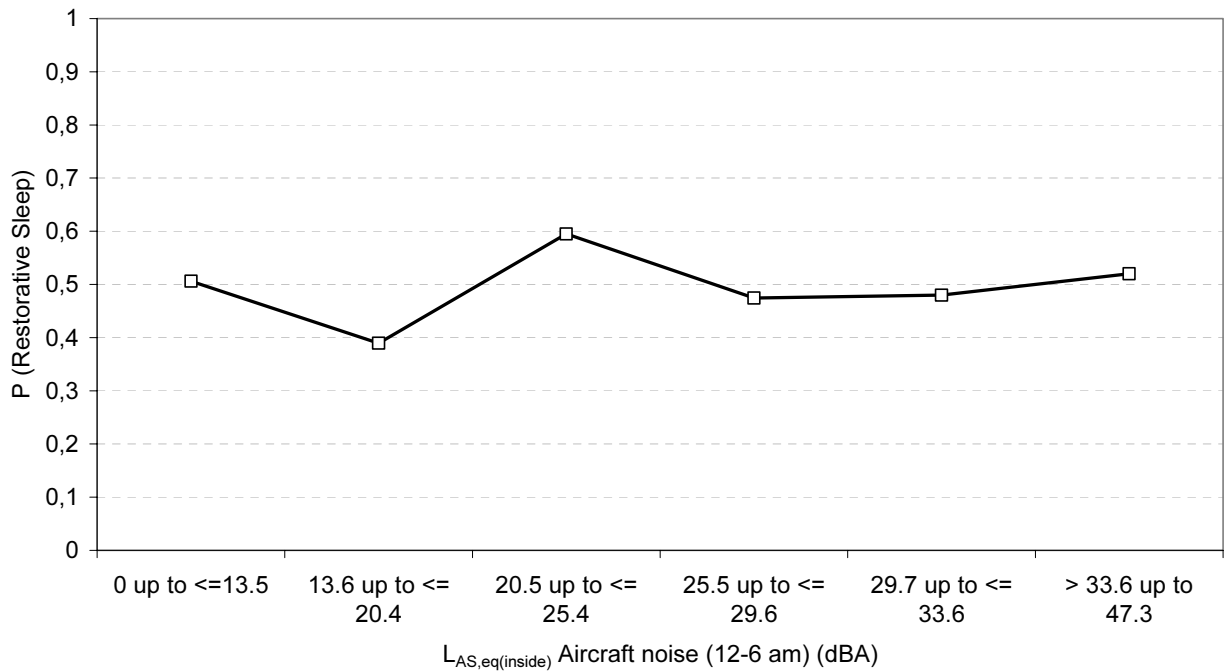


Figure 114: "Restorative sleep" of the field subjects (N = 64) depending on the energy equivalent noise level  $L_{AS,eq}$ .

## SUMMARY AND DISCUSSION

### PART 1: NOISE ANNOYANCE

A laboratory experiment was run to investigate the human-specific psychological effects of nocturnal aircraft noise on annoyance, subjective noise exposure (regarding intensity and frequency) and sleep sensation. The laboratory study was conducted with a sample of 128 subjects during 13 consecutive nights in the occupational medical simulation facility of the DLR Institute of Aerospace Medicine. 112 subjects served as experimental groups, and they were exposed to aircraft noise of various intensities and frequencies during 9 consecutive nights. A study with a total of 64 participants served for validation of the laboratory results. The subjects from the field study all lived in the vicinity of the Konrad-Adenauer-Airport Cologne/Bonn and were examined at home during 9 consecutive nights.

The operationalisation of aircraft noise was achieved in the laboratory by using the physical parameters number of aircraft noise events (level frequency),  $L_{AS,max}$  and  $L_{AS,eq}$ . In the field study, indoor and outdoor noises were simultaneously recorded and used for the calculation of numerous acoustic parameters. In the present analysis, the number of aircraft noise events and the  $L_{AS,eq}$  were chosen as independent variables. However, maximum noise levels could not be selected, since it varied per night due to the real field conditions, which was not the case in the laboratory. By means of a questionnaire that was filled out every morning after waking up in both study settings, the annoyance due to nocturnal aircraft noise, the sleep sensation (regarding sleep quality and sleep quantity as well as awakening frequency), the degree of fatigue and the subjective noise exposure (aircraft noise intensity and frequency of unacceptable aircraft noises) were asked for.

