Comfort studies on aircraft interior sound and vibration

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CONTENTS

ZUSAMMENFASSUNG (SUMMARY)

Komfort ist ein Qualitätsmerkmal, das die Zufriedenheit eines Passagiers in einem Flugzeug maßgeblich beeinflußt. Das individuelle Komforterleben wird durch eine Vielzahl subjektiv-psychologischer und objektiv-physikalischer Faktoren bestimmt, wobei Schall und Vibration wichtige physikalische Einflußgrößen sind. Obwohl Komfort sowohl von Schall- als auch Vibrationsparametern abhängig ist, befaßte sich die Mehrzahl der bisherigen Flugkomfortstudien lediglich mit ihrer Einzel-, nicht aber mit ihrer spezifischen Kombinationswirkung. Der Zusammenhang zwischen physikalischen und psychologischen Faktoren wurde zudem nur selten systematisch untersucht. Da in der Regel ausschließlich subjektive Diskomfort- und Belästigungsreaktionen erhoben wurden, ist eine Generalisierbarkeit auf Komfortuntersuchungen, die sich mit der kombinierten Wirkung von Schall und Vibration (Vibro-Akustik) befassen, nur begrenzt möglich.

Die vorliegende Arbeit, die aus dem BRITE EURAM Projekt IDEA PACI (BE97-4056) hervorging, beschäftigte sich mit der Kombinationswirkung von Schall und Vibration auf das Komforterleben in Flugzeugen. Lexikalische und alltagssprachliche (Metzger, 1994) Begriffsanalysen zum Thema „Komfort“ sowie ergonomische (Krist, 1994, Zhang et al. 1996) und psychologische Komfort- und Wohlbefindensmodelle (Becker, 1991; Pineau, 1982; Slater, 1985) dienten als theoretische Basis der Untersuchungen. Es wurde nach Kriterien gesucht, die zur Verbesserung des Flugkomforts beitragen und beim Komfortdesign von Flugzeugen durch eine entsprechende Optimierung physikalischer Parameter einfließen können. Um eine erste Annäherung an das Komfortverständnis von Passagieren (insbesondere im Hinblick auf Aspekte des vibro-akustischen Komforts) zu bekommen, wurde eine Analyse der zugrunde liegenden Wahrnehmungsdimensionen kombinierter Schall- und Vibrationsreize in Flugzeugen vorgenommen (Studie 1). In einer weiteren Untersuchung wurde die Interaktion zwischen Schall- und Vibrationspegel und deren relativer „Anteil“ an der (vibro-akustischen) Komfortbeurteilung spezifiziert (Studie 2). Mit Hilfe der Methode des semantischen Differentials (SD) können umfassende Eigenschaftsbewertungen von Reizen jeglicher Art vorgenommen werden, um ihre Position im mehrdimensionalen Wahrnehmungsraum zu bestimmen (Osgood et al., 1957). Das SD besteht in der Regel aus einem Satz siebenstufiger bipolarer Rating-Skalen (Polaritäten). Es repräsentiert ein sowohl in der Psychoakustik als auch Kraftfahrzeugindustrie etabliertes Skalierungsinstrument zur Messung der konnotativen Bedeutungsaspekte bzw. affektiven Qualität von unterschiedlichsten Schallereignissen und -eigenschaften. Im allgemeinen werden dabei für die zu untersuchenden Beurteilungskonzepte angemessene, soge-

nannte konzept-spezifische SD verwendet, die im Kontext von Voruntersuchungen nach bestimmten Kriterien der Merkmalsselektion (Quehl, 1997, 1999; Schäfer, 1983; Schäfer & Fuchs 1975) entwickelt wurden. Mit Hilfe des SD ist es möglich, die beurteilten Stimuli auf dem Niveau semantischer Deskriptoren in ein einheitliches Bezugssystem einzuordnen und miteinander zu vergleichen (Schick, 1979, 1995a, 1996a). Auf der Basis einer mehrdimensionalen Wirkungs- und Bedeutungsstruktur ist die Ermittlung einer differenzierten Reiztypologie möglich, die mit physikalischen Parametern in Beziehung gesetzt und rückwirkend für konstruktive Verbesserungen (etwa am Fahrzeug) genutzt werden kann. In dieser Arbeit wurde in einer Reihe von psychoakustischen Vorstudien ein neues, dem Untersuchungsgegenstand methodologisch angepaßtes Erhebungsinstrument entwickelt (Quehl et al., 2000a). Es umfaßte zwei konzept-spezifische SD (je eins für Flugzeuge bzw. Hubschrauber) sowie 46 standardisierte Befindlichkeitsskalen aus der Eigenschaftswörterliste (EWL) von Janke und Debus (1978), die die Befindlichkeitsaspekte des „Wohlbehagens“ und der „Angst“ konstituieren. Beide SD beinhalteten sowohl konnotative Polaritäten zur Bewertung von Flugzeuginnengeräuschen und -vibrationen, zum Komfort und Wohlbefinden als auch denotativ-psychoakustische Eigenschaftspaare zur Beurteilung der Lautheit, Rauhigkeit, Tonhaltigkeit, Schärfe und Schwankungsstärke (Zwicker, 1999; Zwicker & Fastl, 1999). Um einen hohen Grad an ökologischer Validität zu gewährleisten, wurden die Untersuchungen in einem sogenannten Flugzeug-Mock-up (Studie 1) und mit Hilfe eines Vibrationpad (Studie 2) durchgeführt. Da affektive Reaktionen auf Fahrzeugumwelten einen wichtigen Bestandteil des erlebten Komforts darstellen, und sich Komfort und Wohlbefinden gegenseitig bedingen, erfolgte in beiden Studien mit Hilfe der EWL eine Operationalisierung der experimentell induzierten Befindlichkeit der Versuchspersonen (Vpn) im Sinne einer situativen oder kontextuellen Moderatorvariable (Bisping et al., 1990; Blauert & Jekosch, 1997; Evans & Lepore, 1997; Guski, 1997a; Quehl et al., 2000d). Es wurde angenommen, daß diese die Reizbewertung, insbesondere im Hinblick auf Aspekte des (vibro-akustischen) Komforts, moderiert. Die Ergebnisse beider Untersuchungen werden im folgenden beschrieben.

In der ersten Studie wurden die Cruisingsituationen von drei Propellern und vier Jets in einem sogenannten Flugzeug-Mock-up präsentiert und von 117 Vpn mit Hilfe von 15 Polaritäten des SD für Flugzeuge eingestuft. Alle Reize wurden zweimal bewertet, um die Test-Retest-Reliabilität der Beurteilungen zu bestimmen. Die 17 Sitze im Mock-up wurden für beide Flugzeugtypen in vier sogenannte vibro-akustische Cluster unterteilt, die anhand der Spektren der Stimuluskonfigurationen abgeleitet wurden. Die Vpn wurden so auf die Sitze verteilt, daß jedes Cluster mit wenigstens 20 Vpn besetzt wurde.

Die Befindlichkeit der Vpn wurde zu Beginn, zwischen dem ersten und zweiten Versuchsdurchgang und am Ende der Untersuchung mit Hilfe von 46 Befindlichkeitsskalen aus der EWL erhoben.

Die Ergebnisse der Studie lassen sich folgendermaßen zusammenfassen:

(1) Korrelationsanalysen belegten eine signifikante Test-Retest-Reliabilität, so daß die folgenden Auswertungen auf den ersten Versuchsdurchgang beschränkt wurden.

(2) Faktorenanalysen (Hauptkomponentenanalysen mit Varimaxrotation) zeigten, daß die kombinierten Schall- und Vibrationsreize auf den drei grundlegenden Wahrnehmungsdimensionen Komfort, Variation und Tonhaltigkeit beurteilt wurden, die gemeinsam etwa 60% der Urteilsvarianz erfaßten. Die extrahierten Dimensionen bestätigten die häufig in der psychoakustischen und psychologischen Forschung nachgewiesene Evaluation, Potency, Activity (EPA) Bewertungsstruktur (Osgood et al., 1975, Schick, 1995a, 1996a). Komfort erwies sich als kontinuierliche, bipolare Wahrnehmungsdimension, die von „sehr komfortabel“ bis „sehr unkomfortabel“ reichte. Die aufgezeigte Bipolarität wurde durch die Beteiligung affektiver Beurteilungsprozesse begründet, d.h. es wurde Komfort bzw. kein Komfort (Diskomfort) wahrgenommen (Richards, 1980). Während Diskomfort sich primär auf die Intensität der (subjektiv verbundenen) Schall- und Vibrationswahrnehmung wie etwa die erlebte Lautstärke oder Rauhigkeit sowie spezifische Vibrationseigenschaften wie beispielsweise „vibrierend“ bezog, wurde vibro-akustischer Komfort im dreidimensionalen Wahrnehmungsraum durch die semantisch ähnlichen, alltagssprachlichen Merkmale „komfortabel“, „erträglich“ und „akzeptabel“ abgebildet. Dies stand im Einklang mit den ausgewählten Komfortmodellen, denen zufolge Komfort einen Zustand psychologischen Wohlbefindens (im Sinne von Entspannung, Bequemlichkeit, Zufriedenheit, Annehmlichkeit oder Beschwerdefreiheit) repräsentiert, das unter optimalen Bedingungen entsteht.

(3) Es wurde aufgezeigt, daß die Beurteilungen auf den ersten beiden Wahrnehmungsdimensionen signifikant mit akustischen, psychoakustischen und Vibrationsparametern der Reize korrelierten. Um die physikalischen Korrelate der Dimensionen Komfort und Variation zu bestimmen, wurden jeweils repräsentative Qualitäten (Ladungen > .70) ausgewählt, die „gleichsinnig" rotiert wurden. Es wurde angenommen, daß Vpn Eigenschaftsbewertungen von physikalisch unterschiedlichen Stimuli auf der Basis spezifischer Beurteilungsstrategien oder sogenannter „kognitiver Stile“ (z.B. Riding 1997; Riding & Cheema, 1991; Riding & Rayner, 1997, 1998) vornehmen. Um die Vpn nach Personen mit ähnlichen kognitiven Stilen zu gruppieren, wurden für die Komfort- und Variationsdimension getrennte Faktorenanalysen (varimaxrotierte Hauptkomponentenanalysen) über die Vpn durchgeführt.

Es ergaben sich jeweils zwei Gruppen, sogenannte „latent classes“ (McAdams et al., 1995; McAdams & Winsberg, 2000). Beide Gruppen der Komfortdimension erklärten 50 % der Urteilsvarianz, die der Variationsdimension 30% der Varianz. Die beurteilten Reizkonfigurationen nahmen auf den extrahierten Vpn-Gruppen Ausprägungen an, die als „Faktorwerte" bezeichnet und mit den physikalischen Deskriptoren der Reize korreliert wurden. Für Gruppe 1 (N=62) der Komfortdimension und Gruppe 2 (N=17) der Variationsdimension ergaben sich signifikante Korrelationen mit dem Schallpegel (unbewertet und A-bewertet) und Vibrationspegel sowie mit psychoakustischen Parametern für die Lautheit, Rauhigkeit, Tonhaltigkeit und Fluktuationsstärke. Die einheitliche Bewertung der repräsentativen Merkmale innerhalb jeder Dimension konnte demnach durch akustische, psychoakustische und Vibrationsgrößen erfaßt werden. Je lauter, rauher und vibrierender und weniger tonhaltig ein Stimulus war, desto unkomfortabler und variierender bzw. vibrierender wurde er eingestuft. Die Ergebnisse beider Gruppen waren ähnlich, weil 12 Vpn (70%) der Gruppe 2 der Variationsdimension ebenfalls der Gruppe 1 der Komfortdimension angehörten. Aufgrund signifikanter Interkorrelationen zwischen den physikalischen Deskriptoren konnten keine genauen Aussagen darüber gemacht werden, in welchem Ausmaß sie jeweils zu den Beurteilungen auf beiden Wahrnehmungsdimensionen beitrugen.

(4) Die Interpretation der Korrelationen zwischen Faktorwerten (die sich auf die Vpn der Gruppe 1 der Komfortdimension sowie der Gruppe 2 der Variationsdimension bezogen) und physikalischen Parametern erfolgte anhand von gruppenspezifischen Analysen der Reizbewertung und Befindlichkeitsdaten (EWL). Soziodemographische Eigenschaften und Flugerfahrungen der Vpn wurden nicht berücksichtigt, da sie keinen systematischen Einfluß auf die Beurteilungen hatten. In den Auswertungen wurden alle Sitze des Mock-up mit einbezogen, da sich die Bewertungen zwischen den einzelnen vibro-akustischen Clustern nicht signifikant unterschieden. Da es zudem nur durchschnittliche Beurteilungsunterschiede zwischen den Flugzeugtypen Propeller und Jet, nicht aber innerhalb jedes Typs gab, bezogen sich die Gruppenanalysen nur auf diese Durchschnittsbewertung. Es zeigte sich, daß Vpn, die die Beurteilung auf die genannten physikalischen Größen stützten, in Form einer induzierten Verschlechterung ihres Wohlbefindens „sensibler“ oder stärker auf das experimentelle Setting reagierten, was sich in einer signifikant negativeren Komfort-, Schall- und Vibrationsbewertung manifestierte. Diese stärkere Reaktionsintensität bzw. Empfindlichkeit gegenüber dem Untersuchungssetting wurde als Ausdruck einer individuellen, experimentellen Reaktivität (Strelau, 1970, 1974, 1982, 1983, 1987, 1989, 1991, 1993, 1995, 1999) oder allgemeinen Sensitivität

gegenüber „Umweltstressoren" wie Schall und Vibration (Höger, 2000; Weinstein, 1980; Winneke et al., 1992, 1996) interpretiert.

In der zweiten, laborexperimentellen Studie wurden der Schall- und Vibrationspegel der Cruisingsituationen eines Jets und Propellers, die ebenfalls in der ersten Untersuchung dargeboten wurden, mit Hilfe eines sogenannten Vibrationpad systematisch variiert (3 x 3 Design) und jeweils anhand von 15 Polaritäten des SD für Flugzeuge von 30 Vpn eingestuft. Es sollte der relative „Anteil“ von Schall- und Vibrationspegel an der (vibro-akustischen) Komfortbeurteilung bestimmt und entsprechende Kriterien zur Optimierung des Flugkomforts definiert werden. Im Rahmen einer Vorstudie wurden die Abstufungen des Schallpegels mit $\pm$ 3 dB und die des Vibrationspegels mit $\pm$ 4 dB jeweils ausgehend vom Originalpegel festgelegt, was einem Sensitivitätsindex d` > 2.0 entsprach (Macmillan & Creelman, 1991). Interaktionseffekte zwischen Schall- und Vibrationspegel wurden mit Hilfe von Modellen zum Zusammenwirken von Umweltstressoren (z.B. Baum et al., 1982; Campbell, 1983; Evans & Cohen, 1987; Guski, 2001; Hamilton, 1979; Humphrey, 1984; Lazarus & Cohen, 1977; Lepore & Evans, 1996) beschrieben. Um den Einfluß der experimentell induzierten Befindlichkeit auf die Komfortbewertung zu untersuchen, wurde die Befindlichkeit der Vpn zu drei Zeitpunkten mit Hilfe von zehn ausgewählten Skalen aus der EWL, die sich in der ersten Untersuchung aufgrund von Faktoren- und Reliabilitätsanalysen als trennschärfste Items erwiesen hatten, gemessen.

Die Ergebnisse der Studie lassen sich wie folgt zusammenfassen:

(1) Varianzanalytische Auswertungen belegten signifikante Beurteilungsunterschiede zwischen den neun Reizkonfigurationen beider Flugzeugtypen, was eine getrennte Analyse beider Typen implizierte.

(2) Soziodemographische Variablen und Flugerfahrungen beeinflußten die Bewertungen nicht. Es wurde daher auf gesonderte Auswertungen mit Subgruppen aus der Gesamtstichprobe verzichtet.

(3) Faktorenanalysen (Hauptkomponentenanalysen mit Varimaxrotation) bestätigten die Wahrnehmungsdimensionen der ersten Untersuchung. Die dargebotenen Schall- und Vibrationskombinationen wurden auf den Dimensionen Komfort, Vibration und Tonhaltigkeit beurteilt, die gemeinsam etwa 60% der Varianz erklärten. Um Interaktionseffekte zwischen Schall- und Vibrationspegel bezüglich der ersten beiden Wahrnehmungsdimensionen zu analysieren, wurden „aggregierte" abhängige Variablen generiert, indem für jede Reizkonfiguration über die auf den Dimensionen ladenden, zuvor „gleichsinnig" rotierten Merkmale gemittelt wurde.

(4) Varianzanalysen zeigten signifikante Interaktionseffekte zwischen Schall- und Vibrationspegel im Hinblick auf die Komfortbeurteilung. Die Vibrationsbewertung blieb dagegen vom Schallpegel unbeeinflußt, d.h., daß letzerer bei vibrationsrelevanten Eigenschaften nicht berücksichtigt wurde. Im Hinblick auf die Komfortbeurteilung lag eine „additive" Interaktion zwischen den variierten physikalischen Parametern nahe, da die Vibration die Komfortbewertung des Schalls beeinflußte. Mit ansteigendem Vibrationspegel nahm die Komfortbeurteilung des Schalls ab. Umgekehrt bestimmte aber auch der Schall die Komfortbewertung der Vibration. Mit der Höhe des Schallpegels verringerte sich ihre Komfortbeurteilung. Die ermittelte additive Interaktion war unabhängig von der relativen Größe beider Faktoren. Es wurde nachgewiesen, daß der Schallpegel zu etwa 70% und der Vibrationspegel zu etwa 30% die Komfortbewertung bestimmten. Dies stand im Einklang mit Befunden zur interaktiven Wirkung der Umweltstressoren Lärm und Vibration auf subjektive Belästigungsreaktionen (Howarth & Griffin, 1990a; 1990b, 1991; Paulsen & Kastka, 1995; Schust et al., 1997, 1998; Seidel, 1997; Splittgerber et al., 1991; Zeichart, 1998; Zeichart et al., 1994a, 1994b). Es ist zu beachten, daß sich die aufgezeigte additive Interaktion auf logarithmische Reizgrößen bezog. In linearer Darstellung müßte eher von einer „multiplikativen“ Interaktion (im untersuchten Reizintervall) gesprochen werden. Die Ergebnisse wurden mit Hilfe der Kontrasthypothese (Zeichart et al., 1994) interpretiert, der zufolge der dominante, negativ besetztere „Stressor“ (Schall) die Aufmerksamkeit von einem zweiten ablenkt, gegebenenfalls seine Wirkung maskiert und daher subjektive Reaktionen und Bewertungen bestimmt. Diese Hypothese wurde durch die Auswertung eines qualitativen Interviews, das am Ende des Experiments durchgeführt wurde, bestätigt. Es stellte sich heraus, daß die Vpn vor allem die Geräusche (des Propellers) aufgrund der zu hohen Lautstärke negativ einstuften.

(5) Analysen der Befindlichkeitsdaten (EWL) belegten, daß die experimentell induzierte Verschlechterung des Wohlbefindens der Vpn die Komfortbeurteilung von Vibrationen, vor allem bei Reizkombinationen mit dem abgeschwächten Vibrationspegel, signifikant negativ beeinflußte. Dies wurde auf eine erhöhte Sensitivität gegenüber „Umweltstressoren” (Höger, 2000; Weinstein, 1980; Winneke et al., 1992, 1996) zurückgeführt, die ihren Ausdruck in einer interindividuell unterschiedlichen Vibrationsempfindlichkeit fand.

In der vorliegenden Arbeit wurden zur Analyse des vibro-akustischen Komforts in Flugzeugen affektive Komponenten des subjektiven Komforterlebens sowie physikalische Parameter von Flugzeuginnengeräuschen und -vibrationen integriert. Vibro-akustischer

Komfort (genau wie Komfort im allgemeinen) erschien als biploare Dimension des semantischen Wahrnehmungsraumes in Form psychologischen Wohlbefindens, das unter optimalen Bedingungen entsteht. Sein Gegenpol wurde durch Merkmale gekennzeichnet, die sich auf die Intensität der Schall- und Vibrationswahrnehmung bezogen. Die dem vibro-akustischen Komfort zugrunde liegenden optimalen physikalischen Bedingungen beinhalteten eine Verringerung des Schall- (zu 70%) und Vibrationspegels (zu 30%). Aus Sicht des Passagiers könnte demnach das Komfortdesign von Flugzeugen von einer allgemeinen Schall- und Vibrationspegelreduktion im Sinne der Maxime „weniger ist mehr" profitieren.

Da ein signifikanter Einfluß der experimentell induzierten Befindlichkeit (insbesondere des Wohlbefindens) auf die Komfortbeurteilung im Sinne einer situativen oder kontextuellen Moderatorvariable nachgewiesen wurde, erscheint es sinnvoll, ihre Wirkung in Komfortuntersuchungen jeglicher Art systematisch zu kontrollieren.

Methodisch vergleichbare Studien sollten zukünftig mit repräsentativeren Reizstichproben durchgeführt werden, um die aufgezeigten Ergebnisse zu verifizieren. Dabei wäre es wünschenswert, neben Flugzeugen auch andere Fahrzeugtypen sowie den Einfluß weiterer physikalischer Determinanten des subjektiven Komforterlebens (z.B. Temperatur, Ventilation, räumliche Faktoren) mit einzubeziehen.

INTRODUCTION

Background of the research

Today, modern air transportation technology is very advanced in terms of performance, fuel consumption, velocity, and safety. Therefore, the problems facing contemporary aircraft engineers differ considerably from those with which their predecessors had to contend. Due to increased frequent use within shorter and shorter distances, not only safety, maintenance and viability aspects, but rather subjective felt sensations of the passenger in the air vehicle environment have to be taken into account in aircraft design and development. Apparently, comfort is a key variable in research on user acceptance of air transportation systems. What factors determine how comfortable a person feels in an aircraft? Such a question is of both practical and theoretical importance. On one hand, it is the most direct psychological correlate of ride quality when referring to a vehicle's interior environment in terms of passengers' subjective response. On the other hand, it is related to a person's satisfaction with the mode of travel, i.e. his or her willingness to use it again. Hence, comfort is of concern to the aircraft manufacturers and engineers, but also to environmental psychologists primarily interested in the relevance and impact of environmental variables on individual's behaviour and experience (Bell, Fisher, Baum, & Greene 1990; Gifford 1987; Hellbrück & Fischer, 1999; Miller, 1986). Comfort is obviously of significance when dealing with the problem of competitive advantage on the market, too. In the highly competitive business of modern-day transportation systems, the consideration of the user's subjective needs is paramount to the economic survival of aircraft industry. For this reason, present day aircraft design and development is becoming more and more costumer oriented. It has become as essential to discover the standards of comfort required by the user as it is to ensure that his or her journey is both safe and fast.

The comfort sensation felt by the passenger inside an aircraft is influenced by a large variety of objective (physical) and subjective (psychological) parameters. Since aircraft interior sound and vibration are among the known main physical determinants, the research presented here was focused on these peculiar aspects of passengers' comfort, namely sound pressure level and acceleration. Already being a standard approach in automobiles, sound design for aircraft is still lacking primary efforts towards a general sound level reduction characterised by the idea that „less is more". However, apart from a desirable sound reduction from which sound emission and interior cabin sound can benefit, subjective reactions such as annoyance, disturbance, general comfort, and auditory as well as vibratory comfort in particular, represent additional criteria to be considered in order to achieve satisfaction in aircraft passengers. Thus, these responses have direct impact on costumer acceptance and the market position of the aircraft industry. Clearly, it appears that passengers' comfort is related to both sound and vibration level. The link between sound and vibration level seems to be ruled by complex relationships. The results following the application of pure sound abatement systems, for instance, demonstrated that people interviewed showed a preference for high instead of low sound levels at high vibration magnitudes. In this case, lowering of interior sound level decreased subjective comfort. Comfort is therefore a complex function of both sound and vibration. As a result, the design objective should be moved, coherently, towards comfort improvement from sound suppression only. Hence, the current challenge is not to design sound and/or vibration, but to design (vibro-acoustic) comfort.

The objective of the BRITE EURAM project IDEA PACI (BE97-4056) from which the research reported here arose was to define an aircraft passenger sound and vibration comfort index for commercial aircraft and to relate this index to physical, especially acoustic, psychoacoustic and vibration parameters. The intended comfort index was proposed to be calculated by means of an Artificial Neural Network (ANN), which is a representation or virtual model of a typical aircraft passenger („virtual passenger"), aimed at simulating a generic transfer function between physical variables of the external environment and subjective responses of the passenger. The main steps of the IDEA PACI research program can be summarised as follows: first, suitable psychoacoustic and vibration descriptors were selected to have a tool that allowed translating the environmental impact (sound and vibration fields) into subjective sensations. Due to the lack of an adequate methodological instrument for the evaluation of aircraft interior (sound and vibration) environments, four laboratory and field pretests were conducted to develop a suitable methodological tool (especially a concept-specific semantic differential). Then, experimental investigations both on ground and in flight (helicopters) were performed. For the experiments on ground different helicopter and aeroplane setups, so-called mock-ups, have been used. Acoustic and vibration measurements and the passengers' response evaluation to the interior aircraft environment were carried out employing the evolved methodological instrument. The research presented here emerged from on one of these studies. In this way, two sets of data resulted: one describing the physical environment, and the second, defining the related human reaction. The aim of the „virtual passenger" was to find the relationship (or transfer function) between these two general parameters. On the bases of the acquired experimental results, the architecture of the ANN was defined, and it was successively trained and validated. Finally, the ANN predicted comfort levels on both experimental and finite element numerical simulations (FEM) data: the physical parameters that mainly affected the comfort of the passenger during the flight were identified through proper simulations.

Structure of the research

The present research is divided into three main sections. In the first theoretical section, different lexical, ergonomic, psychological as well as everyday comfort (and well-being) definitions and theories are presented. Since the research focused on vibro-acoustic comfort in aircraft, acoustic, psychoacoustic and psychological parameters of auditory and vibratory comfort are introduced. A further chapter is addressed to the perception of low frequency and infrasound. Then, physical properties of aircraft interior sound and vibration are outlined. Next, previous passenger comfort studies are reviewed and a model of passenger comfort is described. The first section ends with a summary of the preceding presentations and a conclusion with respect to the aims of the research. In the second empirical section, the first study regarding the analysis of perceptional dimensions of combined aircraft interior sound and vibration is presented. The study's objectives are exemplified by a review of multidimensional scaling and semantic differential studies concerning the dimensional analysis of timbre perception. A comparison of both procedures with regard to the aims of the first study is made. Subsequently, the development of a so-called concept-specific semantic differential designed for aircraft interior (sound and vibration) environments is described which has been used for both empirical parts of the research. The study's findings are reported and discussed with respect to the theoretical context and previous investigations. In the third empirical section, the second study concerning the interaction between sound and vibration level regarding the comfort evaluation of aircraft interior stimulus configurations is presented. Models and empirical data of environmental stress research regarding the interactive effects of the „environmental stressors” sound and vibration are introduced. Results are reported and discussed on the background of theoretical models and former studies. At the end a general discussion of all findings is given and prospects for further research are outlined.

1. COMFORT THEORIES

1.1 A first approximation: examining and analysing the contents of the term „comfort"

Fundamentally, it may be assumed that relevant (aircraft) vehicle comfort aspects are part of a general comfort concept. In order to achieve a first approximation to the meaning of the term „comfort", an analysis of the different lexical definitions was performed (Collier's Dictionary, 1994; Random House Compact Unabridged Dictionary, 1996; Webster's Ninth New Collegiate Dictionary, 1991; Webster's New Dictionary of Synonyms, 1984). The expression „comfort" is derived from the Latin word confortare, which means „to strengthen much" or „to console". With this meaning, the concept entered into the French and English language. The contemporary (English) definition of the term is manifold: console, solace, physical and mental well-being, physical and mental ease, refreshment, satisfaction, enjoyment, pleasure, support, relief, contentment, freedom from pain/anxiety/distress/worry/want/trouble, strengthening aid, assistance, encouragement, soothe, reassure, pacify, delight, rejoice, gladden, mitigate, alleviate, restore, bring cheer to, give hope. The meaning of the German word „Komfort" is more limited referring to: *„luxurious equipment (e.g., of an apartment), cosy furnishings, convenience, ease"* (German Foreign Word Duden, 1990, p. 411). Altogether, the lexical definitions regard comfort as a positive state or the absence of a negative one. Accordingly, comfort may be interpreted as a bipolar dimension of experience. While the German meaning is restricted to properties of an object's or system's equipment which may cause the sensation of comfort, the English definitions also consider subjective components. This is important in so far as the research reported here concentrated on the passengers' subjective comfort sensation within air vehicle environments.