The following issues were analyzed:

1. *To what extent an interrelation between aircraft noise and the perceived disturbance exist?*
2. *Starting from which level of aircraft noise exposure does the perceived disturbance become relevant?*

In order to determine a *general influence of aircraft noise*, measurements from various days in the laboratory and in the field were compared: There is a so-called "first night effect" in both settings for the *sleep quality* and *sleep quantity* and also for the *awakening frequency* and *fatigue* in the laboratory [cp. Agnew et al. 1966; Basner et al. 2000, 2001; Griefahn 1985; Öhrström & Björkman 1988]. Thus, the subjects sleep qualitatively and quantitatively better in the second night than in the first one, they wake up less frequently, and they are in the mornings less tired in the laboratory. A "last night effect" can be proven neither in the laboratory nor in the field for any of the secondary reactions. In the field, a "weekend effect" also does not exist. Significant "impairments" of all reactions are observed comparing the first noise-exposed night in the laboratory with the second noise-free baseline night. In the first noise-free night following the 9 noise-exposed nights, a significant "improvement" of all dependent variables occurs.

For the laboratory study, there are significant main effects for the maximum noise level and the number of aircraft noise events (level frequency) with regard to all analyzed secondary reactions. This finding is in accordance with previous aircraft noise effects studies on annoyance [Björkman et al. 1992; DFG 1974; Fields 1984, 1993; Finke et al. 1980; Kastka & Faust 1998; Rylander et al. 1972, 1980, 1986; Rylander & Björkman 1988, 1997] and with investigations on sleep sensation (with respect to the reduction of sleep quality) [Öhrström 1995; Öhrström & Rylander 1982, 1990]. According to the hypothesis, paired comparison between the factor stages of the *maximum noise level* (N = 8) proves a significant increase of the annoyance and the subjective noise exposure (regarding intensity and frequency) with growing  $L_{AS,max}$ . The

maximum noise level must be at least 10 dB(A) higher than 55 dB(A) and at least 20 dB(A) higher than 45, 50 and 60 dB(A) to induce a significantly increased disturbance. Regarding assessments of sleep quantity and sleep quality as well as of fatigue, there are no significant differences. With respect to the rated awakening frequency 45 dB(A) only differ from 70 dB(A). The interrelation between the extent of aircraft noise exposure and resulting reaction depends also on the number of flight events [Guski 1999]. According to the hypothesis, paired comparisons of the *number of events categories* (N = 6) indicate that rising the frequency beyond 4 or 8 noise events per night, leads to a significant increased annoyance, subjective noise exposure (regarding intensity and frequency) and fatigue as well as to a significant loss of sleep sensation with regard to sleep quality and awakening frequency. Concerning sleep quantity, 4 noise events only differ from 64 events. Regarding annoyance and rated awakening frequency, 16 movements also differ from 128. Therefore, the frequency of flights passing by plays a more important role than maximal noise levels with respect to the sleep sensation. There are no significant differences between the medium frequencies (n = 32 and 64) and between the upper level categories (75 dB(A) and 80 dB(A)), which is most likely caused by the incomplete multi-factorial experimental design (e.g., at 75 dB(A) not more than 16 aircraft sounds and at 80 dB(A) not more than 8 sounds have been presented). Paired comparisons of the *equivalent noise level categories* (N = 9) demonstrate a significant increase of the annoying impact and subjective noise exposure (regarding intensity and frequency) beyond 33 dB(A). Furthermore, a significant deterioration of all measured sleep variables (except for fatigue) results with increasing aircraft noise exposure > 33 dB(A). The results confirm the validity of the energy equivalent noise level for the prediction of aircraft noise-induced disturbances [Aasvang & Engdahl 1999; Eberhardt et al. 1987; Griefahn 1986; Hellbrück 1993; Schick 1997]. There is no significant differentiation between the medium and the upper level categories of the  $L_{AS,eq}$  (> 39 dB(A)), which is also most likely due to the incomplete multi-factorial experimental design.

In order to derive specific *dose-response relationships for aircraft noise annoyance random effects logistic regression* was performed in an iterative modeling process for both the laboratory and the field study. To generate a *dichotomous dependent annoyance variable*, the categories 3 to 5 of the original 5-point answering scale were combined into one value (1 = existence of aircraft noise annoyance). Thereby it was intended to consider the group of highly annoyed persons [cp. Guski 2001a; Jansen 1986; Rohrmann 1984a] as well as the range of “medium” annoyance.

According to the *first laboratory-specific regression model L1* that integrates the  $L_{AS,max}$  and the number of events as independent variables, the percentage of aircraft noise annoyed persons grows with the increase of the  $L_{AS,max}$  as well as of the frequency of events. This corresponds to the findings of previous studies on aircraft noise annoyance [e.g., Björkman et al. 1992; Fields 1984; Rylander et al. 1972, 1980, 1986; Rylander & Björkman 1988]. 128 noise events of 55 dB(A) lead to the highest amount of predicted noise annoyed persons, which lies over 80%. Contrary to previous investigations, the number of annoyed persons also increases significantly with rising  $L_{AS,max}$ , even if few aircraft movements (< 16 over-flights per night) take place. This is probably due to the laboratory situation of the subjects. The individual sleep differs qualitatively and quantitatively from that at home. In the laboratory, the subjects clearly wake up more often than at home. This may lead to an increased annoying potential of the experienced aircraft sounds when they are alert [Basner 2004]. The assessment of annoyance following noise-induced sleep disturbances is not quite simple since the interviewees shall refer to a completed and unconscious state. Hence, it is based on the remembered and consciously experienced alertness times and difficulties when falling asleep. With numerous nocturnal over-flights it is likely that the subjects consciously experience more aircraft noise events during the periods of alertness and falling asleep. This may disturb nocturnal sleep, and by definition leads to an increased degree of annoyance. The explanation supports the perception of airport residents that a strong increase of modern aircrafts, with a simultaneous

reduction of the emission levels, leads to a qualitative change of the noise exposure. This implies that, today, the affected persons mainly complain about the increased number of flight movements and the lack of intermissions in the noise progression. Thus, the frequency of over-flights plays an important role with respect to aircraft noise annoyance.

The *second laboratory-specific regression model L2* describes an initial augmentation of the proportion of noise annoyed persons depending on the energy equivalent noise level (15% at 30.6 dB(A) to 70% at 46.6 dB(A)). The same average noise levels, which are based on different level frequency combinations (e.g., 128 times 55 dB(A), 4 times 70 dB(A)) do not result in the same degree of annoyance. Therefore, the number of annoyed persons decreases above 46.6 dB(A) due to the underlying level frequency combinations (louder aircraft noise events presented with lower frequencies per night). Thereby, the importance of the number of nocturnal flight movements for the annoyance is confirmed. According to the present analysis, annoyance decreases at a low number of louder noise events [cp. also Finke et al. 1980; Rohrmann 1974; Rylander & Björkman 1997]. Simultaneously, the position of the average noise level in noise effects research as the best (objective) measure for the prediction of noise annoyance is questioned at least for the night. Other investigations on the annoying impact of aircraft noise (at day) confirm this finding [Björkman et al. 1992; Guski 2001; Kastka 1999, 2001a, 2001b; Kastka & Faust 1998; Rylander & Björkman 1988]. The acute disturbing effect of aircraft noise is produced mainly by the single event, i.e., persons do not react to a global noise immission characterized by the average noise level, rather they react to features of single flight events such as their levels and their frequencies.

It applies to both laboratory-specific models that one social image factor (necessity of air traffic) and two personal parameters (gender, aircraft noise pre-annoyance) prove to be significant moderators of aircraft noise annoyance. The predicted amount of aircraft noise annoyed persons is significantly higher

for (1) women, (2) those who are very pre-annoyed due to aircraft noise in their residential area and (3) those who do not regard air traffic as necessary.