Metzger (1994) conducted an interview study to analyse the meaning of the concept comfort in everyday use with regard to the individual dwelling and work place. It was found that comfort describes a quality which persons ascribe to specific objects or situations. Comfort concerned the evaluation of man-environment-interactions; all of them appear to be potentially comfort sensitive. The complexity of the term was reflected in its numerous everyday applications. For instance, it was spoken in the same way about a comfortable car, chair, or dwelling. Data indicated that comfort was primarily associated with ease, relaxation, convenience, and well-being. Furthermore, comfort was related to descriptors of assistance or support. There was also a close relationship between functionality, usefulness and quality of life. On the other hand, the association with security, familiarity, and reassurance or luxury, elegance, and style was rare. Metzger (1994) concluded that the meaning of comfort is not mainly dependent on material resources, but rather it is determined by subjective needs and benefits. Results implied that the comfort of domiciles was more decisive than the comfort experienced at the work place. Technical devices and furniture seemed to be important comfort factors. This finding confirmed that comfort was mainly connected with ease and relaxation. The relevance of comfort regarding technical devices emphasised that aspects of assistance and practicality of an object play an important role in the everyday use and understanding of the term comfort. Therefore, it appears reasonable to separate comfort from luxury and prosperity factors. Based on her empirical findings Metzger (1994) proposed four components of comfort:

(1) Physical freedom of complaints

Physical stimulus configurations do not cause disturbance, annoyance or displeasure.

(2) Ease

Ease refers to the degree of relief (easiness) and relaxation (reduction of physical and psychological strain) to which activities are performed.

(3) Efficiency

Efficiency is related to objective performance data and qualities of an object or its degree of automatisation.

(4) Individuality

Individuality includes the subjective need to express oneself by design options. Aspects of personalisation and freedom of choice (Pineau, 1982), the individual sensation of aesthetics, and the representation of the personal social status were also related to individuality.

Table 1: Results of an experimental questionnaire interview (N=30):
Question: *What do you generally understand by the term comfort?*

Categories	Code	Count	Pct of Responses	Pct of Cases
Well-being	1	17	23,9	56,7
Pleasant atmosphere	2	13	18,3	43,3
Relaxation and relief	3	9	12,7	30,0
Ease and cosiness	4	9	12,7	30,0
Free from annoyance or disturbance	5	7	9,9	23,3
Luxury and extras	6	6	8,5	20,0
Safety	7	4	5,6	13,3
Freedom and voluntariness	8	3	4,2	10,0
Silence	9	3	4,2	10,0
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	Total responses	71	100,0	236,7

Table 1 summarises subjects' multiple answers given in an experimental questionnaire interview (chapter 6.4) regarding the general understanding of the term comfort. In accordance with the lexical definitions and the everyday use of the concept, comfort was particularly associated with well-being, pleasantness, relaxation, and convenience. Furthermore, the freedom from annoyance and disturbance as well as luxury goods, that is, material things providing support or satisfaction, were important constituents of the meaning of comfort.

1.2 Ergonomic approaches to (seat) comfort

A first analysis of the literature regarding the subject of „comfort" of the past 30 years revealed an abundance of ergonomic-technical oriented studies and models. The majority of investigations was dedicated to seat design and seat comfort. Comfort while sitting is a major concern of office workers (Kleeman, 1991; Lueder, 1983) and has been commonly assessed in ergonomic evaluations of offices (Branton, 1966, 1969; Branton & Grayson, 1967; Grandjean, 1984; Gross, Goonetilleke, Menon, Banaag & Nair, 1992; Habsburg & Middendorf, 1977; Helander, Czaja, Drury, Cary & Burri, 1987; Le Carpentier, 1969; Shackel, Chidsey & Shipley, 1969; Zhang, Helander & Drury, 1996) but also vehicle environments (Ebe & Griffin, 2000a, 2000b; Grandjean, 1980; Habsburg & Middendorf, 1980; Jianghong & Long, 1994; Krist, 1994; Rebiffé, 1980). Various models of seat comfort have been advanced. Although they were developed to explain sitting behaviour, they can also be extended to describe the comfort sensation when interacting with other aspects of the environment.
Comfort (while sitting) is a subjective concept which is difficult to define and measure (Oborne, 1978a; Zhang et al., 1996). Branton (1969) suggested for example, like health, the only appropriate definition of seat comfort is in terms of its absence or negative qualities, thus arguing that it is only possible to measure varying degrees of discomfort (see also Corlett & Bishop, 1976; Ebe & Griffin, 2000a; Krist, 1994). Nevertheless, some researchers have tried to measure degrees of positive seat comfort (Jianghong & Long, 1994; Shackel et al., 1969). However, whether the designer's philosophy is to attempt to reduce discomfort to minimum levels or to induce a positive feeling of comfort, the output of these attempts should be the same - namely the production of some kind of optimal state in the person, that is, individual's well-being (Oborne, 1978a).

Commonly, there is only little theoretical consensus on whether comfort and discomfort should be regarded as being a bipolar continuum or as two experimental dimensions.

Some researchers have questioned the common (e.g., lexical), unidimensional definition of comfort and discomfort representing the opposites of a continuous, bipolar scale ranging from a state of extreme comfort through a neutral state to a state of extreme discomfort. For instance, Hertzberg (1972, p. 41) referred to comfort as an *„absence of discomfort [...] a state of no awareness at all of a feeling."* and Branton (1969, p. 205) concurred that comfort *„does not necessarily entail a positive affect."* These definitions regard comfort as a neutral feeling, and only two discrete stages are possible: comfort present or absent. In order to clarify the relationship between comfort and discomfort Zhang et al. (1996) performed a questionnaire study with office workers to identify factors associated with comfort and discomfort while sitting. Twenty-nine descriptors of comfort were classified into the categories relaxation, neutral feeling, well-being/contentment/pleasantness, energy, environmental and social/psychological. The 34 descriptors of discomfort constituted the categories pain, soreness and numbness, fatigue, environmental, and anxiety. Factor and cluster analysis of similarity ratings of all possible pairs of descriptors yielded two main factors which were interpreted as comfort and discomfort. Zhang et al. (1996) proposed a model for the perception of discomfort and comfort based on their findings (Figure 1). It is assumed that discomfort is associated with poor biomechanical factors (joint angles, muscle contractions, pressure distribution) that produce feelings of pain, soreness, numbness, fatigue, and the like. Discomfort can be attenuated by eliminating physical constraints, but this does not necessarily produce comfort. Comfort, on the other hand, is related to feelings of relaxation and well-being. The term „plushness" is used to describe aspects of the chair related to the sensation of aesthetics, softness, and spaciousness. The absence of these impressions will not lead to discomfort because adverse biomechanics conditions are necessary for this. Transitions from discomfort to comfort and vice versa are possible in the intersection of the axes of Figure 1. Thus if discomfort is reduced, comfort may be perceived. If discomfort is increased, such as with growing time and fatigue, comfort will decrease. The presence of adverse physical factors will therefore break the physical harmony and direct attention to discomfort. Although good biomechanics will not increase the level of comfort, it is likely that poor biomechanics may turn comfort into discomfort. Altogether, Zhang et al. (1996) concluded that comfort and discomfort need to be treated as complementary, multidimensional concepts.

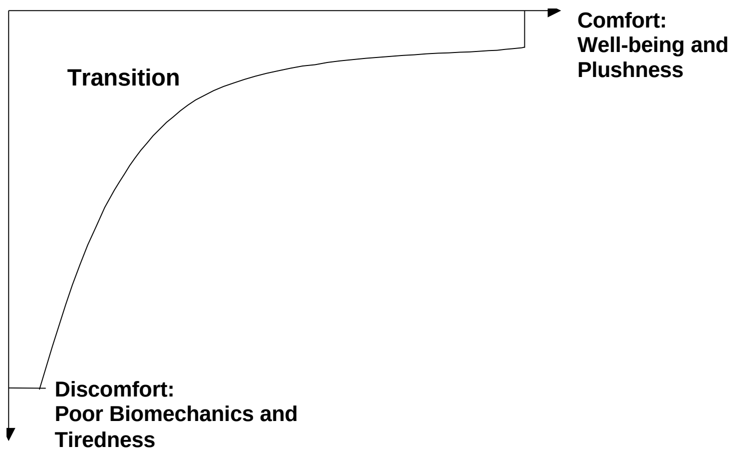

Figure 1: Hypothetical model of comfort and discomfort (adapted from Zhang et al., 1996).

Branton (1966, 1969) advanced with a theory of sitting comfort in terms of „postural homeostasis". Homeostasis is a physiological concept which concerns the selfregulation of body functions (chapter 6.2.1). As far as sitting posture is concerned, Branton (1966, 1969) suggested that to maintain comfort a person will seek stability from the seat. By doing so over a period of time, however, the very stabilising aspects of the seat (e.g., the arm or back rests) will tend to compress the fleshy parts of the body, for example, the buttocks and thighs, so reducing blood circulation trough the capillaries and causing possible numbness. This induces the impetus for a posture change, so decreasing stability, and the circle continues. The homeostatic behaviour of the person sitting, therefore, is constantly to alter posture to maintain comfort (or reduce discomfort). In this way, the author argued, fidgeting can be used as an index of seat comfort or discomfort. The concept of postural homeostasis may be extended to describe comfort-seeking behaviour when interacting with any aspect of the environment, i.e. the more uncomfortable the environment, the more homeostatic behaviour patterns are likely to be exhibited.

Krist (1994) supposed that discomfort (while sitting) arises from the discrepancy between sensory experiences and a mental model of comfort. If differences emerge, they reach consciousness and come into the short-term memory for further processing. Due to its limited capacity, only some sensory experiences will be selected and processed. With regard to their relative significance, Krist (1994) proposed a hierarchical model of discomfort sensations based on Maslow's (1954, 1977) hierarchy of human needs. He assumed that higher (i.e. social and psychological) needs only become conscious if all basic (i.e. physiological) ones are satisfied. A hierarchy of comfort needs can be obtained by analysing the frequency of comfort needs mentioned in interview or questionnaire studies; that is, the more frequently a comfort need occurs, the more rarely it is compensated and belongs to the category of higher (unfulfilled) needs.

Table 2 outlines the multiple answer analysis of an experimental questionnaire interview (chapter 6.4) concerning the subjects' understanding of a comfortable flight situation. Data imply the following factors to be relevant for comfort in aircraft: (1) low, pleasant loudness, (2) small vibrations, (3) no air holes or turbulences, (4) specific sound characteristics (e.g., low frequency, little tonal), (5) comfortable seats, (6) sufficient legroom or room to move, (7) good service. Hence, loudness and further sound characteristics, motion and vibration, as well as seating appeared to represent higher (unfulfilled) comfort needs. They should be optimised in order to increase the comfort of passengers in aircraft. This is in accordance with the empirical findings of the passenger comfort studies by the behavioural approach (chapter 3.2).

Table 2: Results of an experimental questionnaire interview (N=30):
Question: *Which attributes a flight situation must have to be comfortable?*

Categories	Code	Count	Pct of Responses	Pct of Cases
Low, pleasant loudness	1	22	20,8	73,3
Small vibrations	2	15	14,2	50,0
No air holes or turbulences	3	14	13,2	46,7
Specific sound characteristics	4	12	11,3	40,0
Comfortable seats	5	11	10,4	36,7
Sufficient legroom or room to move	6	9	8,5	30,0
Good service and catering	7	8	7,5	26,7
Pleasant climate (temperature, air)	8	6	5,7	20,0
Good pressure compensation	9	3	2,8	10,0
Window seat	10	2	1,9	6,7
Safety	11	2	1,9	6,7
Relaxation	12	1	,9	3,3
Cleanness	13	1	,9	3,3
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Total responses		106	100,0	353,3

1.3 Psychological models of comfort

Corresponding to some of the ergonomic approaches, psychological definitions of comfort often emphasise a multidimensional concept which is influenced by several factors and does not represent merely the opposite of discomfort. In this way, Pineau, (1982, p. 2) defined comfort *„as everything contributing to the well-being and convenience of the material aspects of life; thus it constitutes an improvement of living conditions in inhabited space."* Thus, comfort refers to a state of well-being under optimal conditions. The meaning of comfort differs according to the object or the situation to which it is applied, but all meanings relate to the idea of subjective well-being. In agreement with

Metzger (1994), the author assumed that the desire for comfort arises from environments and life styles which an individual has adopted. Comfort does not simply coincide with the ownership of modern, sophisticated devices or even with comfort technology which has solely created artificial needs. Pineau (1982) therefore postulated that comfort cannot be evaluated by the use of purely materialistic criteria, rather it should be analysed psychologically. He performed a questionnaire and interview study regarding the subjective comfort of a domicile in order to identify basic psychological comfort needs. Four components appeared to play a relevant role in the meaning given to comfort in the dwelling; all representing basic conditions for the development of lasting well-being and comfort sensation.

(1) Personalisation

Personalising a residence means to make it ‚one‘s own‘, in such way that the inhabitant can express oneself by an individual organisation of living space (e.g., arrangement of rooms, furniture, and decor). Personalisation brings about the relationship of intimacy and well-being, as well as of complicity between the individual and the domicile shaped according to individual wishes. In order to achieve it, it is not sufficient to eliminate or reduce the potential interference sources, rather the individual must behave actively to manage conditions for his or her own well-being.

(2) Freedom of choice

Freedom of choice includes all resources which the appropriate living space offers to realise the comfort demands of the inhabitants. The need for calm and silent conditions, and in general the possibility of getting away from other people sharing the dwelling belong to this category.

(3) Space

Space refers to the subjective perception of living room and their emotional evaluation. The people interviewed preferred a domicile which has sufficient area to allow distance to objects or other persons in order to avoid annoyance or limitation of desired behaviour. However, space also functions socially as a meeting place. Altogether, it supports freedom of action and personalisation, while allowing the person to feel at home within the individual territory.

(4) Warmth

Warmth is a source of pleasure and satisfaction. Two different types of warmth can be distinguished. One for example being an open fire or sunlight, a natural warmth restricted to a particular source allowing relaxation and providing security. On the other side, there is the warmth produced by diffuse sources such as central heating, creating an uniform thermal environment which is utilitarian and functional.

The perception and subjective evaluation of localised and utilitarian warmth represent important aspects of comfort.

Slater (1985, p. 4) proposed a definition of comfort as *„a pleasant state of physiological, psychological and physical harmony between a human being and the environment."* Harmony means here that the combination of all parts create an agreeable, consistent or orderly whole. The distinction between an internal and external environment of the body suggested by the author allows to analyse the effects of the mental and physical environment on comfort. Thus, comfort may be mental or physical. Accordingly, Slater (1985) supposed three dimensions of comfort: physiological, psychological, and physical in nature. Physiological comfort is related to the human body's ability to continue functioning. Physiological aspects of comfort can be identified in all parts of the body, in virtually all of its mechanisms and are almost exclusively involuntary. Psychological comfort concerns the mind's ability to keep itself functioning satisfactorily or to create *„peace in mind"* (p. 18). Important factors of psychological comfort are a positive self-image, satisfactory relationships between the individual and other people, and the realisation of privacy. Effects of the physical environment may influence adversely the level of psychological and/or physiological comfort when humans begin to notice problems of physical comfort. Effects of the physical environment can be regarded from two perspectives: the first is the actual physical cause which produces reactions within the different sensory modalities. The second type is associated with the physical properties of the objects within or external to the body. A balance of the three categories of comfort is needed. Without comfort, Slater (1985) stated, human existence loses its quality because persons are permanently in an uncomfortable state.

A psychological model of passenger comfort will be described in chapter 3.1. It follows the outlined approach to auditory (and vibratory) perception (Figure 4 in chapter 1.5).

1.4 Comfort and well-being

Common to all definitions and empirical findings regarding the subject of „comfort" is that the concept refers to a psychological state of subjective well-being induced under optimal conditions. Comfort concerns those aspects of well-being which are related to relaxation, relief, ease, satisfaction, enjoyment, and convenience.
Within the structural model of well-being, Becker (1991) distinguished between „habitual well-being" (HW) and „current well-being" (CW). He subdivided both concepts into

physical and psychological well-being which permits an emphasis of physical aspects, in so far as both physical and psychological well-being cannot be separated severely from each other. HW represents a relatively stable feature which is associated with statements on the individual well-being, that is, judgements on aggregated emotional experiences. HW results from frequent CW as well as the absence and/or the rareness of negative moods. There are a number of models which take into account the multidimensional nature of HW:

(1) Bradburn's two-components approach (1969; Bradburn & Caplovitz, 1965) views a person's location on the dimension of psychological well-being as the result of the individual's position on two independent dimensions – one of positive affect, the other of negative affect. Examples of negative affect are difficulties in work adjustment or interpersonal tensions. Positive affect appears to be related to a series of factors concerning the degree to which an individual is involved in the surrounded environment or social contacts (e.g., number of friends). The model specifies that an individual will be high in psychological well-being to the extent to which he or she has an excess of positive over negative affect and will be low in well-being in the degree to which negative affect predominates over positive, i.e. positive affect minus negative affect results in subjective well-being. Investigations of Diener and colleagues (Diener, 1984; Diener & Emmons, 1984; Diener, Larsen, Levine & Emmons, 1985) proved that the frequency of positive and negative affect is correlated negatively, while its strength positively. This independence of positive from negative affect confirmed well-being as an autonomous psychological construct. Thus, well-being cannot be derived simply from the absence of negative conditions and feelings. Headey, Holmström and Wearing (1984) presented empirical evidence for regarding well-being and ill-being as distinct dimensions. It was found that well-being depended on a wide range of personality traits such as extraversion, optimism and personal competence, and also on the existence of supportive social networks. Ill-being was more strongly connected with poor health, dissatisfaction with material standards of life and low scorings on the trait „personal competence".

(2) Mayring (1987, 1991) advanced four components of well-being: (1) a negative affect factor (freedom of negative affects), (2) a positive short-term factor (joy), (3) a long-term factor (happiness), and (4) a cognitive factor (life satisfaction). The negative affect factor is based on the classical two-components approaches described above. Joy refers to an aspect of well-being which contains short-term, context-specific (current) positive feelings. Life satisfaction has been often employed as a cognitive factor (Michalos, 1985). An example of cognitive processes related to life satisfaction is the cognitive assessment of one's own life. Happiness concerns a

long-term, comprehensive, emotional aspect of well-being. Mayring (1987, 1991) additionally differentiated between a state component (current, intense happiness experiences such as love, nature, music) and a trait component (long-term, global life happiness, based on experiences which have been developed in the course of life) of happiness.

Becker (1991) defined CW as a momentary, real state including interior experiences and subjective sensations of a person (e.g., positive emotions, moods and physical sensations). In psychological mood research CW is also used to denote a „subjective, positive mood" (Abele-Brehm & Brehm, 1986; Becker, 1988, 1991; Janke & Debus, 1978). Mood in this context is assumed to be a relatively stable and mild affective reaction caused by internal or external stimulation (Lazarus, 1991). Within Becker's well-being model (1991) comfort is mainly associated with CW in psychological and physical regard (Kempfert, 1998).

Fischer (1991) suggested two models of environmental psychology concerning the impact of environmental conditions on subjective well-being (HW and CW):

(1) Mehrabian and Russell's approach (1974) proposes that physical and social stimuli (expressed in terms of an „information rate" which describes the spatial and temporal relationships among stimulus components) directly affect the emotional state and behaviour of a person. Three basic emotional response dimensions are supposed to characterise the emotion-eliciting qualities of an environment: pleasure, arousal, and dominance. These dimensions may serve as mediating variables in determining a variety of approach-avoidance behaviours such as physical approach, work performance, exploration, and affiliation. An inverted u-shaped function between the perceived arousal potential (due to the complexity and novelty of the situation in terms of information rate) and the tendency of approach behaviour is postulated, that is, maximal well-being and approach occurs at a moderate arousal level. This relation is, however, only valid for situations which are neutral in regard to pleasure and dominance qualities.

(2) The basic assumption beyond the „complementary/congruence model of well-being" presented by Carp and Carp (1984) is an optimal fit between the person and the environment. „Congruence" refers to the degree of complement between the individual's competencies required for a successful and satisfying life style and the environmental resources and conditions relevant in this regard. Complement can positively influence subjective well-being via the satisfaction of „basic needs" (according to Maslow, 1954, 1977) and „higher needs" (e.g., privacy, aesthetic experiences, and comfort).

The most frequently used technique in psychological mood research is the selfdescription of subjective mood by means of standardised item lists („adjective check lists"). In general, these lists consist of a set of category scales each assigned to monopolar adjectives. Their main advantages are to consider the multidimensionality of moods, to offer material that normally belongs to the individual's store of experience, and to enable a scaling and hence a inter- as well as intraindividual comparability. Janke and Debus (1978) have reviewed (standardised) adjective check lists of psychological mood research for the German- and English speaking areas. The German lists (Abele-Brehm & Abele, 1986; Baumann & Dittrich, 1972; Becker, 1988; Grob, Lüthi, Kaiser, Flammer, Mackinnon & Wearing, 1991; Hecheltjen & Mertesdorf, 1973; Nitsch, 1976; Steyer, Schwenkmezger, Notz & Eid, 1994) have been mainly used for the analysis of the effects of external stimulation. For instance, the German „Eigenschaftswörterliste" (EWL) by Janke and Debus (1978) represents a standardised, multidimensional procedure for quantifying the momentary (real) states. In particular this adjective check list allows the measurement of subjective mood changes depending on environmental conditions. It consists of 15 different aspects of mood altogether, each containing items (monopolar 6-point adjectives) taken from different subscales.

1.5 Auditory comfort: acoustic, psychoacoustic and psychological parameters

Understanding auditory comfort requires an understanding of sound. Sound results from the oscillatory motion or vibration of an object. This motion is impressed upon the surrounding medium (such as air, solid, liquid or other gas) as a pattern of fluctuations in pressure (acoustical oscillations). Sound therefore denotes a mechanical disturbance of the steady pressure in an elastic medium (usually air) which is propagated in all directions at a velocity of about 335 m/s. What actually happens is that the atmospheric particles, or molecules, are squeezed closer together than normal which results in an increase in pressure, and then pulled farther apart than normal. The sound wave moves outwards from the oscillating object, but the molecules do not advance with the wave: they vibrate about an average resting place.

One of the simplest type of sound is the sine wave, also known as sinusoid or sinusoidal vibration, which has the waveform (pressure variation plotted against time) shown in Figure 2. Sine waves produce particularly simple responses in the auditory system, and they have a very „clean" or „pure" sound, like that of a tuning fork. Thus they are also called simple or pure tones. A sinusoid has three physical parameters: the frequency, or number of repetitions of a waveform per second (specified in hertz, where 1 hertz (Hz) = 1 cycle/s); the amplitude, or the extent of pressure variation about the mean or normal; and the phase, or the portion of the cycle through which the wave has advanced in relation to some fixed point in time. The time taken for one complete cycle of the waveform denotes the period which is the reciprocal of the frequency. Human ears are sensitive to sounds between approximately 20 Hz and 20 kHz.

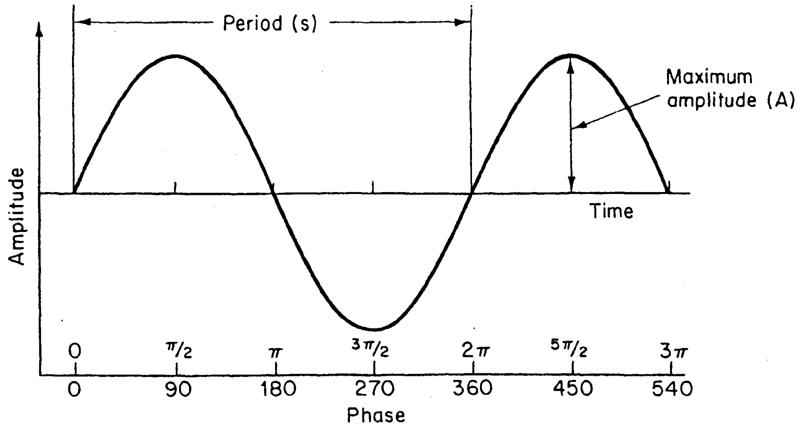

Figure 2: The waveform of a sine wave or sinusoidal vibration. The instantaneous amplitude is given by the expression A sin (2πft), where t = time, f = frequency and A = maximum amplitude (adapted from Moore, 1982).

Sound levels can be quantified either by their intensity (describing the flow of energy in watt through a unit area (usually m^2) in a sound field) or amplitude or pressure. The sound intensity is proportional to the square of sound pressure. The dynamic range of sound intensities (difference between absolute threshold of hearing and the threshold of discomfort, respectively pain in dB SPL) to which humans are sensitive is immense, roughly reaching 10^{12}. This range is a function of frequency; it is approximately 125 to 135 dB at about 4000 Hz, but at lower and higher frequencies it is considerably less (e.g., 80 to 90 dB at 100 Hz). Figure 3 illustrates the that best sensitivity of the human auditory system lies between 500 Hz and 5 kHz. This area is most important for understanding speech. The thresholds of discomfort and pain represent estimates of the upper limit of sound level that humans can tolerate. The threshold of discomfort is approximately 110 to 120 dB SPL, the threshold of pain is about 120 to 140 dB SPL, and both remain relatively unchanged as a function of the frequency content of the stimulus.

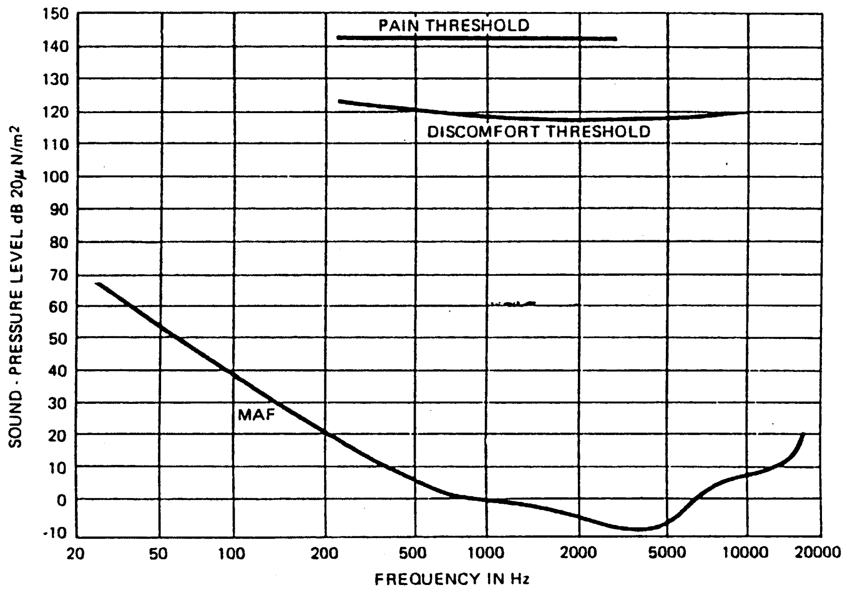

Figure 3: The thresholds of hearing (MAF = Minimal Audible Field), discomfort and pain in decibels of sound pressure level (dB SPL) (adapted from Slater, 1985).

Due to the huge dynamic range of the auditory system, it is convenient to use a logarithmic scale quantifying the ratio of two intensities instead of dealing with sound intensities directly. For this purpose, one intensity is chosen as a standard reference level, I_0, and the intensity of a particular sound, I, is expressed relatively to this. One bel refers to the ratio of intensities 10:1. Thus the number of bels corresponding to a given intensity ratio is obtained by taking the logarithm to the base 10 of the intensity ratio. For example, an intensity ratio of 100:1 equals 2 bels. However, the bel is a rather large unit, and it is conventional to employ a metric one tenth of this size, the decibel or dB, to measure sound intensity levels. The factor 10 arises because this makes the outcome a number in which an integer change is approximately equivalent to the smallest change that can be perceived by the human ear. Hence, the sound intensity level in dB is defined as:

$L = 10 \log_{10} I/I_0$ [dB]

The standard reference level most commonly used is an intensity of 10^{-12} W/m^2, which corresponds to the sound pressure of 2 x 10^{-5}N/m^2 or 20µPa (microPascal). 20µPa equals the average absolute threshold of hearing with the threshold for pain being 20Pa for humans, for a 1000 Hz pure tone, respectively. A sound intensity level specified using this reference level is referred to as sound pressure level (SPL). Since the sound intensity is proportional to the square of pressure, the sound intensity level can also be calculated on the basis of pressure units using the equation:

$L = 20 \log_{10} P/P_0$ [dB]

P is the relative pressure being measured and P_0 is the standard reference pressure. Accordingly, a 10-fold increase in pressure is equivalent to a 100-fold increase in intensity and is represented by + 20 dB. Table 3 gives some examples of sound level, in dB SPL, corresponding to various environmental sounds.

Table 3: Typical sound levels in the environment (adapted from Howard & Angus, 1996).

Example sound	**dB (SPL)**	**Description**
Long range gunfire at gunner's ear	140	Ouch!
Threshold of pain	130	
Jet take-off at approximately 100m	120	
Peak levels on a night club dance floor	110	
Lout shout at 1m	100	Very noisy
Heavy truck at about 10m	90	
Heavy car at about 10m	80	
Car interior	70	Noisy
Normal conversation at 1m	60	
Office noise level	50	
Living room in quiet area	40	Quiet
Bedroom at night time	30	
Empty concert hall	20	
Gentile breeze through leaves	10	Just audible
Threshold of hearing for a child	0	

Auditory sensations, which are (in general) separately distinguishable, can be described in terms of so-called psychoacoustic parameters. Common to these psychoacoustic quantities is the underlying concept of a correct representation of perceptual properties of the human auditory system. Psychoacoustics is therefore concerned with the relationship between physical features of an acoustical stimulus and the auditory sensation evoked. The most important psychoacoustic parameters are loudness, sharpness, tonality, fluctuation strength and roughness (Zwicker, 1999; Zwicker & Fastl, 1999).

The psychoacoustic parameter loudness refers to the perception of sound intensity. The loudness level L_N is measured in phon and loudness in sone. The phone has been derived from equal-loudness contours (isophones) in which the similar loudness of the reference (a pure 1000 Hz tone at different sound level) will be experienced at all points (tones at different frequencies) along each contour. One sone is defined as the loudness of a pure 1 kHz-tone at 40 dB SPL. Similarly, a tone that is judged to be twice as loud as the standard will have a loudness of 2 sone and so on. Stevens (1957) suggested that loudness, as defined by the sone scale, is a power function of physical intensity: $L = kI^{0.3}$, where k is a constant depending on the subject and the units used. Hence, the loudness of a given sound will be proportional to its intensity raised to the power 0.3. A simple approximation is demonstrated by doubling the loudness which is generated by a 10 dB step in sound level. In psychoacoustic research three definitions of loudness (of complex sounds) have been developed based on the sone scale: (1) Stevens' (1955, 1972) loudness, (2) Kryter's (1985) loudness, and (3) Zwicker's (1958, 1960; Zwicker & Scharf, 1965) loudness. Although there are some differences in the models, they consider the auditory system's properties of critical bands and masking effects. It is assumed that the frequency spectrum of a complex stimulus is splitted of into a number of frequency bands (usually third-octave bands), and the SPL in each is then determined. These SPL are then converted into sone. Finally, the contributions of the frequency bands are added together. Kryter's loudness has been employed for the assessment of aircraft exterior sound (Fastl & Widmann, 1990), whereas Zwicker's loudness may be used for noise, speech and music (Fastl, 1990, 1997). Stevens' and Zwicker's loudness are standardised in the ISO/DIS 532 B (1975), *„Acoustics - Methods for calculating loudness level”*.

Another salient feature of auditory stimuli is the perceived sharpness. Sounds with a great share of high frequency components in the spectrum are perceived as sharp (e.g., a piece of chalk scraping a blackboard). The unit for measuring sharpness is called acum and it is defined as the sharpness of a narrow-band noise with a centre frequency of 1 kHz and a level of 60 phon (loudness of a 60 dB tone at 1000 Hz). The sharpness depends mainly on the centre of gravity of the spectral distribution of a sound. The higher the frequency of its location, the sharper the sound is perceived. Sharpness represents an important aspect to describe the timbre of sounds (von Bismarck, 1972, 1974b).

Sounds with single prominent tones are often very annoying, but these tonal components only contribute very little to the overall loudness. Tonality concerns the tonal character of a sound. For determining quantitatively the presence of tonal components or pure tones in the frequency spectrum of a sound, the methods of prominence ratio and the tone-to-noise algorithm are commonly used. The tone-to-noise algorithm is the basis of guidelines for judging environmental sounds with tonal components: ISO 7779 (1999), *„Acoustics - Measurement of airborne noise emitted by computer and business equipment“*, and the German DIN 45681 (draft, 1992).

Fluctuation strength describes the degree of perceived fluctuation of the sound level, or irregularity versus even character of the sound that may arise due to the frequency and amplitude modulation from 1 to 20 Hz. Fluctuations below approximately 15 to 20 Hz are experienced as changes of loudness. The unit of fluctuation strength is vacil and it refers to the fluctuation strength of an amplitude modulated 1 kHz tone (f_{mod} = 4 Hz, m = 1) at a level of 60 dB. The strongest perceived fluctuation originates at modulation frequencies of about 4 Hz (Zwicker & Fastl, 1999).

Yet another important aspect of sound is its perceived roughness. Like for fluctuation strength, roughness results from frequency- and amplitude modulation, but for modulation frequencies between 20 and 250 Hz (Aures, 1985; Daniel & Weber, 1997). The unit for measuring roughness is called asper and it is defined as the roughness of an amplitude modulated 1 kHz tone (f_{mod} = 70 Hz, m = 1) at a level of 60 dB (Aures, 1985). Roughness is highly dependent on the degree of modulation but increases only very little with growing sound level. The strongest perceived roughness arises at approximately 70 Hz (Zwicker & Fastl, 1999).
The weighting functions A, B, C for dB-levels take the frequency dependent sensitivity of the human auditory system into account. The weighting functions are derived from isophones at different levels. For instance, the A weighting function is a simplified version of the 40 phon curve, i.e. the equal loudness contour which passes through 40 dB at 1000 Hz. Accordingly, the dBA refers to the total amount of sound intensity, measured in dB, that is passed through a filter with cut-offs and attenuation rates that match the 40 dB isophone. As a result, the contributions of very high and very low frequency components are small and only those frequencies to which humans are most sensitive (500 Hz to 5 kHz) contribute to the dBA.

Suppose that psychoacoustics seek to define the relation between an auditory sensation like „loud" and the physical property giving rise to this sensation, contemporary psychological approaches attempt to regard auditory perception as an active process related to receiving, actively searching and interpreting of stimuli (Guski, 1997b). Genuit (1994) suggested that both subjective (psychological) and objective (acoustic and psychoacoustic) factors determine the perception of sound events. Blauert and Jekosch (1997) also proposed that cognitive and affective processes influencing the perception, interpretation, evaluation and reaction to auditory stimuli need to be considered in addition to acoustic and psychoacoustic parameters (Figure 4). Cognitive processes involved in sound perception may be perceptual processes by which the stimulus is identified, that is, perceived as a discrete event or a stream of auditory events (Bregman, 1990; McAdams, 1993). Similarly, affective processes related to the perception of sound can be that an auditory event is perceived as threatening and annoying (Bradley & Lang, 2000) or that is experienced as pleasant and makes the listener feel comfortable. The way in which an auditory stimulus is experienced and hence any evaluation or response, will, for instance, depend upon the person's past experiences, memory and a large variety of other psychological variables (see below). Research on human auditory perception has traditionally sought to establish the underlying perceptual dimensions that people use when evaluating sounds (chapter 5).

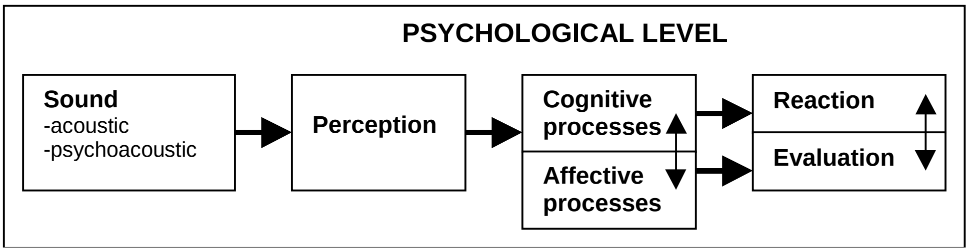

Figure 4: A simple model of auditory perception

According to Västfjäll (2001) one should distinguish between affective evaluations and the reactions to sound events when analysing quality and comfort aspects of the auditory environment. Noise annoyance is the most studied affective reaction to sound (Baird, Harder & Preis, 1997, Berglund, Berglund & Lindvall, 1975a; Guski, 1997b; Schreiber & Kahneman, 2000). A detailed review of theoretical approaches and empirical findings related to the subject „noise annoyance" is given by Schick (1993, 1997). Annoyance caused by sound or noise can be defined as displeasure due to sound exposure that affects health and well-being by its physical presence (Guski, 1997b). Annoyance thus results from unwanted, interfering or disturbing acoustic waves. Correspondingly, annoyance of noise was defined by Kryter (1985) as the quality of unwantedness of a sound. Current definitions of noise often follow the line of reasoning that noise is something unwanted and unacceptable (Finke, Guski & Rohrmann, 1980; Fleischer, 1990; Guski, 1984, 1987; Hellbrück, 1993; Namba, 1994; Preis, 1996; Schick, 1993, 1997). For instance, the German DIN standard 1320 (1997) suggests that *„noise is sound occurring within the frequency range of human hearing which disturbs silence or an intended sound perception and results in annoyance or endangers the health"* (translation by Genuit, 1997). Kryter (1985, p. 1) defined noise as *„an audible acoustic energy that adversely affects the physiological or psychological well-being of people.*" Guski (1997b) pointed out that the term annoyance is used interchangeably with other words, denoting unpleasant or aversive experiences, such as unpleasantness, nuisance, or disturbance. Berglund et al. (1975a) showed that noise annoyance ratings are highly related to ratings of noisiness and loudness. Accordingly, Kryter (1985) employed annoyance synonymously with the denotation noisiness. Annoyance appeared to correlate moderately with objective metrics such as the equivalent dBA level for community and environmental noises, and with psychoacoustic parameters such as loudness, sharpness, tonality, and roughness for specific sound sources (Berglund & Nilsson, 1997; Flindell, 1983, 1997; Guski, 1997b; Kryter, 1985; Kuwano, Namba & Miura, 1989; Kuwano, Kaku, Kato & Namba, 1997; Namba & Kuwano, 1984; Widmann, 1997, 1998). At present, the equivalent dBA level is particularly a widely used index for noise annoyance. However, noise annoyance reactions can be predicted only to some extent by acoustic and psychoacoustic properties; typically less than one third of the variation in individual annoyance[1] reactions is accounted for by physical parameters. An equivalent component of the noise annoyance are the cognitive and affective processes involved in the perception, interpretation and evaluation of a given sound event (Figure 4). The experience of noise is determined by a number of psychological factors. Vallet (1987) and Job (1988) proved by analysing literature that a variety of non-auditory moderators[2] influence the expression of annoyance imputed to noise, and on average their impact is at least as important as that of physical parameters (see also Berglund & Job, 1994; Fields & Walker, 1982, 1983; Guski, 1987, 1999; Höger, 1999; de Jong, 1983; Kastka, 1981; Langdon, 1985; Möhler, 1988; Schick, 1992, 1993). There are two major classes of non-auditory moderators which may cause inter- and intraindividual divergent qualitative and quantitative annoyance responses (Fields, 1993; Guski, 1987, 1997a, 1999; Guski, Schuemer & Felscher-Suhr 1999; Job, 1993; Kalivoda, 1998; Schick, 1993, 1996b, 1997):

(1) Personal variables including acquired, long-term sensitivities, attitudes, and personality traits (evaluation and attitude towards the sound source such as its perceived avoidability, danger potential, or noxiousness, attitudes towards and confidence in the persons perceived as responsible, controllability of the stressor, the individual's noise sensitivity and coping resources, or the emotional-vegetative instability),

(2) Situational or contextual variables including long-term circumstances under which a person lives (living environment), short-term activities (work, communication, sleep) at the time of exposure which may interfere with sound, the individual's state of health as well as the environmental setting (properties of the sound source such as image and size), time of day, and situation, all in all the context of the sound exposure.

Among the personal variables the sensitivity to noise contributes substantially to annoyance reactions (Job, 1988; Miedema & Vos, 1999; Schuemer & Schuemer-Kohrs, 1984; Taylor, 1984). Commonly, noise sensitivity is viewed to be a stable personality trait reflecting attitudes towards a wide range of environmental sounds (Zimmer & El-

[1]However, social surveys generally show high levels of correlation between noise exposure and averaged annoyance reactions of groups (r = 0.9 for aircraft and approaching this for road traffic noise) and accounted for 70 to 80% of the responses' variance in terms of physical parameters (Berglund, Hassmén & Job, 1996; Langdon, 1985; Schick, 1993).

[2]The term „moderator" denotes an intervening qualitative or quantitative variable that interacts with a stimulus or event to influence human behaviour (Evans & Lepore, 1997; Guski, 1997a). Its intervening effect includes „to switch on", „to switch over", or „amplificate or attenuate" the impact of the stimulus. The moderator can define specific subgroups on the basis of personal, situational and contextual variables (see above).

lermeier, 1997). The specific conceptualisation of the sensitivity to noise is, however, rather different depending on the demands of a particular study. Noise sensitivity was regarded as a general noise attitude (Jones & Davies, 1984; McKennell, 1963; Weinstein, 1978), as a general affective tendency to different sounds (Finke et al., 1980), or as generalised experiences with different noise situations (Winneke & Neuf, 1992). Some researchers attempted to link noise sensitivity with fundamental personality traits such as neuroticism or introversion/extraversion with varied success (Broadbent, 1972; Moreira & Bryan, 1972). The individual's response to noise was also interpreted to be part of a more general disposition or sensitivity to respond to environmental stressors (Höger, 2000). Based on a large-scale survey of the evaluation of neighbourhood environmental quality in terms of noise, privacy, air-quality, and neighbourhood amenities Weinstein (1980, p. 242), for instance, concluded that *„much of the variability in reported reactions to noise is due to variations among individuals in the tendency to express critical or negative judgments. These critical tendencies influence a wide range of environmental judgments, not just noise ratings [...]. We term this variation among individuals in the tendency to give negative evaluations the 'critical-uncritical' dimension."* Thus the disposition termed by Weinstein „criticalness" pervades the individual's approach to his or her whole environment. Winneke and Neuf (1992) as well as Winneke, Neuf and Steinheider (1996) found that individual sensitivity to noise or odours moderated to an equal extent the individual annoyance reaction to traffic noise. The individual sensitivities at different modalities appeared to be exchangeable with regard to their impact on stress responses to environmental stressors of specific modality. It was therefore concluded that noise sensitivity may serve as an indicator for the susceptibility with respect to environmental stressors in general.

Besides objective parameters auditory comfort involves both cognitive and affective processes from the first perception of a sound event to its evaluation and the resulting reaction (Figure 4). In relation to the perception of sound the term „comfort" has been primarily used to denote affective evaluations of and reactions to (vehicle) interior environments giving rise to making the person feel pleasant, well and comfortable (Chemnitz, 1990; Friedlein, 1989; Letens, 1991; Richards, 1980). Västfjäll (2001) defined auditory comfort as the absence of annoying and disturbing factors. Thus, both comfort and noise annoyance concern the absence or presence of unwanted and unpleasant sound. Accordingly, Namba (1993) characterised a comfortable sound environment as the situation where are only pleasant and no unpleasant sounds at all. Numerous psychoacoustic investigations were carried out to analyse the underlying perceptual dimensions that people employ when they assess vehicle interior sounds (chapter 5) in order to optimise the auditory comfort of vehicle environments.

1.6 Vibratory comfort: vibration, psychovibration and psychological parameters

Analogous to the auditory modality both objective (vibration and psychovibration) and subjective (psychological) parameters influence the perception of vibratory events with regard to aspects relevant to comfort. Even though some motions may be the source of pleasure or satisfaction and hence produce comfort, *„the study of the relation between vibration and comfort has mainly concerned the extent to which motions are responsible for displeasure, dissatisfaction and discomfort"* (Griffin, 1990, p. 43).

While sound is heard and vibration is felt, physically speaking they are not different, in so far as both result from the appropriate disturbance of an elastic medium (physical oscillations). Vibration is generally defined as oscillatory motion or mechanical oscillation (Griffin, 1990, 1992, 1997). Whole-body vibration is caused by the vibration of a surface supporting the body (e.g., sitting on a seat which vibrates, standing on a vibrating floor or lying on a vibrating surface). Local vibration, in contrast, occurs when one or more limbs (or the head) are in contact with a vibrating surface. Vibration of the whole body results from transport (e.g., road, air, rail and marine transport) and when near some machinery. The (dis)comfort produced by whole-body vibration depends mainly on the magnitude, frequency content, direction and duration of the vibration. Each of these parameters, suitably weighted, has been incorporated into the ISO 2631 standard (1997), *„Mechanical vibration and shock - evaluation of human exposure to whole-body vibration,"* which defines methods for the measurement of periodic, random and transient vibration. The standard offers guidance on the assessment of effects of whole-body vibration on health, comfort, and perception as well as motion sickness.

The magnitude of a vibration can be quantified by either its displacement, its velocity or its acceleration (Figure 5). For practical convenience, the vibration intensity is now commonly expressed in terms of acceleration and is measured by using accelerators. Acceleration is conventionally denoted in 'g' units (1 g being the acceleration due to the gravity on Earth), although it has been changed slightly in recent years to use metric units of metres per squared second (1 g = 9.81 m/s^2). The magnitude of an oscillation may be defined as the distance between the extremities reached by the motion (i.e. peak-to-peak acceleration) or the maximum deviation from some central point (i.e. peak acceleration). ISO 2631 (1997) requires that the vibration magnitude should be calculated as an average value of the frequency-weighted acceleration of the oscillatory motion, usually the root-mean-square value (i.e. m/s^2 r.m.s.). This measure is generally adopted as the preferred method of evaluating and predicting (dis)comfort when subjects are exposed to periodic whole-body vibration.

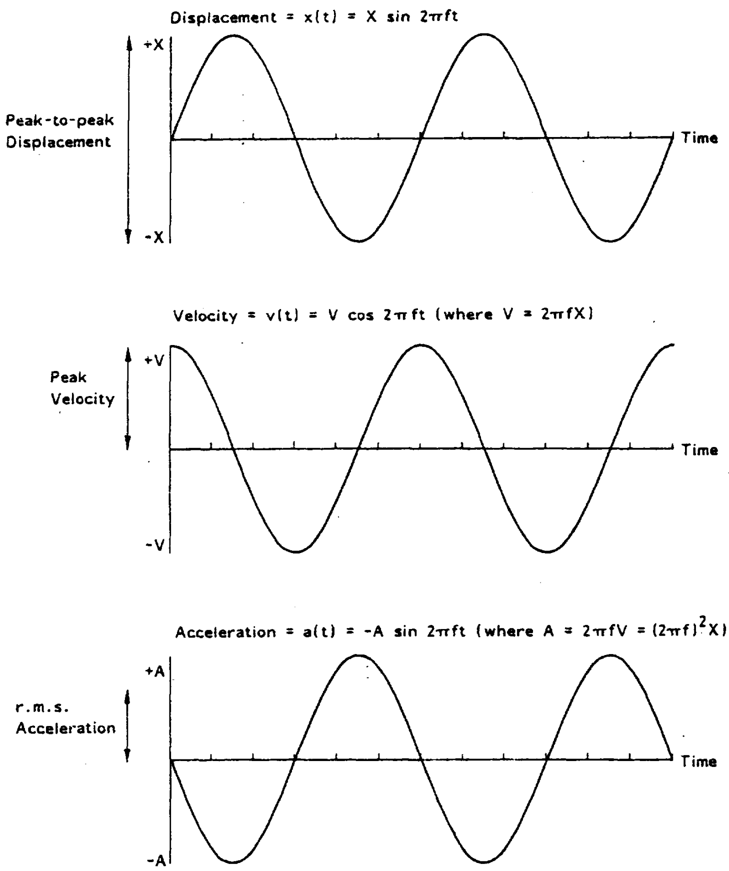

Figure 5: Displacement, velocity and acceleration waveforms for a sinusoidal motion (adapted from Griffin, 1990).

The acceleration magnitude of a vibration can also be expressed as acceleration or vibration level (in decibels) by using a logarithmic scale. The ISO/DIS 1683 standard (1983), *„Acoustics - preferred reference quantities for acoustic levels"*, gives the reference level of 10^{-6} m/s^2 for acceleration. If this reference is used, the acceleration level, L_a (in dB) is given by:

$L_a = 20 \log_{10} a/a_0$ [dB]

With a being the measured acceleration (m/s^2 r.m.s.) and a_0 the reference level of 10^{-6} m/s^2. With this reference level, an acceleration of 1 m/s^2 corresponds to 120 dB, an acceleration of 10 m/s^2 corresponds to 140 dB. A logarithmic scale is commonly used for the evaluation of sound due to the great dynamic range of the human auditory system (chapter 1.5). However, the magnitudes generally of interest with whole-body vibration are contained within a 1000 : 1 range between perception and pain thresholds. Figure 6 illustrates that the absolute threshold of perception of vertical whole-body vibration ranging from 12.5 to 80 Hz lies between approximately .01 and .05 m/s^2 r.m.s. (Bellmann et al., 2000).

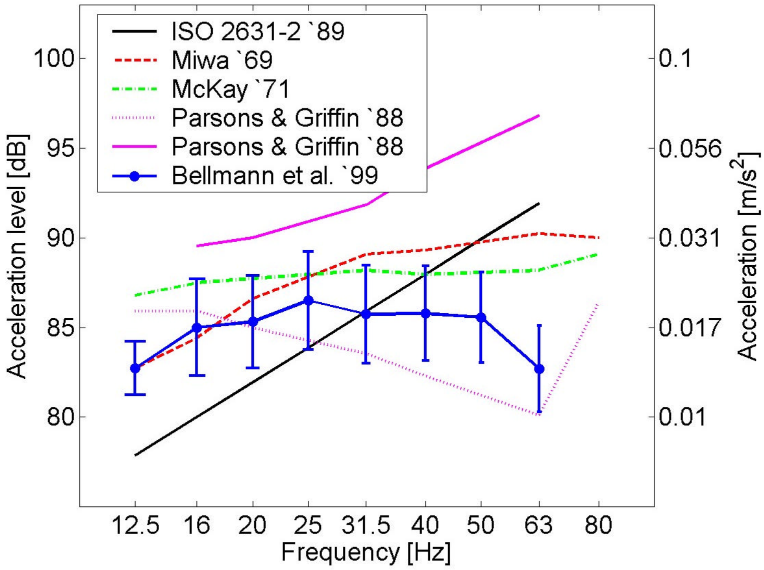

Figure 6: Perception thresholds of vertical whole-body vibration (in dB or m/s^2) (adapted from Bellmann et al., 2000).

A magnitude of 0.1 m/s^2 r.m.s. will be easily noticed, magnitudes around 1 m/s^2 r.m.s. are usually considered to be uncomfortable, and magnitudes of 10 m/s^2 r.m.s. are commonly dangerous (Griffin, 1997). The change in discomfort with a modification of magnitude may be described by a linear relationship in which a doubling of vibration intensity causes a doubling of vibratory discomfort. Accordingly, dividing a vibration magnitude in half can produce a very considerable improvement in comfort. The values presented in Table 4 give approximate indications of likely (dis)comfort reactions to various magnitudes of vibration in public transport according to ISO 2631 (1997).

Table 4: Scale of vibratory (dis)comfort adapted from ISO 2631 (1997).

r.m.s. weighted acceleration (m/s^2)	**(Dis)comfort categories**
< 0.315	Not uncomfortable
0.315 – 0.63	A little uncomfortable
0.500 – 1.00	Fairly uncomfortable
0.800 – 1.60	Uncomfortable
1.250 – 2.50	Very uncomfortable
> 2.00	Extremely uncomfortable

The degree to which vibration is transmitted to the body and its effects in the body to any location highly depends on the vibration frequency. The frequency range of interest most associated with effects of whole-body vibration on health, comfort, and perception is between 0.5 and 80 Hz (ISO 2631, 1997). Although the vibration to which people are exposed normally contains more than one frequency, most experimental research has been concerned with human response to sinusoidal (i.e. single frequency) whole-body vibration. Oscillations at frequencies below about 0.5 Hz can cause motion sickness. At frequencies below 1 or 2 Hz (depending on the vibration direction and body orientation) the forces acting on the body are approximately proportional to the input acceleration and the same motion is transmitted throughout the entire body (Griffin, 1990). Most parts of the body move up and down together. The immediate sensation is of alternately being pushed up and the floating down. The eyes are either able to view objects moving with the body to compensate for the motion or look at non-moving objects. At slightly higher frequencies various body resonances tend to amplify the movement and overall discomfort is influenced by sensations in different parts of the body (e.g., abdomen, thorax, shoulder, face) as the frequency is increased. Vibration acceleration often causes greatest discomfort at about 5 Hz. If the frequency is further increased, the body provides growing attenuation of vibration so as eventually to reduce the location of discomfort so that in close proximity to the vibration input. Such general considerations imply that at low frequencies (below 5 Hz), where the body responds as a virtual rigid system, discomfort will tend to be proportional to acceleration (Griffin, 1990).

The extent to which a given acceleration will cause a larger or smaller effect on the body at different frequencies is now commonly reflected in frequency weightings. Analogous to the weighting functions for dB sound levels (chapter 1.5), these weightings define the values by which the vibration magnitude at each frequency is to multiply in order to „weight" it according to its relative importance with respect to its specific effects on the body. Thus, the frequency weightings may be regarded as a psychovibration parameter due to the correct representation of the properties of vibratory perception. In contrast to auditory perception, further psychovibration quantities have not been defined yet. Frequency weightings for human response to whole-body vibration have been derived from laboratory experiments in which subjects have been exposed to a set of motions having different frequencies. It was intended to determine how the vibration magnitude must be raised or lowered in order to generate the same effect at different vibration frequencies. Data were used to define equivalent-comfort contours (Griffin, 1990; Oborne, 1978c; Oborne & Clarke, 1974) in which a similar degree of comfort will be experienced at all points along any individual contour. Frequency weightings represent the inverse of these contours. Two frequency weightings for the evaluation of vibratory (dis)comfort (one for z-axis and one for x-and y-axis vibration of seated, standing and recumbent persons) are presented in ISO 2631 (1997).

The dependence of vibratory (dis)comfort upon vibration frequency differs for the various directions of vibration. The axes of translational and rotational whole-body vibration are defined by basic-centric co-ordinate systems oriented with respect to the human body. The methods defined by ISO 2631 (1997) apply primarily to seated persons. Figure 7 depicts the translational (fore-and-aft: x-axis, lateral: y-axis, vertical: z-axis) and rotational (roll: r_x-axis, pitch: r_y-axis, yaw: r_z-axis) axes for an origin at the ischial tuberosities of a seated person.

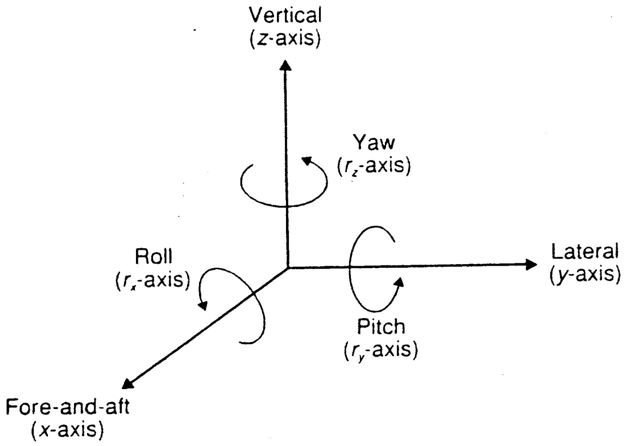

Figure 7: Axes of whole-body vibration for an origin at the ischial tuberosities of a seated person (adapted from Griffin, 1992).

Results regarding the dependence of time of exposure to whole-body vibration are not homogeneous. Although ISO 2631 (1997) states that there is no conclusive evidence to support a universal time dependence of vibration effects on comfort, a simple „fourth power" dependence of time of exposure (determination of the vibration dose value: VDV[3]) is used to approximate how (dis)comfort varies with duration of exposure from the shortest possible shock to a full day of exposure, i.e. $(\text{acceleration})^4 \times \text{duration} = \text{constant}$. The time dependence included in ISO 2631 (1997) implies that the effects of whole-body vibration are independent of durations from 1 minute to at least 4 minutes and then increase so that the acceleration limit for 24 hours is 1/20 of the limit for 1 minute exposures. However, some studies with short-term exposures to whole-body vibration have shown that contrary to the standard, subjective response to vibration appears to be dependent on the exposure time for durations below 4 minutes (Griffin & Whitham, 1976; Hiramatsu & Griffin, 1984; Kjellberg & Wirkström, 1985b; Kjellberg, Wirkström & Dimberg, 1985). Kjellberg et al. (1985), for example, reported that the increase in subjective discomfort was almost linear up to at least 1 hour. This means that

[3] The VDV is given by the fourth root of the integral of the fourth power of the frequency-weighted acceleration.

the rate of growth observed during short exposures might be extrapolated to longer periods of exposure. The relevant experimental literature on time dependence has been reviewed by Clarke (1979) as well as Kjellberg and Wirkström (1985a).