According to the prediction made by *first field-specific regression model F1*, the importance of the number of nocturnal flight movements to annoyance is confirmed. The amount of annoyed persons rises significantly with the increase of the frequency of flights. 138 aircraft noise situations per night cause the highest percentage of annoyed persons (approximately 55%). The *second field-specific regression model F2* describes a significant dependence on the energy equivalent noise level, i.e., the group of aircraft noise annoyed people increases with rising  $L_{AS,eq}$  (up to 30% at 47.3 dB(A)).

Within both field-specific regression models, subjective adaptation to aircraft noise and, additionally within F1 age, are effective personal moderators. The predicted proportion of aircraft noise annoyed persons is significantly higher for (1) people with no aircraft noise adaptation, and (2) older persons.

When comparing the laboratory- and field-specific dose-response curves for common ranges of the independent variables number of events (taking into account the integration of different moderators and that the curve derived from L1 only applies to a maximum noise level of 55 dB(A)), the laboratory curve lies above the field curve (approximately 20% to 40% difference). At maximum noise levels ranging from 20 dB(A) to 70 dB(A) (median = 44 dB(A)), for 4 events per night the predicted proportion of aircraft noise annoyed persons amounts to 2% in the field, compared to 20% in the laboratory at  $L_{AS,max} = 55$  dB(A). 128 aircraft noise events result in 50% in the field, compared to more than 80% in the laboratory. The laboratory curve calculated from L2 ( $L_{AS,eq}$  as independent variable), also lies above the field curve (approximately up to 40% difference). At  $L_{AS,eq} = 30.6$  dB(A), the predicted amount of aircraft noise annoyed persons is roughly the same in both the field and the laboratory with 12% to 15%. At 47.3 dB(A), it is 30% in the field compared to 70% in the laboratory. The *differences between laboratory- and field-specific dose-response curves* are primarily due to the laboratory

situation of the subjects. Field and laboratory studies assign the extremes of a continuum describing different degrees of "naturalistic" investigations. Field studies conducted in natural environments have a high external and ecological validity, contrary to laboratory studies performed under controlled conditions. The relative advantages and disadvantages of laboratory and field approaches have been discussed in many cases [cp. Bortz & Döring 1995]. In the present case, the investigation under laboratory conditions allowed to test *systematically* the influence of the maximum noise level, the energy equivalent noise level and the stimulus frequency of the applied aircraft noise. Thus, with the utmost probability changes of the dependent variables (e.g., the annoyance) could be attributed to the independent variables (high internal validity). However, studies of noise annoyance in the laboratory are problematic, since the assessment of aircraft sounds with respect to their disturbing potential becomes the main task of the subjects, which does not necessarily correspond to the natural conditions in the domestic environment of the involved airport residents and thus may result in higher annoyance judgements [cp. Guski & Bosshardt 1992; Rohrmann 1984]. Furthermore, sleep in the laboratory differs qualitatively and quantitatively from that at home. In the unfamiliar laboratory environment, the subjects clearly wake up more often [Basner 2004]. This may lead to an increased annoyance due to the consciously experienced aircraft noise.

### *3. What are the main characteristics of aircraft noise annoyance?*

By means of varimax-rotated principle component analyses (PCA), the meaning of the aircraft noise annoyance term was specified. For this purpose, data were used from the general questionnaire that had been posted before the studies began. Beside annoyance, the questionnaire asks for a variety of other variables regarding the disturbing impact of aircraft noise at home. The PCA provides three factors for both the laboratory and the field inquiries, which together explain more than 42% of the total variance. The main factor essentially combines the experienced, aircraft noise-induced disturbance of activities such as communication, recuperation and sleep at home, which is accompanied by feelings such as petulance. An important cognitive aspect is the "be-