Besides the magnitude, frequency, direction, and duration of a motion the subjective (dis)comfort responses are also affected by the posture and orientation of the body which may cause large differences in the reactions of the same person on different occasions (intrasubject variability). For instance, the transmission of vibration to the body is highly dependent on the dynamic interaction between the body and the points of contact with the motion. Body posture may alter the vibratory (dis)comfort which can be influenced by the seat design and dynamics. Finally, the vibratory (dis)comfort can vary essentially between individuals (intersubject variability). These differences reflect interindividual variations in non-vibratory moderators such as biodynamic, physiological and psychological variables (e.g., body size and weight, fitness, age, gender, experience, and expectation) (Rao & Ashley, 1976).

1.7 Low frequency and infrasound

Hearing low frequency sound at high levels is often combined with the perception of vibration and hence may influence vibratory (dis)comfort sensations. In general, low frequency sound denotes the audible frequency range below 100 Hz including infrasound (Broner & Leventhall, 1980, 1983; Kubicek, 1989; Tempest, 1976a). Infrasound usually refers to airborne sound below the audible region of frequencies (German DIN standard 1320, 1997). There is, however, only little consensus regarding the upper and/or lower frequency margins of both the low frequency as well as the infrasonic areas. Concerning the low frequency range, Danish, Swedish, German, English, Russian as well as Japanese publications suggested areas between 20 and 40 Hz (Yamazaki & Tokita, 1984), 63 Hz (Yamada et al., 1984), 100 Hz (Andresen & Moller, 1984; Broner, 1978a; Nakamura & Tokita, 1981; Widmann & Goossens, 1993), 125 Hz (Yamada et al., 1984, 1986), 200 Hz (Backteman, 1987; Fuchs, 1993; Holmberg, Landström & Kjellberg, 1997; Persson, Björkman & Rylander, 1990; Persson Waye, 1995; Spannheimer, Freymann & Fastl, 2000), or even 250 Hz (Berglund et al., 1996). Acoustics' textbooks indicate an upper frequency limit of the infrasonic region at 16 Hz (Borucki, 1989), whereas English, Swedish, Danish and German investigations (Berglund et al., 1996; Broner & Leventhall, 1980, 1983; Gabrielson, 1997; Ising, 1983; Kubicek, 1989; Landström, 2000; Swedish Defence Materiel Administration, 1985; Tempest, 1976a, 1979) adopted upper frequency margins ranging from 18 to 22 Hz or even to 31.5 Hz (Moller, Hennigsen & Andresen, 1984). Von Gierke and Parker (1976) as well as Landström and Pelmear (1993) placed the lower infrasonic frequency limit at 0.1 Hz. Nevertheless, most studies have been already broken off at frequencies between 2 to 4 Hz or even at 1.5 Hz (Ising & Schwarze, 1982). The ISO standard 7196 (1995), *„Acoustics – Frequency weighting characteristic for infrasound measurements"*, defines infrasound as sound with a frequency spectrum ranging mainly from 1 to 20 Hz.

The infrasound to which human beings are exposed during everyday life derives from extremely diverse natural and artificial sources (Backteman, Köhler & Sjöberg, 1983a, 1983b; Gabrielson, 1997; Landström, 2000; Stephens, 1972; von Gierke & Parker, 1976). Infrasound typically occurs in natural environments at relatively low levels as a result of events such as earthquakes and volcanic eruptions, water turbulence such as ocean waves and waterfalls, air turbulence, winds, and thunder. Examples of common artificial infrasonic sources are ventilation systems, jet engines, the release of gas or steam under high pressure, electrodes, oil burners, vehicles, diesel engines, compressors, transformers, and machines with vibrating parts of low frequency. Because of its long wavelength (λ = 340 m at 1 Hz), infrasound can be propagated over great distances. This long wavelength also implies that screening can only prevent its distribution to a small extent, i.e. infrasound is less attenuated by walls and other structures; rather it can rattle walls and objects.

Although measurements of hearing perception thresholds in the infrasonic field have been conducted more than 60 years ago (von Békésy, 1936), the wrong concept of a principle inaudibility of infrasound was widespread for a long time. Even though the human auditory system is quiet insensitive to low frequencies, it is capable of perceiving infrasound down to approximately 1.5 Hz where the perception threshold is about 130 dB less than at 1000 Hz (Evans & Yeowart, 1974; Johnson, 1980; Landström, 2000; Landström, Jundström & Byström, 1983; Leventhall & Kyriakides, 1976; Whittle, Collins, & Robinson, 1972; Yeowart, 1976; Yeowart, Bryan & Tempest, 1969). Accordingly, the perception of infrasound requires remarkably high sound pressure levels. The lower the frequency, the higher the level for perception. These high sound levels represent a prominent difference between infrasonic and audible sound. The subjective sensations evoked by infrasonic exposures at moderate levels will vary with the frequency. At frequencies close to 20 Hz the infrasound is usually described as smooth and tonal. The tonal auditory experience ceases at about 15 Hz. At these frequencies the infrasound is perceived as a rapid series of impulses or „pops". Correspondingly, it is described rather as rough than tonal. Even at frequencies below 5 Hz, the individual cycles can easily be noticed and are frequently described as „chugging" or „whooshing" sounds. In the real environment, levels close to hearing thresholds are seldom described as unpleasant, since these levels are often masked by higher frequencies. At higher levels, especially in cases when the infrasound is not sufficiently masked, the sensations may be unpleasant and are frequently described as a feeling of increasing pressure. This sensation may also sometimes persist after the exposure has terminated. Under some circumstances, the perception of infrasound is also based on produced vibrations or resonances in the human body and may interfere with vibratory (dis)comfort sensations. For the production of vibrations in the abdominal or chest area, sound pressure levels around 120-140 dB are required in the infrasonic frequency region (Landström et al., 1983). An important prerequisite for the production of bodily vibrations through infrasound is that the tissue encloses gas, usually air. Examples of tissues which are mechanically most easily affected by the pressure variations of infrasound are lungs, stomach, and the middle ear (Landström, 2000; von Gierke & Parker, 1976).

The first scientific assessments of infrasound were done during the first world war when it was suspected that certain negative effects could arise after infrasonic exposure. Among first effects described in human beings were general symptoms of disturbance, such as diffuse unpleasantness, reduced ability to concentrate, or increased frequency of error (Broner, 1978b). The findings of a wide ranging survey and experimental study performed by Persson Waye (1995) showed that low frequency sound can lead to various negative symptoms at apparently innocuous dBA[4] levels including general annoyance, deterioration of task performance, reduced wakefulness and sleep disturbance both reflecting a general slowdown of physiological and psychological states. Gavreau (1968) even went so far as to attribute modern-day „city fatigue" to infrasonic exposure. It has been suggested by Lindberg and Backteman (1988) that sound with a marked low frequency content contributes to subjective annoyance responses in three different ways: (1) It creates sensation of pressure in the ear, (2) periodic masking effects on medium and high frequencies, with a strong modulation effect that can disturb conversation and (3) through secondary vibratory effects. Today, the effects of short-term (20 sec to 2 min) and long-term exposure (8 hours daily up to one week) to intense as well as moderate infrasound (close to the perception thresholds) have been examined in a number of studies (Ising & Schwarze, 1982; Ising, Markert,

[4] Several investigations (Backteman, 1987; Bryan, 1976a; Kraemer, 1973; Leventhall, 1980; Persson & Rylander, 1988; Persson et al., 1990; Tempest, 1973) have shown that dBA values are unsatisfactory for the assessment of annoyance from sounds containing a considerable amount of low frequency energy (< 200 Hz). It has been found that: 1) Very annoying sounds sometimes had rather low dBA values and 2) Sounds that differed only slightly when measured with the A-weighting curve often were far apart in annoyance rating. The ISO 7196 with its proposed G-weighting curve gives values that correspond well with the subjective annoyance and disturbance rating of infrasound. The G-curve is so defined that is has a gain of 0 dB at 10 Hz, that is, the G-weighted sound pressure level of a pure tone at 10 Hz is equal to the unweighted sound pressure level. Between 1 and 20 Hz the curve approximates a straight line with a slope of 12 dB per octave. In this way each frequency is weighted in accordance with its relative contribution to the perception. Below 1 Hz and above 20 Hz the curve has cut-offs with rates of 24 dB per octave.

Shenoda & Schwarze, 1982; Schust, 1997; von Gierke & Nixon, 1976). Commonly, it was found that if the level of infrasonic exposure exceeds the perception thresholds once, one must already expect subjective (in laboratory and field studies) and to some extent physiological reactions. Only a relatively small increase in sound pressure level seems to be sufficient to cause very strong effects. This is due to the distinct closeness of the of the equal loudness contours (isophones) in the infrasonic region (Andresen & Moller, 1984; Bjarne & Moller, 1981; Moller & Andresen, 1984; Moller et al., 1984; Whittle et al., 1972). Landström (2000) assumed that within the infrasound area, around 5 dB are sufficient for a doubling/halving the experienced disturbance.

There is considerable, thoroughly documented evidence of infrasound in transportation, although until now the results are far from unanimous in their conclusions. Aspinall (1966) studied the sound in cars down to 10 Hz, while Hood and Leventhall (1971), Evans and Tempest, (1972), Tempest and Bryan (1972), Williams and Tempest (1975), Tempest (1976b), Broner (1978a) as well as Beran, Girg and Ledvinová (1992) considered measurements in different means of transportation down to 2 Hz (for a review see Williams, 1985). In Table 5 the measured infrasound levels in dBIL (the total linear level in the frequency range of 2 to 20 Hz) and the sound pressure levels in dBA are shown for different kinds of jet aircrafts. Heron (1973) reported that the sound spectra in the jet aircrafts investigated all showed decreasing sound pressure levels with increasing frequency.

Table 5: Infrasound levels in decibels of total linear level from 2 to 20 Hz (dBIL) and A-weighted sound pressure levels (dBA SPL) in jet aircrafts (adapted from Heron, 1973).

Aircraft	Measured position	dBIL	dBA
Boeing 747	flight deck	94	80
	wing front, aisle	99	78
	wing rear, aisle	97	80
	aft, aisle	104	82
Boeing 727	cockpit	96	81
	aft, aisle position	97.5	84
Douglas DC9	cockpit	93	73
	aft, aisle position	94	84
Fokker F27	behind cockpit	90	86

Altogether, the reviewed studies confirm the presence of considerable sound energy in the infrasonic region, and there is some indication that the low frequency content does in some way influence the assessment of the vehicle environment. Accordingly, it may be concluded that low frequency sound (especially below 20 Hz) plays a part in influencing auditory (and related vibratory) comfort in passenger transportation. Further improvement of the vehicle comfort therefore requires an additional analysis and optimisation of the sound in the low frequency range (Spannheimer et al., 2000).

2. AIRCRAFT INTERIOR SOUND AND VIBRATION

The most salient sources of fixed-wing aircraft interior sound are the propulsion system, being either a propeller or jet engine, and the aircraft structure itself (Borchers et al., 1998; Pope, Wilby, Willis & Mayes, 1983; Smith, 1987, 1989). The term „jet" denotes an aircraft type powered by propellerless gas turbine or modern turbofan engines. Both the jet and propeller engines produce discrete tones and broadband noise. In the propeller aircraft, tones are generated by the rotary motion of the propeller close to non-rotating objects. The frequency spectrum comprises the fundamental blade-pass frequency and its higher order harmonics, whereas typical blade-pass frequencies are around 100 Hz (Hanson, 1979). The broadband noise arises primarily from random fluctuations over a wide frequency range and may be due to the turbulent flow in inlet streams, boundary layers, and wakes behind the blades (Morfey, 1973).

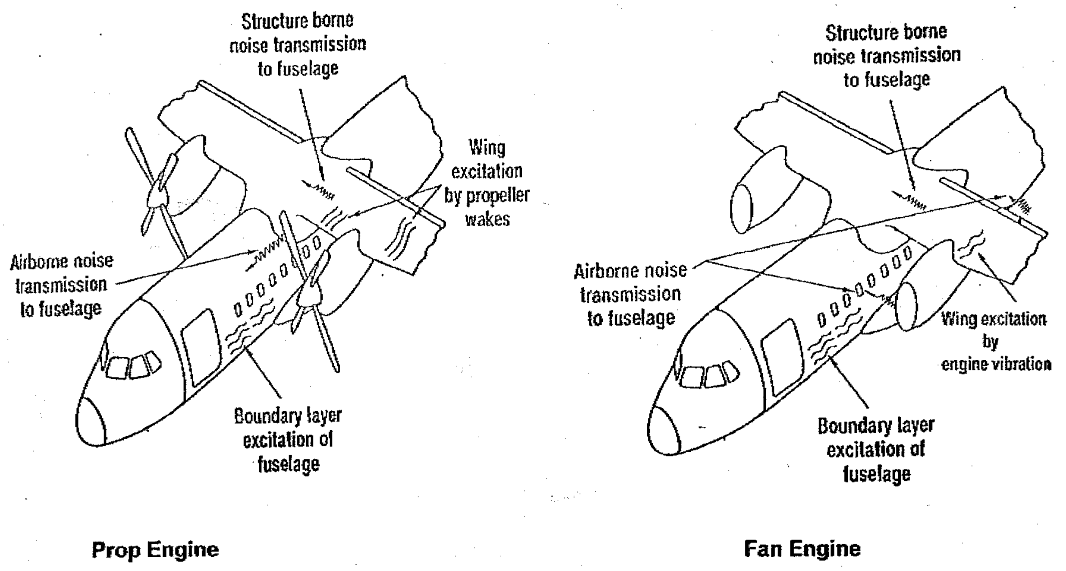

Figure 8: External sources of aircraft interior sound excitation

Hence, another important interior aircraft sound source is airframe sound originating from turbulent air flowing over the aircraft structure (aerodynamics). Sources where turbulence is induced are for instance the main wings, the fuselage, landing gears, and the tail plane (Smith, 1989). Both turbulence in the boundary layer on the outer surface of the cabin as well as propulsion-system-induced engine sound are transmitted into the aircraft via the air (air-borne) and/or via the airframe structure (structure-borne) (Figure 8). Finally, aircraft interior sound may result from internal aircraft systems, particularly the cabin air-conditioning, pressurisation, and ventilation systems. To sum up, a number of sound sources determine the interior auditory environment of commercial aeroplanes. Supposing that sound is mainly generated by the engines, the sound field will vary considerably between different seats (Wilby, 1989, 1992).

Aircraft interior sound levels depend on flying speed and altitude, inside furnishings, as well as the individual seat position. The worst interior environments in terms of sound pressure level are those in helicopters and in propeller-powered aircraft, where intense sound from the rotors is extremely difficult to control, being of low frequency and strongly transmitted via the airframe structure and through the atmosphere, especially in the rotational plane of the propeller. Figure 9 illustrates, for example, that the rotor-craft sound level in helicopter cabins is approximately 10 dBA higher compared to fixed-wing aircraft. Although there is a continuing debate over the most appropriate metric, aircraft interior sound is usually measured in terms of the dBA unit; a good cabin environment being about 70 dBA, a bad one close to 90 dBA (Smith, 1989). Modern passenger cabins are generally less than 80 dBA. The environment is commonly best at the front of the aircraft, and it worsens progressively going rearwards as the fuselage boundary layers grow and the impact of engine sound increases. It is not merely a matter of coincidence that the first-class cabin is always at the front of the aircraft! Figure 9 depicts that a medium- to long-range aircraft cabin is substantially quieter than that of the commuter and short-range aircraft, therefore the sound level may vary within the cabin by up to 10 dBA.

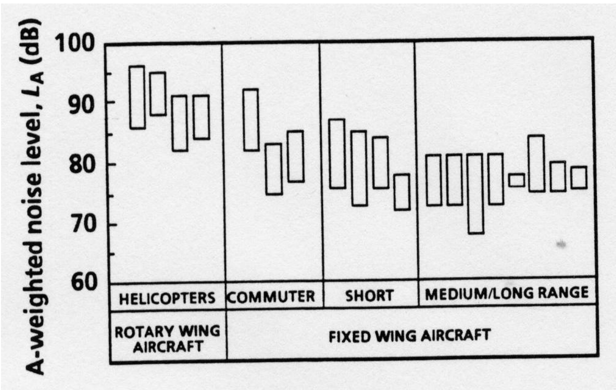

Figure 9: Typical ranges of interior sound in fixed-wing aircraft and helicopter (in dBA SPL) (adapted from Smith, 1989).

The vibratory environment in aircraft is partly composed of oscillatory motion generated from rotating parts within aircraft and partly due to the motion caused by its passage through non-uniform air. The internally generated vibration tends to consist of sinusoidal components; this is the dominant vibration in helicopters and some propeller-driven fixed-wing aircraft (Griffin, 1990). The random excitation caused by air turbulence can effect helicopters but it is more often the dominant motion in fixed-wing aircraft. This type of excitation will give rise to a uniform spectrum dominated by low frequencies with one or two principal components in the in the range from 0.5 to 5 Hz. In order to illustrate the amount and type of vibration that passengers may experience when travelling with an aircraft Figure 10 and Figure 11 are included. Passengers definitely will feel the vibrations of an aircraft in cruise. As long as there is no heavy turbulence, the experienced accelerations are not notably heavier than, for example, when travelling by car.

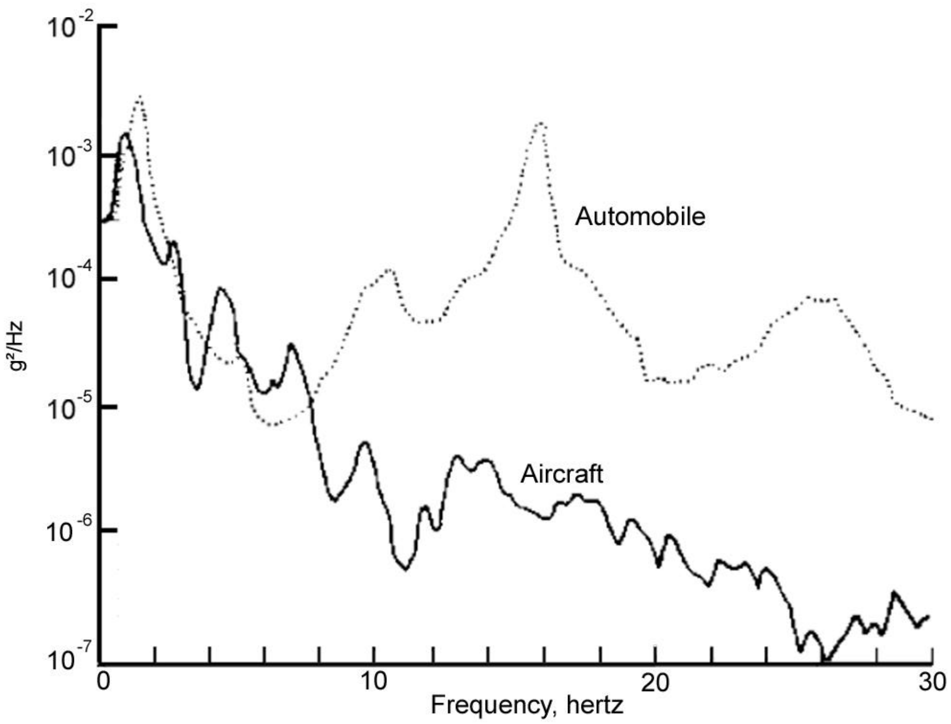

Figure 10: Acceleration power spectra for an automobile and an aircraft in cruise (adapted from Stephens, 1992).

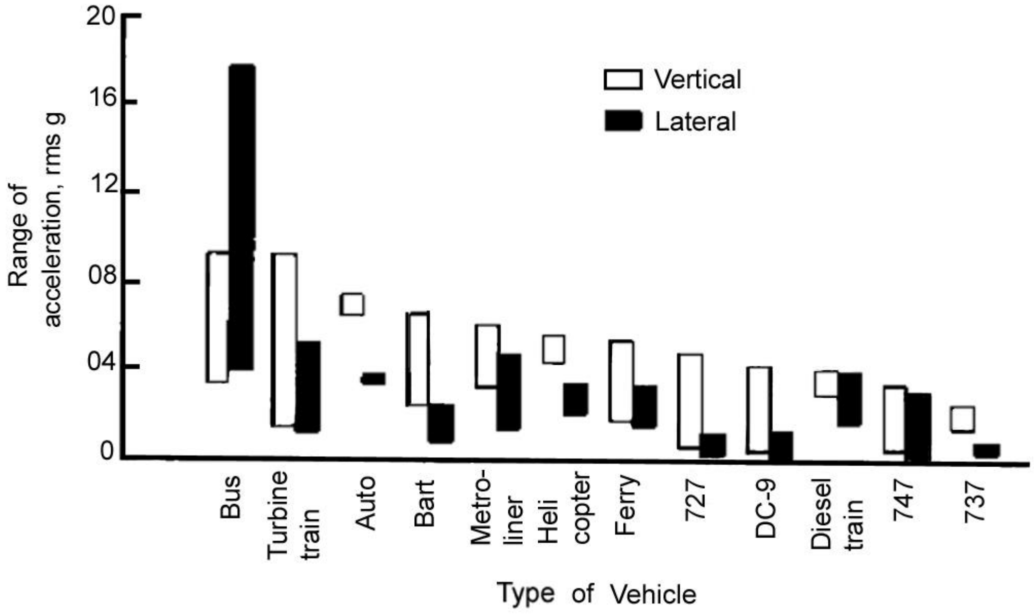

Figure 11: Root-mean-square acceleration ranges of various air and surface vehicles during cruise (adapted from Stephens, 1992).

3. PASSENGER COMFORT STUDIES

3.1 Elements of a model of passenger comfort

The sensation of comfort in vehicle environments involves physical, situational and social aspects of the environment, as well as subjective characteristics of the passenger (Figure 12) (Oborne, 1978a; Quehl et al., 1998; Richards, 1980; Richards & Jacobson, 1975, 1977; Richards, Jacobson & Kuhlthau, 1978). The physical characteristics of a vehicle interior may be grouped into dynamic (or rapidly changing), ambient (or slowly changing), and spatial factors (Table 6). The dynamic factors fall into two categories; characteristics of the vehicle motion and manoeuvres or operating conditions.

Table 6: Physical characteristics of the vehicle environment (adapted from Richards, 1980).

Dynamic Factors	Ambient Factors	Spatial Factors
Longitudinal acceleration	Pressure	Workspace
Vertical acceleration	Temperature	Seat width
Lateral acceleration	Humidity	Leg room
Roll rate	Ventilation	Seat shape
Pitch rate	Odours	Seat adjustment
Yaw rate	Smoke	Seat firmness
Shocks, jolts	Air quality	
Ascents, descents	Illumination	
Change in speeds	Sound	
Turnings		
Turbulences		

Sound is listed as an ambient environmental factor (such as in an aircraft). However, occasionally values of sound will sufficiently change rapidly and frequently to qualify is as a dynamic input. All physical inputs listed in Table 6 can interact and influence comfort either directly or as part of an integrated impression.

Social factors which influence passenger comfort include exchanges with vehicle attendants, operators or other passengers, level of crowding in the station and vehicle, and presence of travelling companions. The way in which a vehicle environment is perceived and hence, any evaluation and response, will also depend upon characteristics of the passenger such as age, gender, previous experience with the vehicle, related attitudes or beliefs concerning the vehicle, proneness toward motion or airsickness, or general health. The passenger will integrate all aspects of the physical and social environment in his or her reaction and evaluation of the vehicle environment. This integration also contains the consideration to the extent in which the environment impinges on various aspects of passengers' activities such as reading or eating while travelling (situational aspects).

In psychoacoustic research the term „comfort" has been mainly employed in association with affective processes, i.e. affective evaluations of and reactions to (vehicle) interior sound environments (chapter 1.5). Following this tradition, Richards (1980) suggested defining passenger comfort as an affective reaction to either an environment or situation. It refers to a kind of psychological state of well-being; its opposite given by a state of subjective discomfort, stress or pain. Hence, the author supposed (in accordance with the lexical and some of the ergonomic descriptions of the term) that comfort represents a continuous, bipolar dimension of experience varying from strongly positive (very comfortable) via a neutral state to strongly negative one (very uncomfortable). He argued that the bipolarity results from the involvement of affective evaluation; comfort is felt or vice versa (Figure 12). As a dimension of a semantic space comfort/discomfort therefore should strongly correlate with assessment. One major focus of the research reported here were the affective components of comfort sensation in vehicles; that is, how individuals react and affectively evaluate physically differing aircraft interior stimulus configurations.

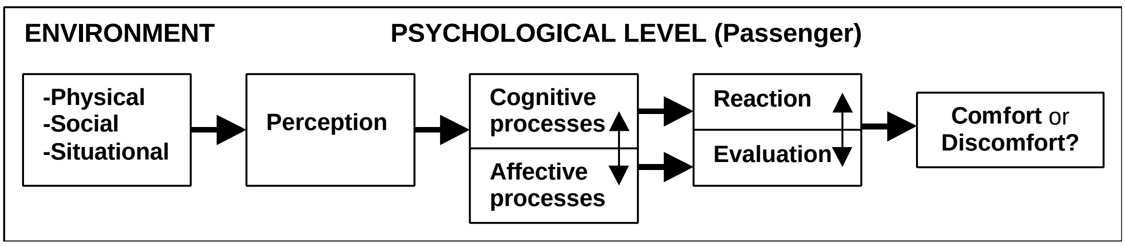

Figure 12: Elements of a model of passenger comfort

Since affective reactions to (artificial and real) vehicle environments represent an integral component of the perceived comfort, and both comfort and well-being are closely related concepts, present research assumed that changes of subjective mood (especially subjects' well-being) induced by an experimental setting may influence the comfort rating understood as an intervening or moderating variable (situational, respectively contextual moderator) (Blauert & Jekosch, 1997; Evans & Lepore, 1997; Guski, 1997a; Quehl et al., 2000d). For instance, it is easy to imagine that if a person feels well, relaxed and calm, the perceived comfort in an experimental situation can be rated greater than if a person would feel annoyed, irritated, excited, or even fearful. Similar to this line of reasoning, Bisping, Steingrüber, Oltman and Wenk (1990) proved that experimentally evoked affective reactions influenced sound evaluation. To analyse the impact of experimentally caused subjective mood changes on the judgement of aircraft interior stimulus combinations, standardised mood scales of the German „Eigenschaftswörterliste" (EWL) (Janke & Debus, 1978) constituting the mood aspects „well-being" and „fear" were selected (chapters 1.4 and 5.4).

3.2 The systems and behavioural approach to passenger comfort

Oborne (1978b) distinguished between the systems and behavioural research approach to passenger comfort. According to the systems approach any journey can be divided into a main stage and several subsidiary stages both prior and subsequent to the main stage. By taking this view, passenger comfort is regarded as an outcome of a set of heterogeneous experiences from the start to the journey's destination. The comfort arising in such way may be interpreted either as a global impression or as an evaluation of subsystems. In this way, Mayr (1959) considered „travelling comfort" to be composed of three subcomponents:

(1) Riding comfort

This is the comfort experienced within the vehicle itself which is determined by all three sets of input listed in Table 6. It is this aspect of the travellers' comfort that is generally termed „passenger comfort".

(2) Local comfort

This is the comfort sensation at the station, airports, interchange points, and the like, and comprises short, dependable and comfortable transfers, clear signs and pleasant waiting rooms (see also Rayman, 1997).

(3) Organisational comfort

This includes factors of organisational origin such as good connections, frequency and reliability of service.

Both local and organisational comfort are mainly determined by aspects of the social environment. According to Oborne (1977, 1978b) a desirable level of comfort will also depend upon a (subjective) trade-off between the journey's duration, frequency, and purpose (e.g., short work trips made on a daily basis vs. longer one-day weekend travel for social and recreational purposes), as well as the passengers' expectations of the journey's comfort (see also Jacobson & Richards, 1976, 1978; Jacobson, Richards & Kuhlthau, 1978, 1980; Neumann, Romansky & Plumber, 1978).