lief in the individual health hazard caused by aircraft noise". In the laboratory inquiry, additional items for the description of the aircraft noise intensity can be found in the first component, which constitute the second factor in the PCA of field data. The second factor of the laboratory PCA contains so-called image variables, which are concerned with the social assessment of air traffic with regard to its "necessity" and "health hazard", the "possibilities of avoiding it", its "eco-friendliness" and its "reliability" [Guski 1999]. For the field data, these items are already integrated into the first component instead of the scales concerning the assessment of the aircraft noise intensity. The third factor includes affective attributes for the field as well as the laboratory inquiries, which aim at the (dis-)contentment regarding aspects of the residential area (e.g., air quality, outer appearance, relaxation and recuperation possibilities), in terms of the so-called "environmental aesthetic" [Booth 1999; Guski 1987; Oliva 1998]. *Therefore, it was possible to verify cognitive and emotional aspects of the concept of aircraft noise annoyance. Apparently, the term corresponds most closely to the aircraft noise-induced disturbance of communication, recuperation and relaxation, and of sleep, combined with feelings of petulance and with the belief in a individual health hazard caused by aircraft noise* [cp. Guski et al. 1999, Guski & Schick 2004; Kastka 2001a; Koelega 1987].

#### 4. *What are important parameters influencing aircraft noise annoyance?*

Non-acoustic, aircraft-noise-relevant moderators were integrated in the modelling of dose-response curves concerning annoyance. Furthermore, influence of *psychological moderators* on aircraft noise *pre-annoyance* (i.e., annoyance due to aircraft noise at home *before* the study) was tested by using Kruskal-Wallis one-way analysis of variance. It is shown that the contextual parameters, such as *the contentment with different aspects of the residential area* ("environmental aesthetic") and the *time of residence* do not have a moderating effect [Booth 1999; Guski 1987; Oliva 1998]. Merely the *overall residential contentment* of the field study participants has a positive influence. Different *domestic noise controls* only moderate the annoyance reaction of the laboratory subjects (i.e., compared to single or double glazed windows, threefold

window glazing is associated with the highest degree of pre-annoyance). The most sensitive conditions are “tilted window-situations” and “outside”, where the outside condition is assessed as more sensitive than the “tilted window-situations” [Kastka 1990, 1999, 2001a]. The social *image of air traffic* (i.e., its rated “health hazard” and “eco-friendliness”) has a significant moderating effect [Guski 1987]. Furthermore, the perceived “necessity of air traffic” plays an important role for the laboratory subjects, whereas the “possibilities of avoiding air traffic” are significant for the field subjects. A “health hazard potential caused by aircraft noise” classified as high is associated with a higher aircraft noise annoyance. The “general health hazard caused by aircraft noise” is perceived as significantly higher than the “individual health hazard”. The *general attitude towards air traffic* is also an effective social moderator, i.e., a negative attitude towards air traffic leads to a higher annoyance. Furthermore, *confidence in people and institutions potentially responsible for causing aircraft noise* has a significant influence. The *belief in successful chances of noise reduction* merely is a moderator for the laboratory sample. In summary, the importance of social moderator variables regarding noise abatement and the reduction of noise annoyance is confirmed [Felscher-Suhr et al. 2001; Fields 1993; Guski 1987, 1999, 2001b]. The *individual noise sensitivity* (i.e., a higher noise sensitivity causes a higher annoyance) and the *subjective noise adaptation* (i.e., a lower adaptation to aircraft noise is associated with a higher annoyance) prove to be substantial personal moderator variables for both the field and the laboratory subjects [Fields 1993; Guski 1987; Job 1999; Miedema & Vos 1999]. The *participation in activities against aircraft noise* also has a significant moderating effect. However, *travelling experiences on aircrafts* and *residential status* (owner vs. renter) of the subjects exhibit no significance.

## **PART 2: MOOD, STRESS AND RECUPERATION**

The examination of the human-specific psychological effects of nocturnal aircraft noise also contained inquiries of mood, stress and recuperation by means of two standardized questionnaires: the multi-dimensional mood ques-

tionnaire (MDMQ) by Steyer et al. [1997], and the recuperation and load questionnaire (RLQ) by Kallus [1995].