Research assigned to the behavioural approach has mainly employed the common view that comfort is a state of well-being induced under optimal conditions (Oborne, 1978a, 1978b; Oborne & Clarke, 1973; Pineau, 1982; Richards, 1980) in which a person takes no further steps to avoid discomfort (Shackel et al., 1969) and loses awareness of his or her environment (Branton, 1969; Hertzberg, 1972). Besides, the passenger has been characterised as an active comfort seeker. Basically, the behavioural approach has analysed comfort at a more molecular level than the systems approach by taking Richards' (1980) view that the majority of subjective responses of the passenger will tend to take the form of (behavioural) affective reactions to specific stimuli in the physical and social environment. Accordingly, quantitative and qualitative measures of the comfort level of each of these responses can be obtained separately by using a range of different research techniques[5] which may then be related to different intensities and qualities of specific environmental factors. Most research by the behavioural approach has been done regarding physical parameters in transportation.

Although vehicle environments clearly involve multiple factors, most research belonging to the behavioural approach has dealt with laboratory and field studies usually of a single environmental variable. Since about 1970, numerous investigations have been performed to determine physical correlates of passenger comfort within vehicle environments (Bryan, 1976b; Bryan, Tempest & Williams, 1978; Eade & Hardy, 1977; Jacobson & Martinez, 1974; Jacobson & Richards, 1976, 1978; Levis, 1978; Manenica & Corlett 1973; Neumann et al., 1978; Oborne, 1975, 1976a; Oborne & Clarke, 1973; Pepler, Sussman & Richards, 1980; Richards & Jacobson, 1975, 1977; Richards et al., 1978; Rinalducci, 1980; Serio & Mufano, 1989). Most of the research concerned aircraft and helicopters, although there are some studies of ground-based vehicles. Richards and Jacobson (1975, 1977), for instance, considered the comfort of aircraft passengers (see also Jacobson & Martinez, 1974; Oborne & Clarke, 1973; Rinalducci,

[5] The methodological procedure of passenger comfort studies was mainly defined by the use of 5- or 7-point Likert scales related to overall comfort evaluations or comfort levels associated with particular environmental variables, the method of magnitude estimation, and paired comparison (Oborne, 1976a, 1976b, 1978b; Richards, 1980). In some experiments (Jianghong & Long, 1994; Neumann et al., 1978), categorial scaling techniques were combined with physiological measurements (e.g., heart rate, galvanic skin response, blood pressure, EMG) to study whether comfort has a physiological basis.

1980). Levis (1978) examined passengers travelling by bus (see also Manenica & Corlett, 1973). Bryan (1976b) and Bryan et al. (1978) discussed sound effects on passengers in cars and lorries (see also Neumann et al., 1978). Investigations on comfort of trains were conducted by Eade and Hardy (1977), Serio and Mufano (1989), Suzuki (1998a, 1998b, 1998c), and Mzail et al. (2000). In general, empirical findings indicated that passenger comfort was dependent on the temperature, ventilation, seating and spatial arrangements, and primarily affected by motion (e.g., manoeuvres of aircrafts and helicopters), interior sound and vibration. Sound and motion or vibration were often perceived to be interdependent. Manenica and Corlett (1973) proved that the comfort relevant aspects were distributed amongst different vehicle populations at various levels and in a unspecific manner. Since aircraft interior sound and vibration represent main physical determinants, current research focused on these peculiar aspects of passengers‘ comfort. The concepts of auditory and vibratory comfort appear to be useful in describing the design of vehicle interior environments with the aim of defining desirable physical properties from passengers' viewpoint. With one exception (NASA studies), research has mainly analysed subjective perceived auditory and vibratory comfort separately. Data on their interaction and/or the relative weightings of sound and vibration concerning comfort are rare. Few attempts have been made to systematically relate interior vehicle auditory or vibratory comfort to acoustic, psychoacoustic and vibration parameters. Annoyance and discomfort reactions, rather, were implied to describe the effects of physical stimuli.

Regarding the auditory comfort in aircraft, Leatherwood (1979) reported that a power law was almost appropriate for describing the relationship between subjective discomfort in aircraft and sound level. McCurdy (1986) showed that annoyance due to interior turboprop aircraft sound was associated with increasing tone frequency. Moreover, for high dB levels, fluctuations increased annoyance whereas for low levels, fluctuations decreased annoyance. Shepard (1976) found that the A-weighted sound level underestimated annoyance ratings of aircraft interior sound composed of low-frequency tones and turbulent boundary layer sound, whereas unweighted sound level overestimated the annoyance ratings. Leatherwood (1974) demonstrated that annoyance was significant larger for sounds including tones than just simply sound.

Concerning the aircraft interior vibratory comfort, Richards and Jacobson (1975) and Jacobson and Richards (1976) reported that aircraft vibration in y- and z-axis (in terms of the unweighted r.m.s. acceleration) were mainly responsible for subjects' discomfort ratings (see also Oborne, 1975, 1976a, 1977). Dempsey, Leatherwood and Clevenson (1976) showed that a linear law was almost suitable for characterising the relation between subjective discomfort in aircraft and vibration magnitude. Ingvarsson and Västfjäll (1999) performed field and laboratory studies to analyse affective reactions to and cognitive evaluations of vibration in aircraft. It was found that the vibrations in the controlled laboratory setting were easily discriminated, rated consistently and correlated highly with objective metrics, whereas in the more complex aircraft environment, the ratings correlated poorly with objective measurements. The authors hypothesised that the low correlation between objective metrics and subjective ratings in the in-flight experiment was due to the complex environment. In the laboratory setting the participants could focus their attention on the perception of the vibrations, whereas in the in-flight experiment visual, auditory and vibratory as well as several internal factors may have influenced the evaluations. Similarly, a variety of investigations have shown that the presence of vibration can induce sound perception and evaluation (chapter 6.3.1).

A variety of field and laboratory investigations were conducted by NASA to study the combined auditory and vibratory discomfort in terms of acoustic and vibration stimulus parameters (Dempsey, Leatherwood & Clevenson, 1976; Dempsey, Leatherwood & Drezek 1976; Dempsey, Leatherwood & Sherman, 1978; Hammond, Hollenbaugh, Clevenson & Leatherwood 1981; Leatherwood, 1979, 1984; Leatherwood, Clevenson & Hollenbaugh, 1984; Leatherwood & Dempsey, 1976; Leatherwood, Dempsey & Clevenson, 1980; Stephens & Leatherwood, 1979, 1990). Data were used to formulate a general passenger discomfort model. The basic approach involves the determination of psychophysical relationships („discomfort curves") governing passengers' discomfort reaction to combined sound and vibration configurations in different vehicle environments (usually aircraft). Physical units are transformed into subjective discomfort units and then combined according to empirically derived discomfort curves (Figure 13). The output of the NASA model is a single total discomfort index. It depicts the direct sum of sound and vibration indices reflecting their relative contributions to total (auditory and vibratory) discomfort.

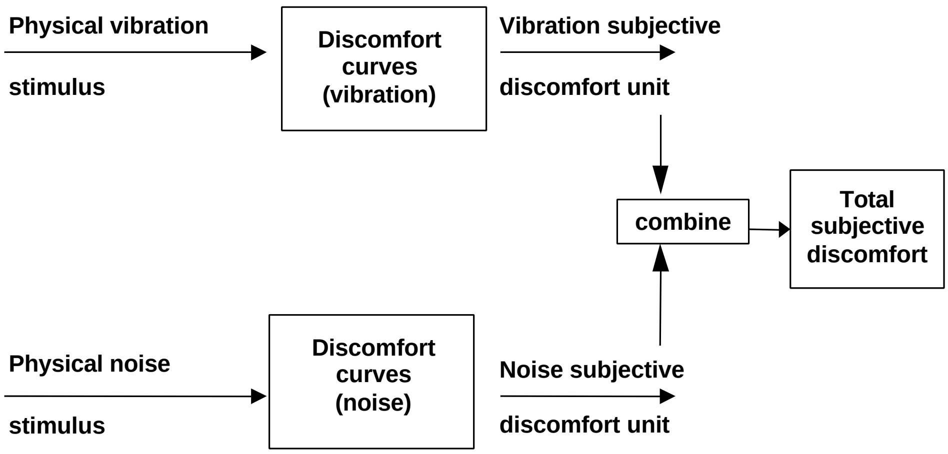

Figure 13: The NASA ride discomfort model (adapted from Stephens et al., 1990).

4. AIM OF THE RESEARCH

The comfort in passenger vehicles is determined by aspects of the physical and social environment as well as characteristics of the travelling person. Most passenger comfort studies concerned the influence of physical parameters in transportation. Interior sound and vibration appeared to be among the known main physical factors. Since the 70ies, a number of field and laboratory investigations were conducted regarding the impact of these peculiar physical components of passengers‘ comfort. Most of the previous research examined subjective auditory and vibratory comfort separately. However, in many vehicles such as aircraft, both sound and vibration are of major importance for the perceived level of comfort. The current research simultaneously addressed the perception of combined aircraft interior sound and vibration which may interact and induce the evaluation of comfort. In order to adjust aircrafts to the subjective comfort needs of the passengers, the way individuals perceive combined sound and vibration stimuli (particularly with regard to aspects relevant to combined auditory and vibratory, also called vibro-acoustic comfort) must be understood, that is, to determine the underlying perceptual dimensions and physical correlates. A common technique for establishing dimensions of perception is the application of the semantic differential which measures peoples’ affective judgement of stimulus words and concepts. The basic intention of this procedure is to scale the aspects of any object's connotative meaning (i.e. emotive, affective and evaluative factors). The semantic differential offers the possibility to comprehensively characterise subjective experiences in any sensory modality, to sort them into a homogeneous reference system, and to make comparisons on the level of semantic descriptors (Schick, 1979, 1995a, 1996a). Physical properties of the stimuli may then be assigned to the affective features of subjective sensations. This, in turn, can be retroactively useful for the optimisation of, for example, aircraft interior sound and vibration. A survey of psychoacoustic and relevant psychological literature of the past 30 years revealed that little is known about the perceptual dimensions and physical correlates related to aircraft interior sound and vibration. Only a few attempts have been reported where aircraft interior auditory or vibratory (dis)comfort and annoyance ratings have been connected with physical description of the stimuli. Since previous research was mainly restricted to relate assessments of subjective annoyance and discomfort to physical descriptors, they seemed to be limited to their application to vibro-acoustic comfort optimisation.

To achieve a high degree of ecological validity (the extent to which a controlled laboratory investigation can be generalised to natural settings), the judgement of comfort due to the aircraft interior sound and vibration should be performed in an experimental setting that is as realistic as possible. For this purpose, realistic aeroplane set-ups, so-called mock-ups, as well as a sound and vibration reproduction system may be used to ensure that stimuli can be presented in a realistic and appropriate manner. As far as affective reactions to artificial and real vehicle environments are an integral component of the perceived comfort, with comfort and well-being representing closely related concepts, it was hypothesised that changes of subjective mood (especially subjects' well-being) evoked by the experimental setting can moderate the comfort rating of presented stimuli. Differences in reaction intensity or susceptibility in terms of induced subjective mood modifications might be due to individual variations of experimental reactivity[6] or general sensitivity to respond to ambient „environmental stressors" such as sound and vibration (Höger, 2000; Weinstein, 1980; Winneke et al., 1992, 1996). To study the influence of experimentally caused changes of subjective mood on assessment, standardised mood scales of the German „Eigenschaftswörteliste" (EWL) (Janke & Debus, 1978) constituting the mood aspects „well-being and „fear" were employed in the current research.

The present research focused on the affective components involved in subjective comfort sensation; i.e. how subjects react and affectively evaluate aircraft interior stimulus configurations which physically differ with regard to acoustic, psychoacoustic and vibration parameters. The aim was to analyse the perceptual dimensions and physical correlates distinguishing combined sound and vibration configurations in aircraft in order to approximate passengers' conception of (combined auditory and vibratory, also known

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[6]Commonly, reactivity concerns the individual disposition to react to internal or external stimuli. In current differential and personality psychology the concept of „reactivity" is mainly viewed as a fundamental personality trait. It is assumed that reactivity plays a pivotal role in determining effects of environmental factors (for a detailed review see Janke & Kallus, 1995). On the energy level of behaviour, Strelau (1970, 1974, 1982, 1983, 1987, 1989, 1991, 1993, 1995, 1999) proposed that reactivity is a primary feature of temperament. Reactivity, which has its roots in the concept of strength of excitation (Pawlow, 1951-1953), is defined as *„a temperament feature which determines a relatively stable intensity (magnitude) of reactions for a given individual. [...] individuals differ in the degree as well as in the range in which the intensity (magnitude or amplitude) of reaction is expressed [...] Crucial to our understanding of reactivity is the fact that it co-determinates sensitivity (sensory and emotional), as measured by sensory thresholds, and the organism's capacity to work (its endurance), as manifested in reactions to strong or prolonged stimulations"* (Strelau, 1983, p. 177). Strelau distinguished between high- and low-reactive individuals. High-reactive individuals may be characterised in terms of high sensitivity (low sensitivity thresholds) and low endurance, whereas low-reactive individuals have a low level of sensitivity (high sensitivity thresholds) and a high level of endurance. Since arousal mechanisms augment stimulation in high-reactive individuals, they only need low levels of stimulation to attain an optimal level of arousal. Whereas in low-reactive individuals these mechanisms tend to suppress stimulation and such persons have a high need for stimulation in order to maintain an optimal level of activation. The difference between low-reactive individuals and high-reactive persons is described by the fact that they use different styles of action in order to cope with the stimulation rate of the situation. In high-reactive individuals an adjunctive style of action, aimed at decreasing the stimulation rate of activity or of the situation in which activity is performed, is dominant. For low-reactive individuals the straightforward style of action is typical; this style is aimed at supplying stimulation.

as vibro-acoustic) comfort and to define desirable physical properties for aircraft's comfort design from their viewpoint (Quehl et al., 2000b, 2000c). In particular, the interaction between sound and vibration level regarding the comfort rating of aircraft interior sound and vibration combinations should be determined (Quehl et al., 2001). Hence, the objectives of the research reported here were:

(1) to develop a methodological instrument for the assessment of aircraft interior (sound and vibration) environments,

(2) to investigate the perceptual dimensions underlying combined aircraft interior sound and vibration (especially regarding aspects related to vibro-acoustic comfort),

(3) to examine the relation between perceptional dimensions and conventional acoustic, psychoacoustic and vibration parameters,

(4) to determine the interaction between sound and vibration level regarding the comfort rating of aircraft interior stimulus combinations, and

(5) to analyse the relationship between experimentally evoked subjective mood changes and the (comfort) judgement of combined aircraft interior sound and vibration stimuli.

Two studies are reported separately in the next two chapters. Each chapter covers both a theoretical as well as an empirical part. In study 1, seven sound and vibration configurations of two cruising aircraft types (four jet and three propeller aeroplanes) were presented in an aircraft mock-up and rated by using a semantic differential designed for the assessment of aircraft interior (sound and vibration) environments. The aim was to establish perceptual dimensions of combined sound and vibration in aircraft and to seek their physical correlates. In study 2, sound and vibration combinations of two cruising situations also presented in study 1 (jet 1 and propeller 2) were systematically varied in sound pressure level and vibration magnitude (3 x 3 design) and implemented as stimuli in a laboratory experiment using a so-called „sound and vibration reproduction system". Each configuration was assessed by means of the semantic differential also employed in study 1. The intention was to estimate the interaction between of sound and vibration level regarding the comfort judgement of aircraft interior sound and vibration combinations. In both investigations, the influence of experimentally induced changes of subjective mood on (comfort) rating was examined.

5. STUDY 1: *Perceptual dimensions of combined aircraft interior sound and vibration*

Auditory sensations are based on fundamental perceptual dimensions (McAdams, 1989, 1993). It is a primary concern of psychoacoustic research to define the nature of the underlying perceptual dimensions that people use when evaluating sounds. Study 1 focused on the perceptual dimensions discriminating combined aircraft interior sound and vibration in order to approximate passengers' understanding of (combined auditory and vibratory, respectively vibro-acoustic) comfort.

A. THEORETICAL PART

5.1 An example: dimensional analysis of timbre perception

In order to illustrate the objectives of study 1 an example of dimensional analysis related to the perception of timbre is given which was examined in a variety of psychoacoustic studies. According to the definition proposed by the American Standard Association (1960, p. 45) *„timbre is that attribute of auditory sensation in terms of which a listener can judge that two sounds similarly presented and having the same loudness and pitch are dissimilar."* Timbre, by definition, indicates that portion of perception not explained by loudness and pitch. It refers to the „colour", quality or aesthetic aspect of sounds by which the particular peculiarity of an auditory event, its individuality and sound source can be identified (Namba, 1992; Schick, 1994a, 1994b). Starting with the first investigations on timbre by von Helmholtz (1863), several efforts have been undertaken by introspective psychologists (such as Stumpf, 1883, 1890) and psychophysicists (such as Lichte & Gray, 1955; or Stevens, Guirao & Slawson, 1965) to define a set of verbal attributes such as brightness, fullness, sharpness, roughness, volume and density, to describe timbre. Detailed reviews of these analyses were conducted by Licklider (1951), Rahlfs (1966), Plomp and Steeneken (1969), Plomp (1970, 1976) and von Bismarck (1972). The reviewed studies shared the conclusion that timbre is a perceptual dimension having a multidimensional character. Two methods, multidimensional scaling and the semantic differential, appeared to be suitable to measure this multidimensionality.

5.1.1 Multidimensional scaling studies

Timbre analysed with multidimensional scaling (MDS) procedures is based on similarity (or dissimilarity) evaluations of sounds. The aim is to determine the structure of the underlying multidimensional perceptual representation of timbre („timbre space"). The basic assumption beyond MDS is that subjects use a small number of perceptual dimensions associated with the sounds to rate how similar (or dissimilar) they are. In general, the principle of MDS is the following: A set of stimuli (for instance, tones equalised in pitch, loudness, duration, and spatial position) is presented to subjects in all possible pairs, and for each pair they are asked to assess how similar (or dissimilar) the two tones are to each other by using a numerical scale. It is postulated that there is a mental representation of each timbre that has particular prominent components and that the number on the scale reflects a comparison based on these components. The resulting similarity (or dissimilarity) ratings are analysed using multidimensional scaling algorithms (Kruskal, 1964a, 1964b; Shepard, 1962a, 1962b; Windsberg & De Soete, 1993, 1997) which convert the judgements to a representation of the timbres in a low-dimensional geometric space where Euclidean distances between points correspond to perceived (dis)similarities between stimuli. An important distinction among the different MDS procedures is the kind of spatial model employed to describe the distances between pairs of sounds. The resulting geometrical structure is interpreted as reflecting the perceptual dimensions listeners use to compare the timbres, or, alternatively, as indicating the structure of mental representations that allows them to make orderly comparisons. The spatial configuration is often given a psychoacoustic meaning by relating the extracted dimensions to acoustic and psychoacoustic properties of the tones.

The Euclidean distance model assumes that the set of perceptual dimensions is the same for all subjects. However, in some cases the sounds may have unique perceptual features that no others in the set have. They have „specifities" that make them dissimilar to all other timbres, but such features cannot be explained by the common dimensions along which all the sounds vary in a continuos fashion (Krumhansl, 1989). There are two possible reasons for such specifities: Either a given specificity characterises an additional dimension along which only one timbre changes, or there are one or more features not present in the rest of stimuli. Hence, the model can be extended to include specifities on individual timbres in addition to the shared dimensions. Different subjects can weight the various dimensions and specifities in individual ways according to their perceptual salience. Accordingly, subjects form so-called „latent classes" or subpopulations that can be determined on the basis of their evaluations. The classes are latent because it is not known in advance to which one a particular subject belongs (McAdams, Winsberg, Donnadieu, De Soete & Krumhansl, 1995; McAdams & Winsberg, 2000).[7]

Numerous studies have performed MDS analyses on similarity (or dissimilarity) ratings for musical performance of instruments or synthesised tones meant either to imitate conventional instruments (winds, bowed string, plucked strings, or mallet percussion) or to represent a hybrid of a pair of these instruments. In all of these studies two- or three-dimensional spatial solutions were found. The perceptual axes have been related either qualitatively or quantitatively to acoustic and psychoacoustic properties of the stimuli. The first dimension seemed to be associated with the spectral energy distribution (or spectral envelope) of the instruments and was therefore primarily interpreted as a spectral dimension representing the degree of „brightness" of sound quality (Grey, 1975, 1977, 1978; Grey & Moorer, 1977; Krumhansl, 1989; Miller & Carterette, 1975;

[7] In study 1, the idea of latent classes was applied due to the hypothesis that subjects may base the judgement of physically differing sound and vibration configurations on specific evaluation strategies. Principal component analysis involving subjects should cluster persons having similar strategies. Evaluation strategies have been employed in the sense of so-called „cognitive styles". Differential and personality psychology of perception assumes that interindividual differences in perceptions and experiences are due to dispositions in personality. Various factors of personality, circumstances and their interaction induce a part of perception and may change the meaning of sensory stimulation. In part these subjective characteristics, which alter in the course of time and depend on the situation, find expression in quite different interindividual experiences and evaluations. In this context, the term cognitive style denotes the specific ways in which individuals conceptually organise the content of perceptions which, in turn, reflect an individual's personality (Armelang & Bartussek, 1997; Fiedler, 1985; Fink, 1987; Fisseni, 1998; Floyd, 1976; Messick, 1996; Pervin, 1980). Since the mid-1940s, there have been various influences in different areas of psychology which have contributed to the emerge of several models of cognitive style which were reviewed, for instance, by Riding and colleagues (Riding 1997; Riding & Cheema, 1991; Riding & Rayner, 1997, 1998). Common to all theories and research on cognitive style is an emphasis on structural properties rather than on properties concerning contents. It is assumed that the way in which any new information is received, processed, and interpreted depends on the capabilities and characteristics of the pre-existing cognition structure into which it is read (Harvey, 1963, 1966, 1971; Harvey, Hunt & Schroder, 1961, Schroder, Driver & Streufert, 1967, Schroder & Suedfeld, 1971). The first influence in an emerging theory of cognitive style was in the psychology of perception, exemplified by the work of Witkin and colleagues (Witkin, 1964, 1975; Witkin & Goodenough, 1981). Differences in individuals were identified who were deciding whether an object was upright in space. Further experimental work, reflecting an emphasis on the „regularities" of information-processing, derived from the Gestalt School of German perceptual psychology, led to the discovery of field dependence-independence as a perceptual style. Individuals were found to rely upon the surrounding „field" or context to a greater or lesser extent, when reorienting an object to the vertical. Kagan, Moss, and Sigel (1963) viewed cognitive style as stable individual preferences in mode of perceptual organisation and conceptual categorisation of the external environment. The authors studied cognitive style by analysing how individuals group objects. It was postulated that individuals could be grouped on the basis of their proclivity to analyse and differentiate the stimulus environment (see also Kagan, Rosman, Day, Albert & Philips, 1964). Bieri (1971) supposed that individuals learn strategies, programs, or other transformation operations to translate the objective stimuli into meaningful dimensions and termed these strategies „cognitive structures". Zajonc (1968) similarly maintained that cognitive structures mediate between environmental input and the organism's output. He added the idea that cognitive structures organise behaviour as well as input. Goldstein and Blackman (1978) proposed likewise that cognitive style is related to the specific ways in which individuals conceptually structure the environment. Messick (1976, 1996) as well as Riding and Rayner (1997, 1998) defined cognitive style in terms of consistent patterns of organising, processing and representing information. Harvey's (1963, 1966, 1971) view that cognitive style denotes the manner an individual perceives and processes stimuli so that the environment takes on psychological meaning integrates the cited definitions. Harvey et al. (1961) performed an analysis of cognitive structure in terms of differentiation, discrimination, and integration. Differentiation corresponds to the number of dimensions used in evaluation, discrimination deals with the structure within these dimensions, and integration refers to the relations among the dimensions (for more details see Seiler, 1973).

Pitt & Crowder, 1992; Plomp, Pols & van der Geer, 1966; Pols, van der Kamp & Plomp, 1969; Saldana & Corso, 1964; Wedin & Goude, 1972). Many investigations proved that the mean frequency (centroid) in spectral distribution corresponds to this dimension, suggesting a perceptual predominance of spectral features in timbre judgements (Grey & Gordon, 1978; Iverson & Krumhansl, 1993; Krimphoff, McAdams & Winsberg, 1994; McAdams et al., 1995, 2000). The second dimension appeared to be connected with the temporal envelope of the tones and was mainly described as a dynamic dimension called „attack quality” or „attack rapidity". For example, sharp or biting attacks, such as that of the harpsichord, were found at one end of this dimension and softer attacks as with the clarinet were found at the other (Grey, 1975, 1977, 1978; Grey & Gordon, 1978; Grey & Moorer, 1977; Iverson & Krumhansl, 1993; Krimphoff et al., 1994, Krumhansl, 1989; McAdams et al., 1995, 2000; Pitt & Crowder, 1992; Saldana & Corso, 1964). The psychophysical nature of the third dimension seemed to vary with the stimulus set used, corresponding either to temporal variations in the spectral envelope (Grey, 1975, 1977, 1978; Grey & Gordon, 1978; Krumhansl, 1989) or the spectral fine-structure (Krimphoff et al.s’, 1994, analysis of Krumhansl’s, 1989, stimuli). The spectro-temporal dimension has also been labelled as “spectral flux” (Krumhansl, 1989; McAdams et al., 1995, 2000). For instance, instruments with a spectral envelope barely evolving over the duration of the tone (like the oboe) had low spectral flux compared to those whose spectrum changed a great deal (usually brightness increasing and decreasing with intensity as in the brass instruments). Additionally, some timbres could be distinguished by perceptual features specific to each („specifities”), such as unique patterns in the harmonic spectra (Krumhansl, 1989).

5.1.2 Semantic differential studies

The fundamental postulate underlying the SD technique is that perceptions of the external environment do not reflect only physical and physiological conditions, rather that they are also influenced by a large amount of non-conscious knowledge, for instance, in the form of conveying meaning (Krampen, 1991; Schick, 1995a, 1996a, 1998, 2000). It is assumed that this meaning can determine behaviour just as physical stimulus parameters. At the present time, Osgood's theory of meaning (1952, 1962, 1964, 1971, 1972, 1976; Osgood & Suci 1952, 1955; Osgood, May & Miron, 1975; Osgood, Suci & Tannenbaum, 1957, 1961) is still used to represent the meanings of all kinds of concept. His approach will be outlined only coarsely since it was already described in detail by Quehl (1997, 1999). Osgood and colleagues developed a method for the measurement and analysis of meaning: the semantic differential (SD). The SD essentially consists of a set of 7-point rating scales with bipolar adjectives at each end (e.g., „good” vs. „bad”) which are called polarities. It measures peoples’ affective evaluations of stimulus words and concepts. The original intention of this procedure was to scale the aspects of any object's connotative meaning for a specific individual. Connotative aspects of meaning refer to emotive, affective and evaluative factors, sensations, or moods elicited by a word, roughly speaking, the term’s associations for an individual. The denotative meaning of an object is given by its definition such as in a dictionary. Whereas the denotation of an object often agrees interindividually, its connotation, may, however, vary from subject to subject. The basic theoretical assumption beyond the SD is that language represents an important tool to describe the „meaning” of all types of concept. Osgood supposed that adjectives „mediate" between the words and their meaning. These mediation processes correspond, by definition, to the nature of meaning. Osgood performed a number of experiments applying widely varied samples of concepts to determine independent basic dimensions of these processes. Three dimensions of meaning were generally found by means of factor analysis. They together accounted for about two thirds of the data’s variance and appeared in approximately the same order of importance. The first dimension was identified as evaluative, polarities with high loadings on this factor were, for example, „good” vs. „bad”, „beautiful” vs. „ugly”, and „happy” vs. „sad”. The second dimension was considered as a potency variable referring to power and its associations such as size, weight, and toughness. The highest loadings here were, for instance, „large” vs. „small”, „strong” vs. „weak”, and „heavy” vs. „light”. The third dimension indicated activity. It referred to quickness, excitement, warmth, and agitation. Examples of its most distinctively loaded adjective pairs were „active” vs. „passive”, „fast” vs. „slow”, and „hot” vs. „cold”. Although there were a number of other dimensions around which attributes tend to cluster and which were not contained in the three main dimensions (e.g., a stability, tautness, novelty, or receptivity factor), the Evaluation, Potency, and Activity (EPA) structure was regarded to be a stable core of meaning processes. The EPA dimensions have been verified and replicated in an impressive number of studies (Osgood et al., 1975). When the SD technique was applied cross-linguistically and cross-culturally, strong evidence was yielded for the universality of the EPA dimensions as affective features of meaning. For instance, Ertel (1964, 1965) made use of the SD under the name „impression differential” in his cross-cultural comparative investigations on phonetics. The EPA structure was therefore interpreted as a universal semantic feature of language which can serve as a metric for comparing the connotative aspects of meaning for concepts in different languages and cultures. However, it has to be taken into account that the relative importance and relationship among dimensions may vary with the kinds of concept being rated, i.e., with the frame of reference of evaluation. Accordingly, Osgood emphasised that the EPA structure will not exhaust the dimensions along which meaningful judgements can be differentiated (see also Quehl, 1997, 1999; Schäfer, 1983; Schäfer & Fuchs, 1975; Schick, 1979).