The following hypotheses were tested:

- *The mood is impaired by nocturnal aircraft noise exposure, which is denoted by the decrease of the scale values of the MDMQ.*
- *The degree of stress increases in correspondence with the extent of aircraft noise exposure. The scale values for stress (RLQ) rise with an increasing noise exposure.*
- *The degree of recuperation is reduced corresponding to the extent of noise exposure. The scale values for recuperation (RLQ) decline with increasing aircraft noise exposure.*

The following changes of mood, stress and recuperation were found by means of the laboratory and field inquiries:

1. The inter-individual comparison between the control and experimental groups from the laboratory study yields a *significant influence of aircraft noise "itself"* on the mood aspects "GB mornings" and "AF mornings" (both MDMQ), and "restorative sleep" (RLQ). This signifies that the experimental groups have a significantly worse mood and are distinctly more fatigued than the control groups. After the noise exposure nights, the control groups have a significantly more restorative sleep than the experimental groups.
2. With the course of both the laboratory and the field study, a significant "first night effect" (comparison of the first and second study night) emerged regarding the mood variables "GB mornings" (good – bad mood in the mornings), "AF mornings" (alertness – fatigue in the mornings) and the scale "restorative sleep". In the field, this also applies to the RLQ-scales "FATIG" (fatigue – time pressure), "LOAD-SOM" (somatic complaints), "CONFL" (unresolved conflicts – failure),

“STRESS-T” (total stress), and “REC-T” (total recuperation). This “first night effect” indicates that the subjects feel significantly better and more rested after the second examination night and are significantly less stressed and more recuperated the subsequent evening. A significant “weekend effect” in the field study regarding almost all mood, stress and recuperation parameters, points out that the subjects’ mood is significantly less impaired at the weekends and that the weekend is associated with a significantly higher recuperation value (i.e., less stress). However, this does not apply to the scale “restorative sleep”. Unlike in the laboratory data, a “last night effect” exists for all morning values of the MDMQ, i.e., due to the prospect of the approaching end of the study, the mood is significantly more positive on the final morning.

3. There is *no significant impact of aircraft noise* (i.e., no main effects for the aircraft noise parameters  $L_{AS,max}$ ,  $L_{AS,eq}$ , number of events) on the mood aspects “GB mornings” and “AF mornings”, and “restorative sleep” of the experimental groups, i.e., the scale values do not decline with increasing aircraft noise exposure (in the meaning of an impairment).

Since the mood, stress and recuperation of the experimental groups do not systematically vary depending on the nocturnal aircraft noise exposure, the three hypotheses have to be rejected. There is *no significant influence of aircraft noise on mood, stress and recuperation*. This is confirmed by the results of the analyses of dose-response curves. For the laboratory as well as in the field study, no significant dose-response relationships could be found between the nocturnal aircraft noise exposure and the corresponding changes of mood, stress and recuperation [cp. Öhrström 1995; Öhrström & Rylander 1982].

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## List of Abbreviations

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<b>Abbreviation</b>	<b>Meaning</b>
AMSAN	occupational medical simulation facility
BImSchG	federal immission protection act
BImSchV	federal immission protection regulation
dB	decibel, physical unit of the sound pressure level
dB(A)	physical unit of the A-weighted sound pressure level
DF	degree of freedom
RLQ	recuperation and load questionnaire
FAT	fatigue questionnaire or fatigue
$L_{\max}$	maximum value of the sound pressure level (maximum noise level)
$L_{\text{eq}}$	energy equivalent noise level (= temporal mean) of the sound pressure level
$L_{\text{AS,eq}}$	energy equivalent noise level (= temporal mean) of the A-weighted, "slowly" measured sound pressure level
$L_{\text{AS,max}}$	maximum value of the A-weighted, "slowly" measured sound pressure level
LRA	logistic regression analysis
MDMQ	multi-dimensional mood questionnaire
NAT70	number of single sound events exceeding $L_{\max}$ values of 70 dB(A) (number above threshold)
PCA	principal component analysis
Q1, Q3, Q3	1st quartile, 2nd quartile, 3rd quartile
STRAIN	study on human specific response to aircraft noise