In psychoacoustic research, the SD has been mainly used for the measurement of connotative aspects of meaning, respectively affective qualities of complex sound events or particular auditory characteristics such as timbre. The SD offers the possibility to comprehensively characterise subjective hearing experiences, to sort sound events into a homogeneous reference system, and to make comparisons on the level of semantic descriptors (Schick, 1979, 1995a, 1996a). The semantics of hearing may then be translated into acoustical terms. For this purpose, specific psychoacoustic properties like roughness or sharpness can be assigned to affective features of auditory sensation. This, in turn, may be retroactively useful, for example, for the optimisation of vehicle interior sound environments. Whereas psychologists as Hofstätter (1957, 1969: method of polarity profiles) and Ertel (1964, 1965: impression differential) intended to develop standardised lists of adjectives, psychoacousticans generally constructed a so-called „concept-specific” SD suitable for the assessment of particular sound events or specific features. This procedure follows Osgood et al.s' (1957, 1975) recommendation to adapt the SD to the requirements of each specific research (see also Bergler, 1975; Flade, 1978; Kasmar, 1970). Most psychoacousticans started their search for appropriate adjectives with spontaneous verbal descriptions within the context of acoustic studies („Please, try to describe what you have heard in your own words”). Another method was to select attributes from the literature available and to have their suitability rated by naive subjects (von Bismarck, 1972, 1974a, 1974b; Hashimoto, 1994; Takao & Hashimoto, 1994).
Various SD investigations have been carried out to define the underlying dimensions related to timbre perception. In general, factor analysis (usually varimax rotated principal component analysis) of the sound evaluation was used to derive the perceptual dimensions. In this way for instance, Rahlfs (1966) extracted dimensions said to correspond to timbre qualities such as „feminine”, „masculine” and „loneliness”. Jost (1967) conducted an extensive semantic study of clarinet timbre where „volume” and „density” seemed to be the most important salient dimensions of timbre perception. Wedin and Goude’s (1972) analysis revealed a classification of instrument types into „woodwind”, „brass”, and „string”. Pratt and Doak (1976) found three dimensions of timbre perception: „brilliant”, „rich”, and „warm” with the arbitrary opposites „dull”, „pure”, and „cold”, respectively. The authors proved that synthetic tones of varying spectral content were

almost reliably classified using the „brilliant vs. dull” scale. Von Bismarck (1974a, 1974b) performed an influential and extensive factorial investigation on timbre's verbal attributes. Principal component analysis of the judgements of synthetic, harmonic complex tones and sounds established four factors carrying 90% of the total variance in the ratings: „dull” vs. „sharp”, „compact” vs. „scattered”, „empty” vs. „full”, and „colourless” vs. „colourful”. The „dull” vs. „sharp” factor appeared to be particularly important and explained 44% of the variance.

Furthermore, innumerable SD studies were carried out to define the basic perceptual dimensions of complex sound events or other auditory properties than timbre. For example, Solomon (1958, 1959a, 1959b) derived eight dimensions discriminating the perception of sonar signals by means of factor analysis of SD data. These dimensions were confirmed later in the investigations by Gabrielsson and Lindström (1985) on the transmission qualities of loudspeakers. Early Japanese psychoacoustic studies were conducted by Enomoto and Yoshoda (1968), Kitamura, Namba and Matsumoto (1968), and Manabe, Namba, Yoshida, Yoshikawa, Kuroda and Matsuki (1968) by using concept-specific SD for the assessment of different kinds of sound (cited from Schick, 1996a). Additionally, psychoacoustic research sought to describe perceptional dimensions of:

- different types of synthesised or originally recorded environmental sounds (Abe, Ozawa, Suzuki & Sone, 1998, 2000; Kerrick, Nagel & Bennett, 1969; Namba, 1992),
- industrial sounds (Hawel, 1967a, 1967b),
- danger signals (Bock, Lazarus & Höge, 1985; Lazarus & Höge, 1986),
- speech perception and intelligibility (Lazarus-Mainka & Raschdorf, 1985),
- musical performance (Namba, Kuwano, Hatoh & Kato, 1991),
- trend monitoring sounds or „trendsons” in helicopters (Edworthy, Hellier & Hards, 1995),
- high speed trains (Lambert, 1997; Lambert, Champelovier, Vernet, Annequin, & Baez 1994; Lambert, Champelovier, & Vernet, 1996),
- car interior sounds (Bisping, 1994, 1995, 1997; Boemak, 1994; Chouard & Hempel, 1999; Handmann & Bodden, 1995), and
- the German maglev Transrapid (Quehl, 1997, 1999; Umweltbundesamt, 1997).

Reference must also be made to the research on Japanese vehicle acoustics (Hashimoto, 1994; Kuwano, Namba, Hato, Matui & Imai, 1993, 1994; Takao & Hashimoto, 1994) or Japanese helicopter acoustics (Namba & Kuwano, 1990; Namba, Kuwano & Koyasu, 1993). Schick (1994b, 1994c, 1995a, 1995b, 1996a) reviewed the history of sound evaluation in passenger cars, especially regarding Japanese applied vehicle research.

Although psychoacoustic SD studies focused on very different sets of polarities and sounds, outcomes of factor analysis were rather similar. In general, two or three perceptional dimensions have been steadily extracted to be important factors distinguishing auditory sensations. They were interpreted as representative for loudness (synonymous: „volume", „magnitude", „powerful", „powerfulness", „potency"), pitch (synonymous: „brightness", „clarity", „metallic", „metallicness", „activity"), and aesthetic-evaluative aspects (synonymous: „evaluation", „evaluative", „pleasant", „pleasantness", „aesthetic state"). For instance, Namba et al. (1993) found a high correlation between the loudness dimension and $L_{eq(A)}$ of helicopter interior sounds and a lower correlation between the aesthetic-evaluative dimension and $L_{eq(A)}$. Results suggested that low level sounds in helicopters tend to be preferred than high level ones, though other factors also affected the impressions belonging to the evaluative dimension. The loudness, pitch, and aesthetic-evaluative dimensions were viewed as having confirmed the classical EPA structure (Schick, 1995a, 1996a).

5.2 Comparison of multidimensional scaling and semantic differential procedures regarding the dimensional analysis of combined aircraft interior sound and vibration

SD and MDS procedures have been compared with regard to the objectives of study 1, namely the analysis of the perceptual dimensions underlying combined sound and vibration in aircraft.

(1) Economic practicability

The application of MDS is restricted to a quite small set of stimuli of relative short duration, since the number of stimulus pairs and the duration of an experiment will extend quickly with the number of stimuli. In the present study, seven combined sound and vibration configurations were given twice to account for test-retest reliability. Due to the stimulus duration (120 seconds) and the number of possible combinations (N=42) the experiment did not appear to be practicable when using MDS since the expected duration would have probably caused exhaustion in subjects. It was not possible to split one experimental session into several parts due to economic reasons.

(2) Characteristics of the stimuli to be judged

It is recommended that the stimuli should sound different regarding specific properties (e.g., in timbre) when employing MDS, as subjects are easily overloaded when asked to rate the similarity (or dissimilarity) of strongly resembling stimuli. In the given study, the stimulus configurations did not differ considerably with regard to acoustic, psychoacoustic and vibration parameters (chapter 5.4). Hence, MDS did not seem applicable.

(3) Interpretation of the perceptual dimensions

The interpretation of the derived perceptual dimensions has often been relatively difficult and imprecise in MDS studies (Kendall & Carterette, 1991, 1993). This problem usually does not arise within SD investigations since there is a relationship between perceptual dimensions and pre-selected qualities of a concept-specific SD from the very beginning. In the current study, the interpretation of the dimensions was additionally facilitated by an interrelation of the SD responses with physical and qualitative data. Since it has often been criticised that the pre-selection of polarities may not unquestionably conform with those subjects would use spontaneously, or can even ignore important aspects, a pool of appropriate attributes has been pre-selected by psychoacoustic experts and subjects in four laboratory and field pretests (chapter 5.3).

(4) Measurement of affective components involved in (combined auditory and vibratory, termed as vibro-acoustic) comfort

For the previous reasons, but mainly due to study 1's aim to focus on the affective components involved in aircraft interior (vibro-acoustic) comfort, the SD appeared to be method of choice since it measures peoples' affective evaluations, especially subjective sensations or emotive impressions (connotative aspects of meaning) of any kind of stimuli in any (e.g., auditory and vibratory) modality.

B. EMPIRICAL PART

5.3 Development of a concept-specific semantic differential designed for aircraft interior (sound and vibration) environments

When reviewing recent psychoacoustic and relevant psychological literature of the past 30 years it became obvious that little is known about the perceptual dimensions and their physical correlates related to aircraft interior sound and vibration. Hence, an appropriate SD for the assessment of aircraft interior environments has not been elaborated yet. Therefore, a decision was made to develop two suitable, concept-specific SD designed for aircraft (jet- and propeller aeroplanes as well as helicopters) interior (sound and vibration) environments. For this purpose, four laboratory and field pretests were carried out with psychoacoustic experts as well as naive subjects (Quehl et al., 2000a). With one exception all pretests were performed in German. The intention was to find semantic descriptors which were meaningfully related to aircraft interior sound and vibration and enabled persons to evaluate and distinguish among different sound and vibration configurations. A review of the psychological literature on SD indicated that no standardised procedure for the development of a concept-specific SD exists. Osgood and colleagues just recommended to consider some theoretically based criteria (see also Quehl, 1997, 1999; Schäfer, 1983; Schäfer & Fuchs, 1975) such as dimensional representativity, concept adequacy, polarity, semantic stability, linearity. They have been taken into account.

(1) In order to get first impressions on combined sound and vibration evaluations, psychoacoustic pretests have been conducted in a laboratory at the University of Oldenburg and during a real helicopter flight at an industrial partner of the BRITE-EURAM project. The laboratory pretests (N=12) were carried out with a so-called „sound and vibration reproduction system" (SVRS), developed at the Institute for Technical and Applied Physics (ITAP), to reproduce combined sound and vibration stimuli. Material and set-up of the pretests were rather similar to that of study 2 (chapter 6.4). Twelve subjects were exposed individually to three real aeroplane (Airbus) and six helicopter flight presentations given in different random orders. The duration of each situation was 25 seconds. The Airbus presentations included two typical cruising and one landing situation; the helicopter flights covered the cruising of three types of helicopters of different size (small: < 3000 kg, medium: > 5000 kg, and large > 10000 kg) at two cruising speeds (40 and 120 knots). Due to the lack of calibration tones the original sound and vibration levels could not be adjusted for these pretests. Therefore, the same L_{eq} of 80 dB(A) was generated for all presentations. At the beginning of the experiment the participants' seat posture was specified on the SVRS (chapter 6.4). Then, subjects were instructed by the experimenter who explained the different tasks required (Appendix I). In a warming-up session, each flight situation was presented 25 seconds in order to avoid „anchor" or „ceiling" effects. The subjects only had to „feel" and listen to the presentations. During the real helicopter flight with an A109 (Type I-CVMD, 1976 model) ten typical flight conditions (take-off, cruising at 40, 60, 80, 100, 120, 150 knots, stand still, landing) were judged by a sample of five psychoacoustic experts who were international partners involved in the BRITE-EURAM project. The field pretest was performed in English. At the beginning, the experts received a similar written instruction which was applied to the laboratory pretests. For both laboratory and field pretests the combined CIS-method (category scaling combined with the method of intermittent

and subsequent thinking aloud), according to Schulte-Fortkamp (1994, 1995, 1996), was employed: auditory and vibratory discomfort of each situation was rated by means of a six-point category scale ranging from „not uncomfortable“ to „extremely uncomfortable“ according to ISO 2631 (1997). Furthermore, subjects were asked to comment what was going through their minds in each flight situation. Finally, all participants were administered a narrative, semi-structured interview based on their discomfort evaluations and written comments. Subjects in the laboratory pretest were additionally inquired for problems regarding scaling discomfort.

Data analysis of the laboratory pretests showed:

1. The <u>mean</u> auditory discomfort evaluation ranged from 2.5 to 3.5; the <u>mean</u> vibratory discomfort assessment lied between 1.5 and 3.5. The standard deviation for sound and vibration judgements was approximately 1.0. Hence, sounds were judged to be more discomfortable than vibrations. Some subjects even reported that they found the vibrations reassuring in sense of a „massage effect". This was an valuable clue for the duration of the vibrations to be applied to the main experiments.
2. Regarding the auditory and vibratory discomfort, the Airbus presentations were evaluated to be one to two categories less discomfortable than the helicopters.
3. Most of the subjects described that they had no difficulties imagining a real flight situation under laboratory conditions, especially for the helicopter presentations. This was an important indication for the suitability of the SVRS concerning the simultaneous reproduction of combined sound and vibration stimuli in a laboratory setting.
4. Seven subjects had problems with scaling discomfort. They claimed imbalance between the number of discomfort categories (five) and the single comfort category („not uncomfortable“) and had difficulties rating a negative psychological state. Thus, data confirmed that assessments of subjective discomfort are limited to their application to vibro-acoustic comfort. For that reason, subsequent research was focused on the rating of comfort.

Data analysis of the field pretest revealed:

5. The <u>individual</u> auditory discomfort judgements ranged from 2.0 to 4.0; the <u>individual</u> vibratory discomfort evaluations were between 2.0 and 5.0. Accordingly, vibrations were rated more discomfortable than sounds.

Based on the examination of content of the comments written by the subjects and experts as well as semi-structured interviews, semantic descriptors related to aircraft interior sound and vibration were extracted to create two concept-specific SD:

(2) At first, a pool of 160 unipolar adjectives was generated. Then, a sample of nine

„experts" (three psychologists, physicists and pilots) was constituted to assess how „suitable" these attributes are for the evaluation of flight situations (see also Gabrielsson & Lindström, 1985; Kendall & Carterette, 1993; Schick, 1968) (Appendix II-1). For this purpose, a five-point category scale was used ranging from „very suitable" to „very unsuitable". Only qualities with a mean value $\geq$ 3.5 on the suitability scale were selected. This led to a pool of 80 items. According to the procedure of singular, controlled association proposed by Schäfer and Fuchs (1975), in the next step the experts associated appropriate opposites for the chosen features (Appendix II-2). Only adjectives were considered with at least 50% corresponding opposites. The outcome was an experts' SD consisting of 64 polarities. In order to validate this SD two further laboratory pretests were conducted by using the SVRS:

(3) In the first pretest a sample of 34 subjects judged a typical helicopter cruising situation (120 knots) which was presented for 2 minutes at a L_{eq} of 95 dB(A) and at a vibration level (acceleration level in dB re 10^{-6} m/s^2) of 106.5 dB. At the beginning of the experiment the participants' seat posture was specified on the SVRS (chapter 6.4) and instructions were given. The first task was to rate the flight situation by means of the experts' SD (Appendix III-1). The second task was to evaluate how „suitable" the qualities are for the assessment of flight situations by using the same scaling procedure also employed for the experts (Appendix III-2). The rating for suitability reduced the original set to 28 adjective pairs. Factor analysis (principal component analysis with varimax rotation) involving the remaining attributes derived four main factors or dimensions carrying about 60% of the total variance in the judgements. The first factor accounting for approximately 25% of the variance was interpreted as a combined loudness and vibration dimension. Polarities with high loadings on this factor were, for instance, „loud" vs. „quiet", „vibrating" vs. „not vibrating", and „palpable" vs. „impalpable". The second factor explaining about 20% of the observed variance represented aspects of comfort. The highest loadings here were, for example, „comfortable" vs. „uncomfortable", „bearable" vs. "unbearable", and „pleasant" vs. „unpleasant". The third and fourth factors accounted for approximately 8% of the variance. Factor 3 was labelled as an evaluative dimension related to specific sound characteristics. Its most distinctively loaded adjective pairs were „threatening" vs. „harmless", and „shrill" vs. „dull". The fourth factor showed high loadings for „well-sounding" vs. „ugly-sounding" and „strong" vs. „weak". Representative polarities were chosen with loadings of at least > .60 on each factor. At the end, a concept-specific SD designed for helicopter interior (sound and vibration) environments was established consisting of 15 adjective pairs.

(4) To prove the validity of the helicopter SD for the evaluation of aeroplane interior (sound and vibration) environments, a similar pretest was carried out with a sample of 26 subjects. Here, a typical airbus cruising situation was presented for 2 minutes. A L_{eq} of 68 dB(A) and a vibration level of 80 dB were generated. The assessment for the attributes' suitability using the five-point category scale decreased the original pool to 21 polarities. Application of factor analysis extracted four factors explaining about 65% of the observed variance. The first factor carrying about 30% of the variance was defined as a comfort dimension related to the intensity of interior sound and vibration. Qualities with high loadings were, for instance, „comfortable" vs. „uncomfortable", „threatening" vs. „harmless", „loud" vs. „quiet", and „shaking" vs. „calm". Factor 2 accounted for roughly 15% of the variance and was associated with aspects of comfort and sound. The most distinctively loaded adjective pairs were „acceptable" vs. „unacceptable", „muffled" vs. „not muffled", and „bearable" vs. „unbearable". The third and fourth factors each explained about 10% of the observed variance. The third factor was interpreted as a variation dimension. The highest loadings here were „monotonous" vs. „varied", and „regular" vs. „irregular". Factor 4 showed high loadings for the polarities „vibrating" vs. „not vibrating" and „high-frequency" vs. „low-frequency". Adjective pairs were selected with loadings of at least > .60 on each dimension. Finally, a concept-specific SD for aeroplane interior (sound and vibration) environments was derived containing 10 polarities.

Both helicopter and aeroplane SD cover semantic descriptors for the perception of interior sound and vibration, as well as for comfort and well-being: 15 adjective pairs regarding aeroplanes and 20 related to helicopters (Table 7). Five polarities are consistently related to the flight situations' „comfort" („comfortable" vs. „uncomfortable", „bearable" vs. „unbearable"), their evaluation („threatening" vs. „harmless"), and vibrations („shaking" vs. „calm", „vibrating" vs. „not vibrating"). The SD for helicopters integrates further adjectives regarding vibrations and movements („crumpled" vs. „smooth", „rotating" vs. „still", „palpable" vs. „impalpable", „strong" vs. „weak", „dangerous" vs. „safe"), the crowded situation inside („oppressing" vs. „liberating"), distinct sound properties („shrill" vs. „dull", „pushy" vs. „reserved"), and two individual comfort qualities („pleasant" vs. „unpleasant", „well-sounding" vs. „ugly-sounding"). The SD for aeroplanes has additional attributes concerning flight situations' monotony and regularity („monotonous" vs. „varied", „regular" vs. „irregular"), the specific sound characteristics („muffled" vs. „not muffled", „high-frequency" vs. „low-frequency"), and one particular comfort polarity („acceptable" vs. „unacceptable"). In order to compare the psychoacoustic parameters for the aircraft interior sound and vibration configurations to be calculated from the recorded signals with the subjective data, psychoacoustic descriptors for loudness, roughness, sharpness, tonality and fluctuation strength, according to Zwicker and Fastl (1999) and Zwicker (1999), have been integrated in both SD.

The SD for aeroplanes was applied to both studies described in the next sections. It was employed in the same language in which it was developed (German), ensuring semantic stability.

Table 7: Polarities of the semantic differentials for aeroplanes and helicopters

POLARITIES		HELI-COPTER	AERO-PLANE
bearable	unbearable	X	X
comfortable	uncomfortable	X	X
threatening	harmless	X	X
shaking	calm	X	X
vibrating	not vibrating	X	X
dangerous	safe	X	-
pleasant	unpleasant	X	-
oppressing	liberating	X	-
well-sounding	ugly-sounding	X	-
crumpled	smooth	X	-
rotating	still	X	-
strong	weak	X	-
shrill	dull	X	-
palpable	impalpable	X	-
pushy	reserved	X	-
muffled	not muffled	-	X
acceptable	unacceptable	-	X
regular	irregular	-	X
monotonous	varied	-	X
high-frequency	low-frequency	-	X
loud	quiet	X	X
rough	not rough	X	X
tonal	not tonal	X	X
unsteady	steady	X	X
sharp	not sharp	X	X
TOTAL		**20**	**15**

5.4 Method

Subjects. One-hundred-seventeen subjects participated in the experimental study, 37 being females and 80 males, aged from 19 to 61 years (mean = 28.97; median = 26.00). Most of the subjects were students and trainees working at the German aircraft company involved in the BRITE-EURAM project or employees of the company. Additionally, persons from outside the company were acquired by announcements in newspapers and by posters at different locations (universities, banks, tourist information). Subjects were naive to the experiment, and reported to have normal hearing. All were paid for participation.

Forty-one per cent of the participants flew yearly, 45.3 % seldomly flew, 6.8 % had never flown before. Seven per cent reported to fly more than once a year. The usual purpose of their flights was pleasure (76.9 %), the remaining subjects flew for business (11.1 %) or other reasons (11.9 %). Eighty-eight per cent of the sample flew by economy class, 12 % travelled by first class.

Design. The experimental design was a 2 (*aircraft types*) x 3, respectively 4 (*sound and vibration configurations*) factorial design (Table 8). Groups of subjects participated in two experimental runs, each involved the exposure to seven interior sound and vibration combinations simulating two aircraft types in cruise (jet and propeller aeroplane). For testing reliability all stimuli were presented twice. Every configuration was given for 120 seconds and rated on 15 adjective pairs of the SD for aeroplanes. For each experimental series participants were randomly assigned to one of 17 presentation orders. Both runs were separated by a 10 minute break. The total duration of the study was about 80 minutes, including the break.

Table 8: Schematic diagram of the experimental design

Factor A: Aircraft types						
Propeller			**Jet**			
Factor B: Sound and vibration configurations			**Factor B:** Sound and vibration configurations			
Prop. 1	Prop. 2	Prop. 3	Jet 1	Jet 2	Jet 3	Jet 4

Material and set-up. Seven combined interior sound and vibration configurations simulating jet aircraft (N=4) and propeller aircraft cruise flight (N=3) were presented to the subjects. Due to the presentation of (more or less) real aircraft cruising situations a high degree of ecological validity (extent to which a controlled laboratory investigation can be generalised to other - natural - settings), could be achieved. The experiments were performed in an aeroplane set-up, also called mock-up, situated in a unechoic hall. The mock-up was the fuselage of a DO328 without the cock-pit and the tail. The fuselage was hanging at the attachment points where the wings carry the real fuselage.

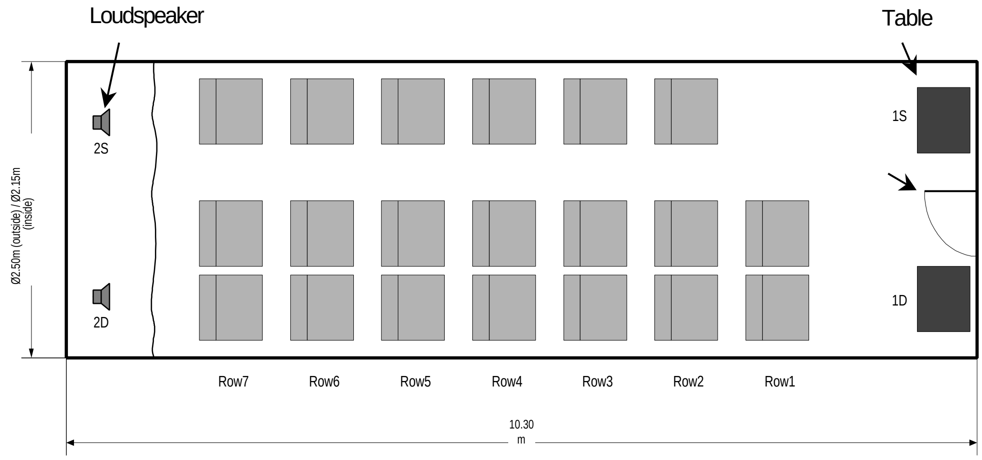


Figure 14: Arrangement of seats in the aeroplane (D0328) mock-up

The mock-up could be accessed via a wooden staircase in the front. The interior was completely furnished as in a real aircraft with luggage bins and carpet. The windows were covered with light blue sheets in order to prevent the participants from looking out outside into the laboratory hall. The cabin was equipped with 20 seats in a single/double seat arrangement (Figure 14) so that a maximum of 17 subjects could participate in the experiment at the same time. Three seats in the front were designated for the experimenter who was sitting in the cabin during the whole experiment in order to instruct the participants. Seat positions in the mock-up were grouped into sound and vibration fields based on cluster analyses of the spectra of both aircraft types measured at the subjects' ears. Four groups were found for both propeller and jet stimuli. It was assumed that persons sitting at seats of one cluster were exposed to the same vibro-acoustic field. At least 20 participants were subjected to the same vibro-acoustic cluster.

Several types of transducers at different locations at the fuselage were used for excitation of the sound field. The sound field in the interior was created from a loudspeaker ring located in the propeller plane of the cabin (propeller sound). For the realisation of the vibrations (mainly in z-axis) at the seats electrodynamic transducers were placed underneath the floor in front of the passenger seats.

For all seven configurations sound and vibration signals were recorded at each seat by using microphones hanging down from the ceiling in the height of the passengers head and accelerometers placed in the front of the seats at the floor. The measured data were employed for the calculation of acoustic, psychoacoustic and vibration parameters averaged over all seats (Table 9). Parameters were computed from the recorded time series with the analysis system BAS 4.0 (HEAD acoustics GmbH). Third octave band sound pressure levels (in dB re 2 x $10^{-5}N/m^2$) were determined according to ISO 532B (1975). Vibration levels (acceleration levels in dB re 10^{-6} m/s^2) were calculated from the frequency weighting Wk and energy summation of the recorded acceleration data in accordance to ISO 2631-1 (1997).

Table 9: Acoustic, psychoacoustic and vibration parameters of the aircraft interior sound and vibration configurations

Stimulus	**Level** [dB]	**Level** [dB(A)]	**Loud-ness** [sone]	**Rough-ness** [asper]	**Sharp-ness** [acum]	**Fluctuation-strength** [vacil]	**Tonality** [P/R]	**Vibration level** [dB re 10^{-6} m/s^2]
Propeller 1	95.71	81.91	58.24	2.48	2.30	4.17	7.13	85.68
Propeller 2	95.06	81.25	55.28	2.25	2.29	4.09	7.14	85.56
Propeller 3	94.85	81.06	54.85	2.25	2.29	4.09	7.12	85.25
Jet 1	86.88	76.72	41.82	1.88	2.36	3.93	7.36	80.82
Jet 2	87.31	76.05	39.99	1.60	2.22	3.96	7.26	80.85
Jet 3	88.11	76.82	42.15	1.77	2.25	3.99	7.22	81.08
Jet 4	87.35	77.54	43.91	2.03	2.36	4.09	7.33	80.92

Since it was shown that effects of whole-body vibration may change for durations from 1 to at least 4 minutes (chapter 1.6) and that vibrations of relative short duration (25 seconds) can have a reassuring „massage effect" which might influence their (comfort) evaluation (chapter 5.3), it was decided to present all stimuli for 120 seconds.
In order to avoid sequence effects, the presentations were randomised for each group of subjects in the two experimental runs. Accordingly, the signals used for generating the different configurations were recorded prior to the experiments and combined into different orders. Seven-teen random sequences of sound and vibration combinations were generated by a midi-controlled synthesiser set-up which produces order spectra related to original structure and airborne signals. The technical equipment for the simultaneous sound and vibration reproduction was controlled by a second experimenter sitting outside the mock-up.

Variables. The experimental variables were *aircraft types*, and *sound and vibration configurations*. The dependent variable was given by *evaluation* of sound and vibration combinations of two aircraft types by means of 15 bipolar adjectives of the SD, each enclosing seven categories. The assessments were employed to determine perceptual dimensions describing combined sound and vibration in aircraft. For each stimulus a randomised sequence of the attributes was applied. Configurations were announced as „flight situations". During the training an overview of the stimulus range was offered. After warming-up, participants spontaneously marked for each adjective pair the category they thought suitable for describing their perception of each sound and vibration combination.

Subjects' *subjective mood* was measured at three times using 46 standardised mood scales (monopolar 6-point adjectives) of the German „Eigenschaftswörterliste” (EWL) constituting the mood aspects „well-being" and „fear" (Janke & Debus, 1978).[8] At each time a randomised order of the mood scales was used. The EWL allows the measurement of subjective mood changes depending on environmental conditions. It was intended to analyse the influence of experimentally induced modifications of subjective mood on (comfort) evaluation of the stimuli in the sense of a situational or contextual moderator variable.

Procedure. One-hundred-seventeen subjects were exposed to two experimental runs both containing seven interior sound and vibration combinations simulating jet and propeller flight in cruise. Stimuli were presented in different random sequences per experimental series. Altogether, 17 series were carried out, each conducted with six persons on average. The study was performed in the native language of the subjects (German). Before the experiment started, participants were instructed by the experimenter in the mock-up to explain the different tasks required (Appendix V-1 and V-3). Then, the subjects' seat posture was defined. They were asked to sit in a comfortable upright posture with their back supported by the backrest and their feet on the floor throughout the experiment. Feet and thighs should be positioned horizontally and lower legs vertically. In order to avoid „anchor" or „ceiling” effects the participants were given practice in using the SD before experiment properly started (Appendix V-2). For this aim, all sound and vibration configurations were played briefly (15 seconds) and the subjects' task was to judge them by using the adjective pair „beautiful” vs. „ugly". After practising, participants were inquired to rate the stimuli on 15 qualities of the SD. Every configuration was presented for 120 seconds. Thirty seconds after the presentation's start participants were given a sign by the experimenter who held a sheet of paper with the corresponding number of the sound and vibration combination with which the evaluation began. After each stimulus a break of 60 seconds gave the subjects the opportunity to continue the rating. Between the first and second experimental run there was a 10 minute break during which the participants left the mock-up cabin. The pro-

[8] The mood aspect of „well-being" includes 24 adjectives of the subscales „elated mood“ and „self-confidence”. „Elated mood“ refers to a feature which is characterised by the absence of mood impairments (e.g., carefree, cheerful), hence it is pleasure-oriented and connected with euphoria (in the sense of pleasure). „Self-confidence“ represents primary the pleasure component of mood, and is closely related to efficiency, achievement-oriented activation and extraverted behaviour (extraversion). The mood aspect „fear” is constituted among the subscales „dreaminess“ and „depression“ by 22 attributes of the subscale „fearfulness“ which is closely related to the subscale „excitement”. „Fearfulness” concerns all sensational gradations of momentary fear. „Excitement” is characterised by motoric restlessness, strain, and emotional imbalance (emotional instability) connected with performance inefficiency (Appendix IV).

cedure of the second part was similar to the first, but it was done without further instruction and practice. For testing reliability the same configurations were given again in a randomised order which differed from the sequence of the first run. At the end, subjects answered questions of a qualitative questionnaire on general remarks to the experiment, the ecological validity of the presentations (measured on a six-point scale ranging from „not realistic" to „very realistic"), and willingness to participate again (Appendix VI).

Subjects' subjective mood was scaled by means of 46 mood scales of the EWL before the experiment took place, between the first and second run, and at the end.

The whole study took about 80 minutes, including the break between the two parts.

5.5 Results

5.5.1 Test-retest reliability

Test-retest reliability was determined by correlating the first and second evaluation of all sound and vibration stimuli using the SD. Pearson's product-moment correlation coefficients were $r = .958$ for propeller 1, $r = .956$ for propeller 2, $r = .971$ for propeller 3, $r = .963$ for jet 1, $r = .991$ for jet 2, $r = .979$ for jet 3, and $r = .970$ for jet 4. All coefficients were highly significant ($p < .01$). Results indicated that subjects were almost consistent in their assessment. Due to the high test-retest reliability the following analyses were focused on the SD data of the first experimental run.

5.5.2 Principal component analysis

The assessment of combined aircraft interior sound and vibration may establish a multidimensional, semantic space of perception which should be analysed in order to adjust aircrafts to the subjective comfort needs of passengers. Factor analysis (principal component analysis with varimax rotation) can be used to describe the nature of perceptual dimensions, i.e. the geometrical arrangement of the adjectives and stimuli that indicates their perceived similarity (or dissimilarity). In study 1, different factor analyses were performed on the correlations between the ratings for each polarity on:

(1) all seven sound and vibration configurations,

(2) the combinations of each aircraft type separately, and

(3) the propellers' and jets' mean evaluation.

Factor analyses generally resulted in three orthogonal factors or perceptual dimensions with eigenvalues larger than 1.0 (Kaiser criterion). These together accounted for about two thirds of the total variance in the data. Rotated component diagrams are given in Appendix VII-1 to VII-5. Table 10 presents the varimax rotated factor loadings related to the evaluation of all stimuli (factor analysis 1). At the bottom of Table 10 the percentage of explained variance is given for each factor. The rotated factors were represented by attributes of the SD listed in descending order of their loadings. The dimensions were interpreted by means of clustered adjectives loaded at least > .50 on each. The main factor (F1) carrying about one third of the variance in the assessments was labelled as a comfort dimension related to aircraft interior sound and vibration. One pole was characterised by terms such as „acceptable", „bearable", „comfortable" and „muffled”. The feature „muffled” was a particular item for the jets. It only loaded on the first dimension when the evaluation of the jets was regarded in the analysis (Appendix VII-2). The other side of the comfort dimension was associated with the qualities „loud”, „threatening”, „rough”, „sharp” and „vibrating”. The adjectives „vibrating”, „threatening”, and „sharp” were specific items for the propellers (Appendix VII-3). Attributes denoting aspects of variation loaded on the second dimension (F2). It was associated at one end with time characteristics of the stimuli like „monotonous" and „regular" and on the other side with vibration features such as „unsteady" and „shaking". The quality describing the tonal content of the configurations loaded on the third dimension (F3).

Table 10: Rotated factor matrix involving the evaluation of all stimuli (factor analysis 1)

	Component		
	F1 (37.7%)	F2 (13.3%)	F3 (7.3%)
acceptable	-,866	-,136	9,199E-02
bearable	-,851	-,144	8,891E-02
comfortable	-,848	-4,065E-02	-3,903E-03
loud	,814	-3,865E-02	,125
threatening	,645	,274	,162
muffled	-,641	-4,401E-02	-,297
rough	,602	,102	6,583E-02
sharp	,510	,222	,108
vibrating	,502	,317	,251
high frequency	-,351	,266	-,318
monotonous	5,970E-02	-,809	-6,480E-03
regular	-,162	-,787	-2,115E-02
unsteady	,203	,720	-8,604E-02
shaking	,500	,569	,197
tonal	3,053E-02	4,057E-02	,923

5.5.2.1 Interpretation of the perceptional dimensions

5.5.2.1.1 Correlation with physical parameters of the sound and vibration configurations

Physical correlates of the comfort and variation dimensions were analysed by selecting representative adjectives for both the propellers' and jets' evaluation with loadings > .70. The physical correlates of the tonality dimension were not examined because it explained less than 10 % of the variance in the data. Characteristic qualities of the comfort dimension were „acceptable", „bearable", „comfortable", and „loud"; the variation dimension was represented by „monotonous", „regular", and „unsteady". A similar rotation of the selected attributes was carried out because for almost all factor analysis procedures the solutions are subjected to rotation. Regarding the comfort dimension, the adjectives „acceptable“, „bearable", and „comfortable" were rotated to „unacceptable", „unbearable", and „uncomfortable"; related to the variation dimension „monotonous" and „regular" changed to „varied" and „irregular". It was postulated that persons may base the assessment of physically differing stimuli on specific evaluation strategies understood as individual „cognitive styles" (e.g., Riding 1997; Riding & Cheema, 1991; Riding & Rayner, 1997, 1998). Utilisation of factor analysis involving participants should cluster subjects having similar styles understood as „latent classes" or subpopulations of the sample (McAdams et al., 1995; McAdams & Winsberg, 2000). The outlined hypothesis will be illustrated by the following example. It is supposed that persons A, B, C, D, E, F and G judge seven sounds concerning comfort by means of an unipolar „comfort scale". Stimuli vary physically with regard to their „measured" loudness and sharpness (Table 11).

Table 11: „Measured" physical loudness and sharpness of the sounds G1 to G7

Sound	Loudness	Sharpness
G1	2	7
G2	2	3
G3	3	6
G4	3	5
G5	4	4
G6	4	2
G7	5	2

Each person may base his or her comfort rating on individual strategies involving specific weights associated with loudness (L) and sharpness (S):

A: L + 0.5 S
B: 0.5 L + S
C: L + S
D: 0.3 L + 0.7 S
E: 0.7 L + 0.3 S
F: 0.9 L + 0.1 S
G: 0.1 L + 0.9 S

Table 12: Comfort evaluation of the sounds G1 to G7

	G1	**G2**	**G3**	**G4**	**G5**	**G6**	**G7**
A	5.5	3.5	6.0	5.5	6.0	5.0	6.0
B	8.0	4.0	7.5	6.5	7.0	4.0	4.5
C	9.0	5.0	9.0	8.0	8.0	6.0	7.0
D	5.5	2.7	5.1	4.4	4.0	2.6	2.9
E	3.5	2.3	3.9	3.6	4.0	3.4	4.1
F	2.5	2.1	3.3	3.2	4.0	3.8	4.7
G	6.5	2.9	5.7	4.8	4.0	2.2	2.3

Results of assessment (Table 12) were subjected to factor analysis (varimax rotated principal component analysis) which yielded two orthogonal factors. Outcomes are shown in Figure 15.

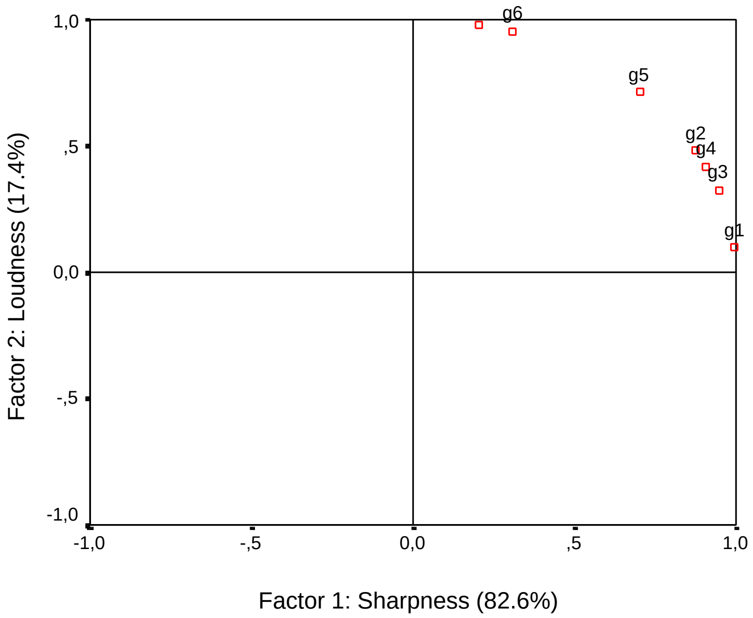


Figure 15: Rotated component diagram regarding comfort evaluation of the sounds G1 to G7

The first dimension represents sharpness, the second characterises loudness.
Analogous to the described example, factor analysis involving participants was applied to the comfort and variation dimensions in order to derive independent clusters of persons or „latent classes” using specific styles of evaluation with regard to physical varying stimuli. For both dimensions two latent classes were found. Groups of the comfort

dimension (GC1: N=62; GC2: N=28) accounted for roughly 50% of the total variance. Clusters of the variation dimension (GV1: N=38; GV2: N=17) carried about 30% of the variance (Figures 16 and 17).

In the next step, it was hypothesised that stimuli evaluated on representative adjectives of the comfort and variation dimensions according to individual strategies or styles should take particular values on the yielded groups of subjects. These values were labelled as „factor scores". The factor scores of all sound and vibration configurations on the characteristic attributes were correlated with acoustic, psychoacoustic and vibration parameters of the stimuli. Due to the small number (N= 3 or 4) of stimuli per aircraft type, correlation analysis was not conducted separately for each single type. Rather, it was performed together for all configurations of the jet and propeller but applied individually to the comfort and variation dimensions. Tables 13 and 14 depict the correlations between factor scores and physical descriptors. Pearson's correlation coefficients indicated that GC1 and GV2 homogeneously based their assessments on sound pressure level measured in dB, dB(A), vibration or acceleration level, as well as psychoacoustic parameters for loudness, roughness, fluctuation strength and tonality. Correlation coefficients were highly significant ($p < .01$) and ranged from $r = .635$ regarding fluctuation strength to $r = .966$ regarding dB. Most of the physical parameters were highly intercorrelated ($r > .950$). For instance, the correlation between the vibration level and dB was $r = .998$. Negative correlations were obtained only with regard to tonality. Concerning sharpness, coefficients did not reach significance at all.

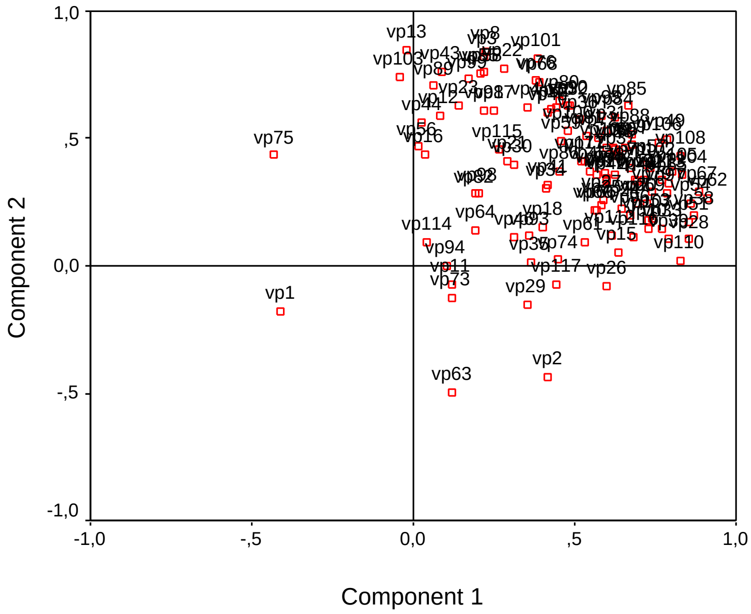


Figure 16: Comfort dimension: factor analysis involving subjects

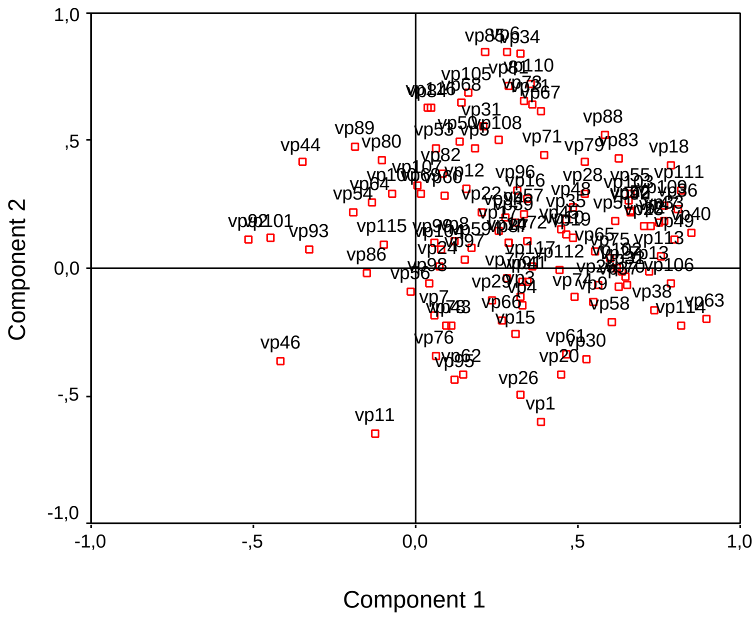


Figure 17: Variation dimension: factor analysis involving subjects

Table 13: Comfort dimension: correlation of factor scores with acoustic, psychoacoustic and vibration parameters

Correlations

		GC1	GC2	DB	DBA	LOUDNESS	ROUGHNESS	SHARPNESS	FL.STRENGTH	TONALITY	VIBRATION
GC1	Pearsons' Correlation	1,000	,000	,966**	,954**	,950**	,851**	-,045	,769**	-,884**	,965**
	Significance (2-tailed)	,	1,000	,000	,000	,000	,000	,820	,000	,000	,000
	N	28	28	28	28	28	28	28	28	28	28
GC2	Pearsons' Correlation	,000	1,000	,121	,150	,155	,201	,165	,135	-,029	,126
	Significance (2-tailed)	1,000	,	,539	,445	,430	,305	,400	,494	,884	,522
	N	28	28	28	28	28	28	28	28	28	28
DB	Pearsons' Correlation	,966**	,121	1,000	,982**	,984**	,878**	-,087	,792**	-,914**	,998**
	Significance (2-tailed)	,000	,539	,	,000	,000	,000	,661	,000	,000	,000
	N	28	28	28	28	28	28	28	28	28	28
DBA	Pearsons' Correlation	,954**	,150	,982**	1,000	,999**	,950**	,090	,858**	-,836**	,984**
	Significance (2-tailed)	,000	,445	,000	,	,000	,000	,650	,000	,000	,000
	N	28	28	28	28	28	28	28	28	28	28
LOUDNESS	Pearsons' Correlation	,950**	,155	,984**	,999**	1,000	,949**	,073	,857**	-,841**	,985**
	Significance (2-tailed)	,000	,430	,000	,000	,	,000	,710	,000	,000	,000
	N	28	28	28	28	28	28	28	28	28	28
ROUGHNESS	Pearsons' Correlation	,851**	,201	,878**	,950**	,949**	1,000	,355	,895**	-,651**	,884**
	Significance (2-tailed)	,000	,305	,000	,000	,000	,	,064	,000	,000	,000
	N	28	28	28	28	28	28	28	28	28	28
SHARPNESS	Pearsons' Correlation	-,045	,165	-,087	,090	,073	,355	1,000	,165	,448*	-,051
	Significance (2-tailed)	,820	,400	,661	,650	,710	,064	,	,400	,017	,795
	N	28	28	28	28	28	28	28	28	28	28
FL.STRENGTH	Pearsons' Correlation	,769**	,135	,792**	,858**	,857**	,895**	,165	1,000	-,664**	,781**
	Significance (2-tailed)	,000	,494	,000	,000	,000	,000	,400	,	,000	,000
	N	28	28	28	28	28	28	28	28	28	28
TONALITY	Pearsons' Correlation	-,884**	-,029	-,914**	-,836**	-,841**	-,651**	,448*	-,664**	1,000	-,893**
	Significance (2-tailed)	,000	,884	,000	,000	,000	,000	,017	,000	,	,000
	N	28	28	28	28	28	28	28	28	28	28
VIBRATION	Pearsons' Correlation	,965**	,126	,998**	,984**	,985**	,884**	-,051	,781**	-,893**	1,000
	Significance (2-tailed)	,000	,522	,000	,000	,000	,000	,795	,000	,000	,
	N	28	28	28	28	28	28	28	28	28	28

**. The correlation is at the 0,01 niveau (2-tailed) significant.

*. The correlation is at the 0,05 niveau (2-tailed) significant.

Table 14: Variation dimension: correlation of factor scores with acoustic, psychoacoustic and vibration parameters

Correlations

		GV1	GV2	DB	DBA	LOUDNESS	ROUGHNESS	SHARPNESS	FL.STRENGTH	TONALITY	VIBRATION
GV1	Pearsons' Correlation	1,000	,000	,027	,036	,037	,056	,036	,053	-,028	,022
	Significance (2-tailed)	,	1,000	,890	,856	,851	,778	,857	,791	,886	,911
	N	28	28	28	28	28	28	28	28	28	28
GV2	Pearsons' Correlation	,000	1,000	,900**	,870**	,868**	,737**	-,119	,635**	-,808**	,910**
	Significance (2-tailed)	1,000	,	,000	,000	,000	,000	,546	,000	,000	,000
	N	28	28	28	28	28	28	28	28	28	28
DB	Pearsons' Correlation	,027	,900**	1,000	,982**	,984**	,878**	-,087	,792**	-,914**	,998**
	Significance (2-tailed)	,890	,000	,	,000	,000	,000	,661	,000	,000	,000
	N	28	28	28	28	28	28	28	28	28	28
DBA	Pearsons' Correlation	,036	,870**	,982**	1,000	,999**	,950**	,090	,858**	-,836**	,984**
	Significance (2-tailed)	,856	,000	,000	,	,000	,000	,650	,000	,000	,000
	N	28	28	28	28	28	28	28	28	28	28
LOUDNESS	Pearsons' Correlation	,037	,868**	,984**	,999**	1,000	,949**	,073	,857**	-,841**	,985**
	Significance (2-tailed)	,851	,000	,000	,000	,	,000	,710	,000	,000	,000
	N	28	28	28	28	28	28	28	28	28	28
ROUGHNESS	Pearsons' Correlation	,056	,737**	,878**	,950**	,949**	1,000	,355	,895**	-,651**	,884**
	Significance (2-tailed)	,778	,000	,000	,000	,000	,	,064	,000	,000	,000
	N	28	28	28	28	28	28	28	28	28	28
SHARPNESS	Pearsons' Correlation	,036	-,119	-,087	,090	,073	,355	1,000	,165	,448*	-,051
	Significance (2-tailed)	,857	,546	,661	,650	,710	,064	,	,400	,017	,795
	N	28	28	28	28	28	28	28	28	28	28
FL.STRENGTH	Pearsons' Correlation	,053	,635**	,792**	,858**	,857**	,895**	,165	1,000	-,664**	,781**
	Significance (2-tailed)	,791	,000	,000	,000	,000	,000	,400	,	,000	,000
	N	28	28	28	28	28	28	28	28	28	28
TONALITY	Pearsons' Correlation	-,028	-,808**	-,914**	-,836**	-,841**	-,651**	,448*	-,664**	1,000	-,893**
	Significance (2-tailed)	,886	,000	,000	,000	,000	,000	,017	,000	,	,000
	N	28	28	28	28	28	28	28	28	28	28
VIBRATION	Pearsons' Correlation	,022	,910**	,998**	,984**	,985**	,884**	-,051	,781**	-,893**	1,000
	Significance (2-tailed)	,911	,000	,000	,000	,000	,000	,795	,000	,000	,
	N	28	28	28	28	28	28	28	28	28	28

**. The correlation is at the 0,01 niveau (2-tailed) significant.

*. The correlation is at the 0,05 niveau (2-tailed) significant.

5.5.2.1.2 Interpretation of the correlations

The interpretation of significant correlations between the latent classes GC1, respectively GV2 and physical parameters of the stimuli was based on:
(A) combined sound and vibration evaluation by using the SD, and
(B) mood scale analysis.
In the following, results related to the WHOLE sample have been preceded to the GROUP specific analyses of GC1 and GV2.

(A) COMBINED SOUND AND VIBRATION EVALUATION BY USING THE SD

(A1) Influence of vibro-acoustic clusters on evaluation regarding the WHOLE sample

Differences between the judgements due to the four vibro-acoustic clusters were tested by two 3-factorial (15 x 3, respectively 4 x 4) ANOVAs[9] applied separately to each aircraft type with one between-subjects factor (*vibro-acoustic clusters*) and two within-subjects factors (*adjectives of the SD*, *sound and vibration configurations*).
Findings indicated that *vibro-acoustic clusters* did not vary significantly with regard to the assessment of the propeller, $F(3;105) = .268$, $p < .848$, and the jet, $F(3;105) = 1.992$, $p < .120$. A significant interaction between *vibro-acoustic clusters* and both main factors was obtained neither concerning the propellers' $F(15.702;1648.668) = 1.255$, $p < .116$, nor the jets' evaluation $F(16.812;1765.306) = 1.290$, $p < .084$. *Sound and vibration configurations* and *vibro-acoustic clusters* did not interact significantly regarding the propeller, $F(1.975;207.427) = .916$, $p < .483$, and related to the jet, $F(2.858;300.039) = .920$, $p < .505$. As illustrated by the semantic profiles (Figures 18 and 19), no differences between judgements of the *sound and vibration configurations* WITHIN each aircraft type were found [propeller: $F(1.975;207.427) = .143$, $p < .865$; jet: $F(2.858;300.039) = 1.964$, $p < .123$]. Only the interaction between *adjectives of the SD* and *sound and vibration configurations* were highly significant [propeller: $F(15.702;1648.668) = 1.575$, $p < .028$; jet: $F(16.812;1765.306) = 2.533$, $p < .001$]. Altogether, it was concluded that the *vibro-acoustic clusters* did not systematically influence

[9] In the present research, all data were subjected to the GLM (General Linear Model) procedure for repeated measures analysis of variance (ANOVA) according to Greenhouse and Geisser (1958). Repeated measures designs involve, in addition to the assumptions of normality and homogeneity of variance, the requirement that the correlations among pairs of levels of the repeated variable should be homogenous. This is a rather stringent assumption and application of the Box-test (Winer, 1971) often reveals a violation of the requirement for a normal F-test. In order to compensate this, it is common to employ a conservative procedure proposed by Greenhouse and Geisser (1958). It involves a correction of the degrees of freedom by weighting them with the factor ε which is calculated from the variance-covariance matrix. The more the requirements are violated, the smaller ε will be which results in reduced degrees of freedom.

the assessment of combined aircraft interior *sound and vibration configurations* by using *adjectives of the SD*. Therefore, GROUP analyses of GC1 and GV2 was not carried out for each single cluster. Rather, all 17 seats of the mock-up have been taken into account.

(A2) Influence of personal characteristics on evaluation regarding the WHOLE sample

In most studies of the behavioural approach, it was reported that passengers' characteristics had <u>no</u> significant influence on comfort rating. In order to analyse the impact of subjects' personal attributes on judgement, a statistical comparison was made using 15 (*adjectives of the SD*) x 7 (*sound and vibration configurations*) within-subjects ANOVAs with *gender, educational qualification, current occupation, flight frequency, purpose of flights*, or *usual flight class* as different between-subjects factors and with *age* as a co-variate. Analysis of variance revealed no differences between assessments due to individual features (*gender*: $F(1;102) = 2.586$, $p < .111$; *educational qualification*: $F(2;101) = 1.116$ $p < .332$; *current occupation*: $F(2;97) = 1.426$, $p < .245$; *flight frequency*: $F(4;99) = 1.994$, $p < .101$; *purpose of the flights*: $F(2;95) = 1.033$, $p < .360$; *usual flight class*: $F(1;96) = .231$, $p < .632$; *age*: $F(1;102) = .946$, $p < .333$). In addition, significance of the interaction between all factors was not found, indicating that evaluation of the stimuli did not depend on subjective characteristics. Hence, GROUP analyses did not consider specific sociodemographic data of persons belonging to GC1 or GV2.

(A3) Evaluation differences between both aircraft types regarding the WHOLE sample

Due to the almost identical rating of combined sound and vibration configurations within each aircraft type, the „mean" judgement of each type was calculated by averaging the assessments on the 15 attributes of the SD for three, respectively four stimuli. Differences between the mean evaluation of the jet and the propeller were determined by a 2-factorial (15 x 2) within-subjects ANOVA with the factors *adjectives of the SD* and *aircraft types*. Results showed a highly significant interaction between both factors, $F(7.583;856.843) = 91.431$, $p < .0001$, suggesting that the aircrafts' mean rating differed from each other significantly. Application of T-tests proved significant differences ($p < .01$) on 12 of 15 qualities of the SD. As illustrated by the mean semantic profiles (Figure 20) the propeller generally gave a more negative impression than the jet. It was rather perceived as „shaking", „uncomfortable", „low frequent", „unbearable", „threatening", „unacceptable", „not muffled", „vibrating", „loud", „sharp", „rough", and „tonal" than the jet. The differences amount up to 1.5 scale points, for instance, for the adjectives „comfortable", „bearable", „acceptable", and, „loud". No significant differences were found with regard to the adjective pairs „monotonous” vs. „varied", „regular” vs. „irregular", and „unsteady” vs. „steady”. The mean assessment of the propeller ranged from 2.19 („loud”) to 5.33 („comfortable”) with standard deviations between .81 („loud”) and 1.33 („threatening”). The jet was evaluated between 2.62 („monotonous”) and 5.15 („unsteady”) with standard deviations ranging from 0.91 („shaking”) to 1.47 („acceptable”). Since propeller's and the jet's stimuli only differed significantly on average GROUP analyses related to GC1 and GV2 were focused on the mean judgement of both aircraft types using the SD.

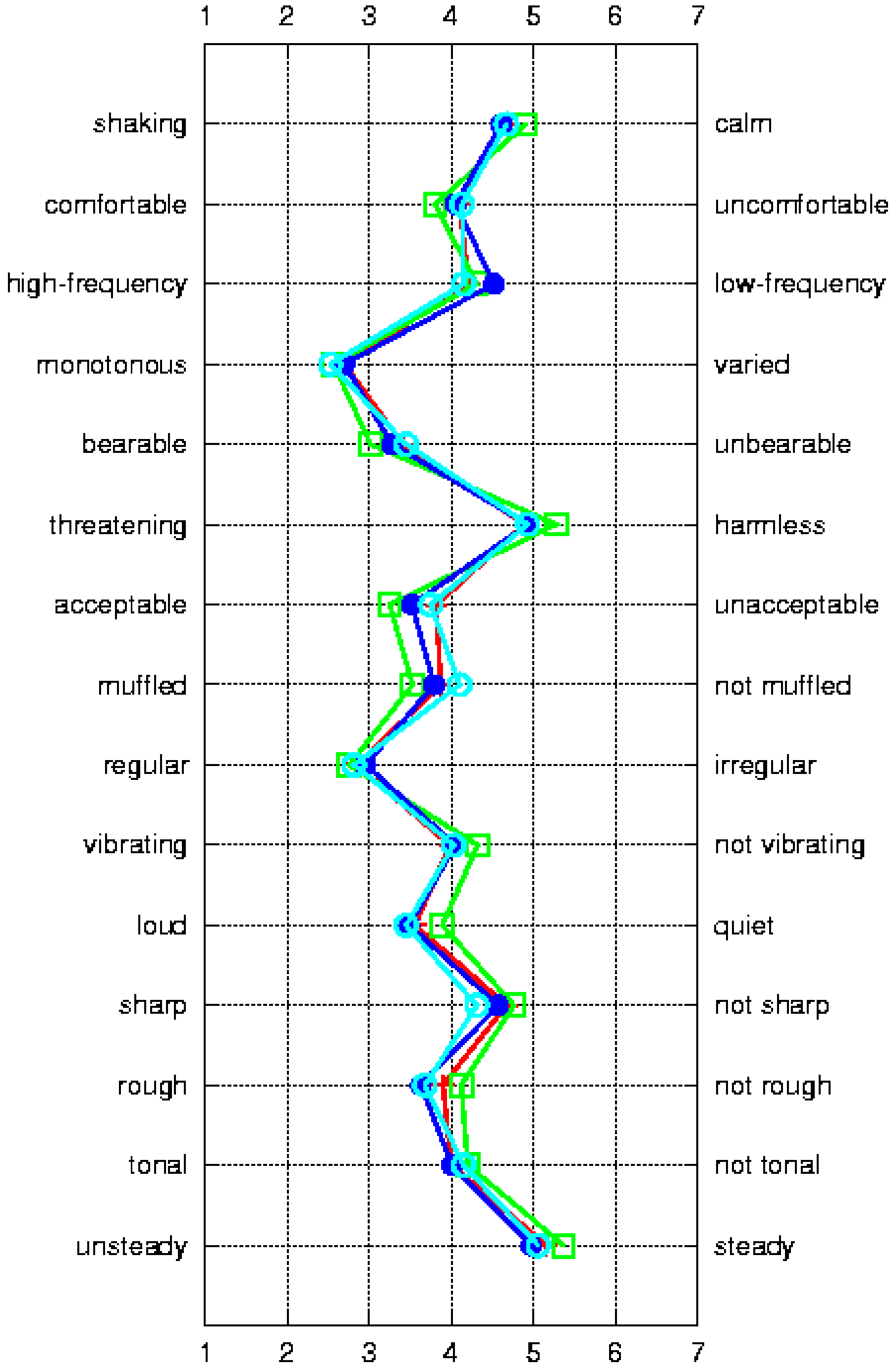


Figure 18: Semantic profiles of jet 1 (+), jet 2 (□), jet 3 (●) and jet 4 (○)

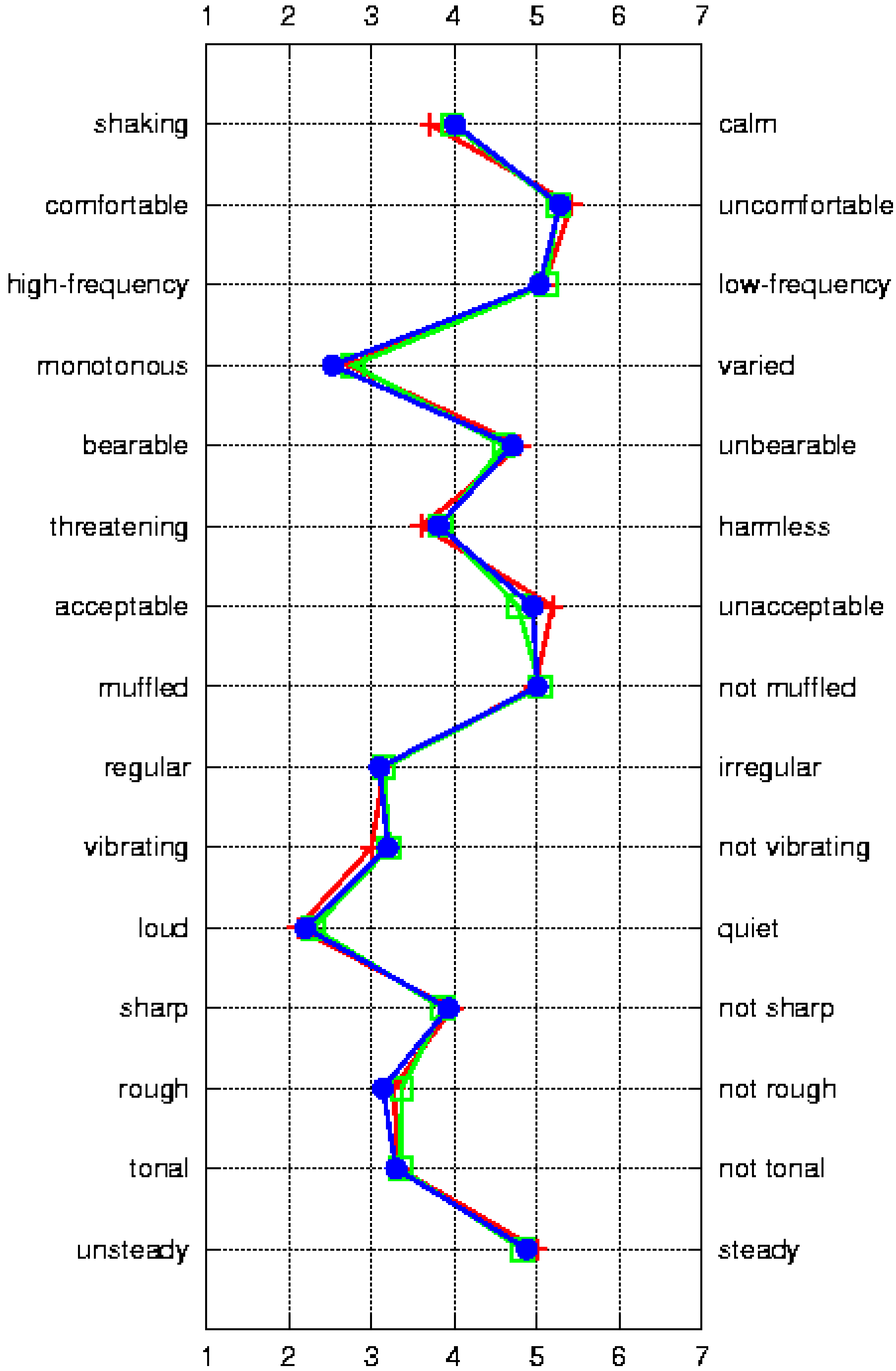


Figure 19: Semantic profiles of propeller 1 (+), propeller 2 (□), and propeller 3 (●)

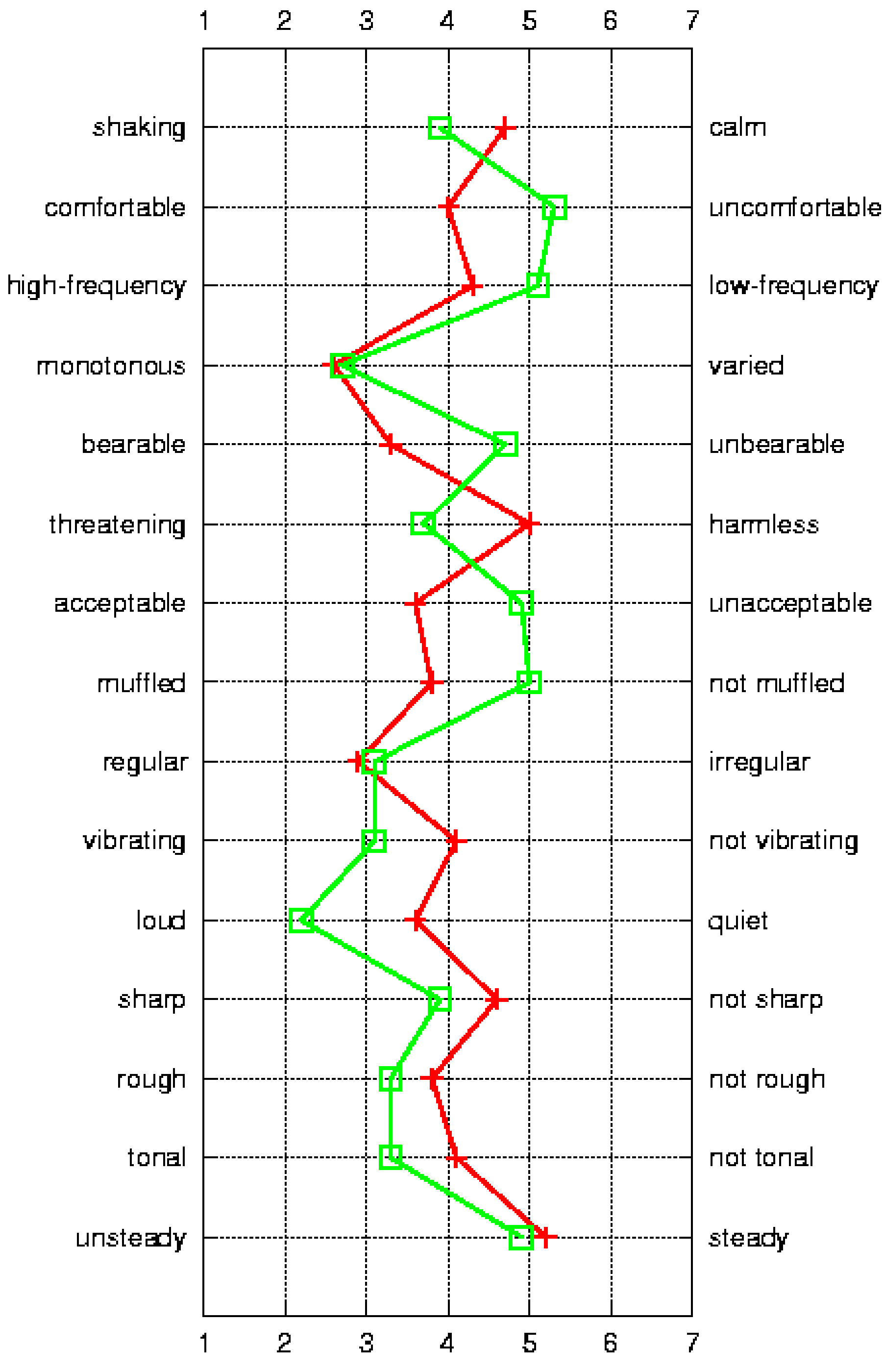


Figure 20: Mean semantic profiles of the aircraft types propeller (□) and jet (+)

(A4) Comfort dimension: GROUP analysis regarding evaluation differences

Concerning the comfort dimension, a 3-factorial (15 x 2 x 2) within-subjects ANOVA over the mean evaluation of the propeller and the jet was performed with *adjectives of the SD* and *aircraft types* as within-subjects factors and with *group* (latent class having a specific cognitive style) as the between-subjects factor. The *group* factor reached significance, F(1;87) = 6.361, p < .013. The interaction between *adjectives of the SD* and *aircraft types*, F(8.072;702.246) = 65.967, p < .0001, as well as between *adjectives of the SD* and *group*, F(5.091;442.955) = 10.308, p < .0001, were also significant. Significance of *aircraft types*, F(1;87) = .271, p < .604, and of the interaction between *aircraft types* and *group*, F(1;87) = .023, p < .880, was not found. More important for the present discussion, the interaction between all factors was significant, F(8.072;702.246) = 7.695, p < .0001. This meant that the judgement of both *aircraft types* was dependent on the affiliation to a specific *group* of subjects (latent class) using of a particular cognitive style. In order to analyse the particularities of GC1 and GC2 with regard to their evaluation strategy, T-test comparisons were performed. Data showed significant differences (p < .01) between both groups with regard to comfort and vibration qualities as well as certain sound attributes. Differences were clearer concerning the propeller (Figure 21). GC1 (N=62) perceived the propeller as being significantly more „shaking", „uncomfortable", „unbearable", „threatening", „unacceptable", „vibrating", and „unsteady" than GC2 (N=28). The assessments ranged from 2.05 („loud", GC1) to 5.69 („comfortable", GC1). Standard deviations lied between .69 („loud", GC2) and 1.36 („tonal", GC1). The jet was rated by GC1 as being significantly more „unbearable", „unacceptable", „irregular", „loud", „tonal", and „unsteady" than GC2 (Appendix VIII). Differences were up to 1.5 categories, particularly connected with the comfort attributes „comfortable", „bearable", and „acceptable". The ratings were between 2.33 („regular", GC2) and 5.56 („unsteady", GC2) with standard deviations ranging from .74 („regular", GC2) to 1.42 („tonal", GC2).

(A5) Variation dimension: GROUP analysis regarding evaluation differences

With regard to the variation dimension, a similar 3-factorial (15 x 2 x 2) ANOVA showed no significance of the between-subjects factor, F(1;50) = .688, p < .411, and of *aircraft types*, F(1;50) = 1.661, p < .203. *Adjectives of the SD* interacted significantly with *group*, F(5.298;264.907) = 3.330, p < .005, but the interaction between *aircraft types* and *group* was not significant, F(1;50) = 1.310, p < .258. However, *adjectives of the SD* and *aircraft types*, F(6.413;320.658) = 49.197, p < .0001, and all factors, F(6.413;320.658) = 4.889, p < .0001, interacted significantly, suggesting that aircraft types' evaluation was influenced by the between-subjects factor *group*. T-tests revealed significant differences ($p < .01$) between GV1 (N=38) and GV2 (N=17) concerning the assessment of vibration and sharpness qualities of the propeller. As illustrated by Figure 22 GV2 evaluated the propeller as being „varied", „irregular", „sharp", and „unsteady” rather than GV1. The judgements lied between 1.76 („loud”, GV2) and 5.86 („comfortable”, GV2) with standard deviations varying from .71 („loud”, GV1) to 1.46 („tonal”, GV1). Significant differences with regard to the jet's judgement were not found at all.

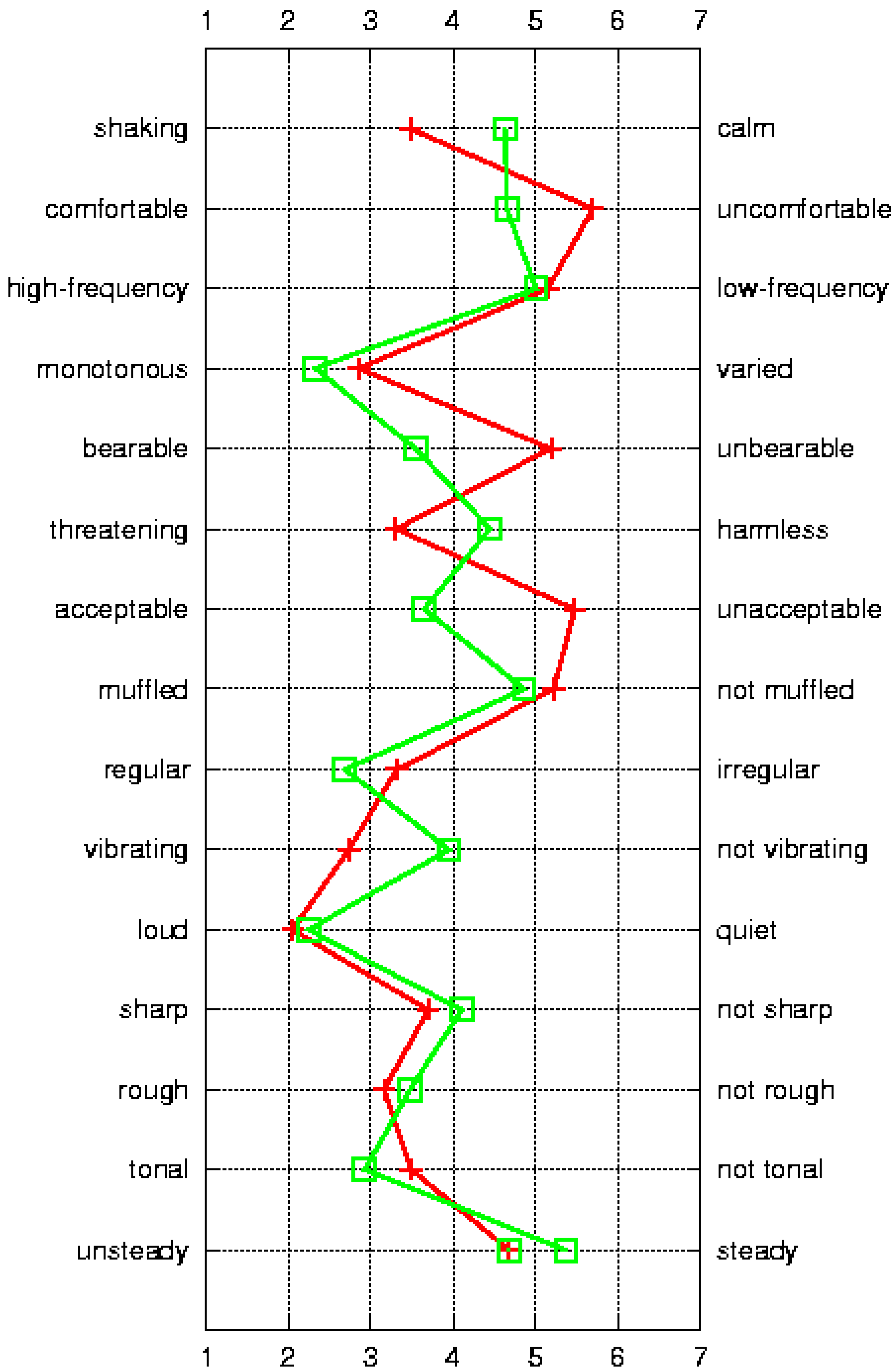


Figure 21: Comfort dimension: mean semantic profiles of the aircraft type propeller for GC1 (N=62; +) and GC2 (N=28; □)

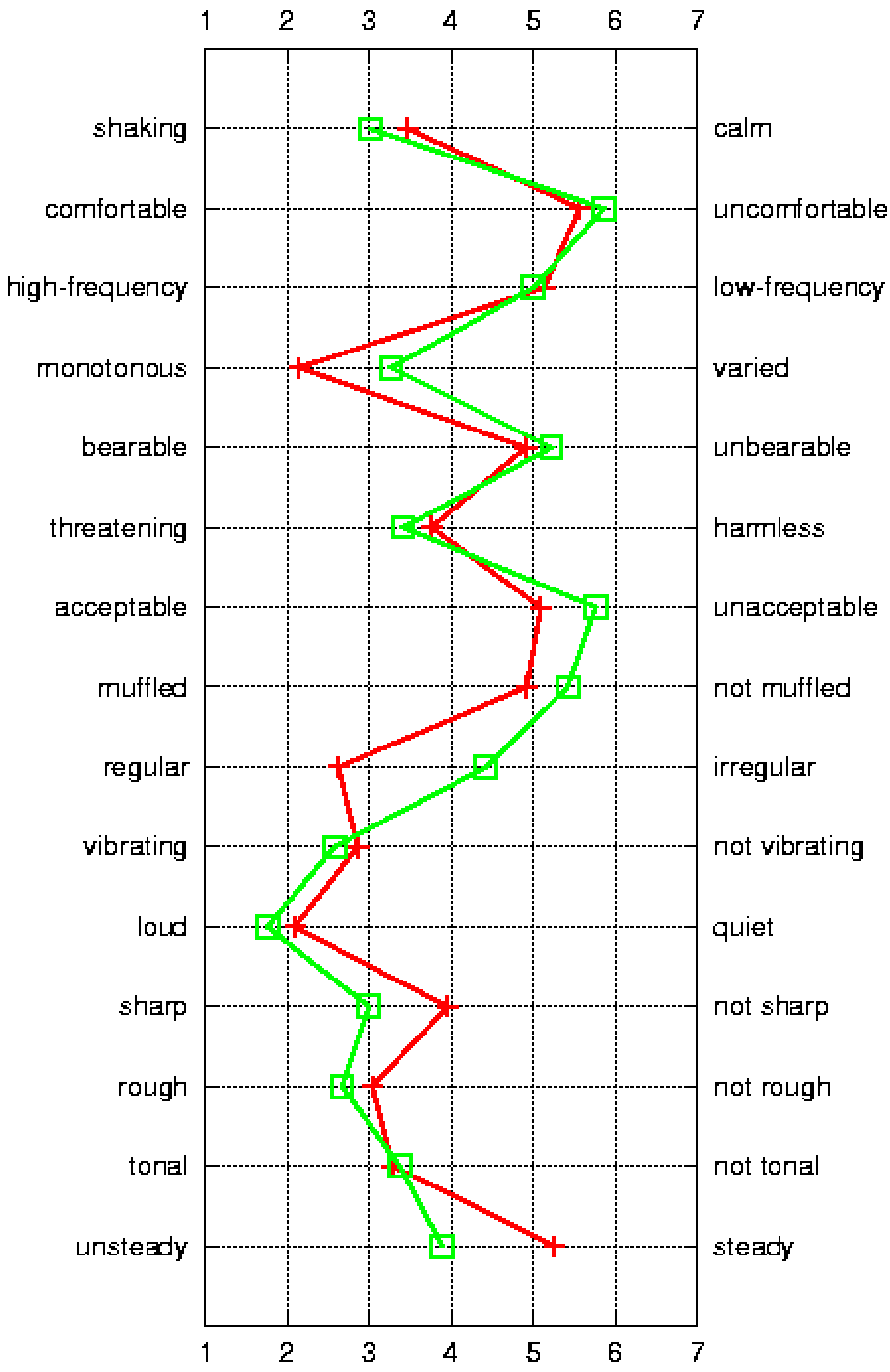


Figure 22: Variation dimension: mean semantic profiles of the aircraft type propeller for GV1 (N=38; +) and GV2 (N=17; □)

(B) MOOD SCALE ANALYSIS

The impact of experimentally induced changes of subjective mood on the (comfort) rating of combined aircraft interior sound and vibration was analysed by measurements of participants' subjective mood. For this purpose, 46 standardised mood scales of the EWL constituting the mood aspects „well-being" and „fear" (Janke & Debus, 1978) were employed at three times (T1-T3).

(B1) Reduction of the mood scales

The original set of 46 mood scales was reduced by factor analysis (principal component analysis with varimax rotation) and reliability analysis conducted at each of the three times of measurement (T1-T3). Applying the Kaiser criterion two dimensions were found which explained about 50% of the variance in the judgements. They were interpreted by means of adjectives loaded at least > .50 on each. The first dimension carrying 30% of the variance was related to 15 attributes describing positive mood aspects and was labelled as „well-being”. The second dimension accounted for 20% of the observed variance and was associated with 14 adjectives attached to negative mood aspects. It was characterised as „ill-being”. Data were in accordance with the presented two-components approaches of well-being (Bradburn, 1969; Bradburn & Caplovitz, 1965; Diener, 1984; Diener & Emmons; 1984; Diener et al., 1985; Headey et al., 1984) which consider well-being and ill-being as autonomous psychological dimensions. A reliability analysis was employed involving the representative mood scales of each mood dimension to select those adjectives with the most discriminative power (Cronbach's Alpha > .85). With regard to well-being, the attributes „content", „excellent", „in good spirits", „merry", „unhindered", were chosen. Concerning ill-being, the qualities „unsteady", „disorganised", „driven", „irritable", „unbalanced" were selected (Appendix IV). Mean values were calculated by averaging the ratings on the characteristic scales of well-being and ill-being at each measurement time.

(B2) Influence of experimentally induced changes of subjective mood on stimulus evaluation regarding the WHOLE sample

A 2-factorial (2 x 3) within-subjects ANOVA was carried out over the means of well-being and ill-being items tested at three times to examine if alterations of subjective mood have been caused by the experimental setting. *Subjective mood* (well-being and ill-being) and *times of measurement* were within-subjects factors. Data showed significant effects of *subjective mood*, $F(1;107) = 175.752$, $p < .0001$, and of *times of measurement*, $F(1.786;191.065) = 18.165$, $p < .0001$. The interaction between both factors also reached significance, F(1.492;159.627) = 38.637, p < .0001, suggesting that *subjective mood* depended on the *times of measurement*. Regarding well being, T-test comparisons accordingly indicated, that T1 and T2 as well as T1 and T3 differed significantly (p < .01). Furthermore, significant differences (p < .01) emerged between ill-being at T1 and T2 as well as at T2 and T3.

Difference scores with regard to well-being and ill-being between T1 and T2 were calculated, and a median split of the sample was conducted. The median of well-being was .60; the median of ill-being was -.20. It was postulated that subjective mood of persons with difference scores under the median was influenced less by the experimental setting (group 1) than subjective mood of persons with differences larger than the median (group 2). Since well-being and comfort represent closely related concepts (chapter 1.4), it was hypothesised that group 1 and group 2 should differ in the (comfort) assessment of the stimuli.

The impact of subjective mood changes on the mean judgement of each aircraft type was determined by two separate 2-factorial (15 x 2) ANOVAs applied to the mean propeller and mean jet rating with the within-subjects factor *mean evaluation* and the between-subjects factor *group* (according to the mediansplit of the sample regarding alterations in well-being and ill-being). Outcomes proved a significant effect of modifications in well-being on the *mean evaluation* of the propeller, F(1;108) = 4.897, p < .029, but no significant influence on the jet's *mean evaluation*, F(1;110) = .187, p < .666. Related to the changes in well-being, a highly significant interaction between propeller's *mean evaluation* and *group*, F(5.388;581.949) = 6.545, p < .0001, as well as between *group* and jet's *mean evaluation*, F(5.488;603.666) = 6.319, p < .0001, was found, indicating that judgements were dependent on experimentally evoked alterations in well-being. No significant differences emerged between more or less induced subjects regarding ill-being, [propeller: F(1;108) = .037, p < .849, and jet: F(1;110) = .050, p < .823]. The two-way interaction were not significant concerning the propeller's, F(5.030;543.291) = 2.630; p < .108, and jet's *mean evaluation*, F(5.051;555.561) = 1.117, p < .350. T-test applications to the median split of the sample regarding well-being implied that group 1 (N=68) and group 2 (N=45) differed significantly (p < .01) in rating on seven (for the propeller) and six (for the jet), respectively, out of 15 attributes of the SD. Group 2 judged the propeller as „unbearable", „threatening", „unacceptable", „loud", „sharp", „rough", and „unsteady" contrary to group 1 (Figure 23). Differences amount up to 1 scale point, especially for the comfort qualities „bearable", „threatening" and „acceptable". The evaluation of the propeller varied between 1.93 („loud", group 2) and 5.58 („comfortable", group 2) with standard deviations ranging from .77 („loud", group 1) to 1.41 („tonal", group 2). Subjects belonging to group 2 assessed the jet as being more „uncomfortable”, „unbearable", „threatening", „unacceptable", „loud", and „rough” than persons of group 1 (Figure 24). The jet was rated between 2.60 („monotonous”, group 2) and 5.29 („threatening”, group 1). Standard deviations lied between .83 („unsteady”, group 2) and 1.31 („tonal”, group 1).

Altogether, results of mood scale analysis involving the WHOLE sample confirmed that modifications of subjective mood (especially subjects' well-being) induced by the experimental setting influenced the comfort (and sound) evaluation of combined aircraft interior sound and vibration stimuli. Hence, GROUP analyses included the investigation of particularities of experimentally caused subjective mood changes in persons belonging to GC1 or GV2.

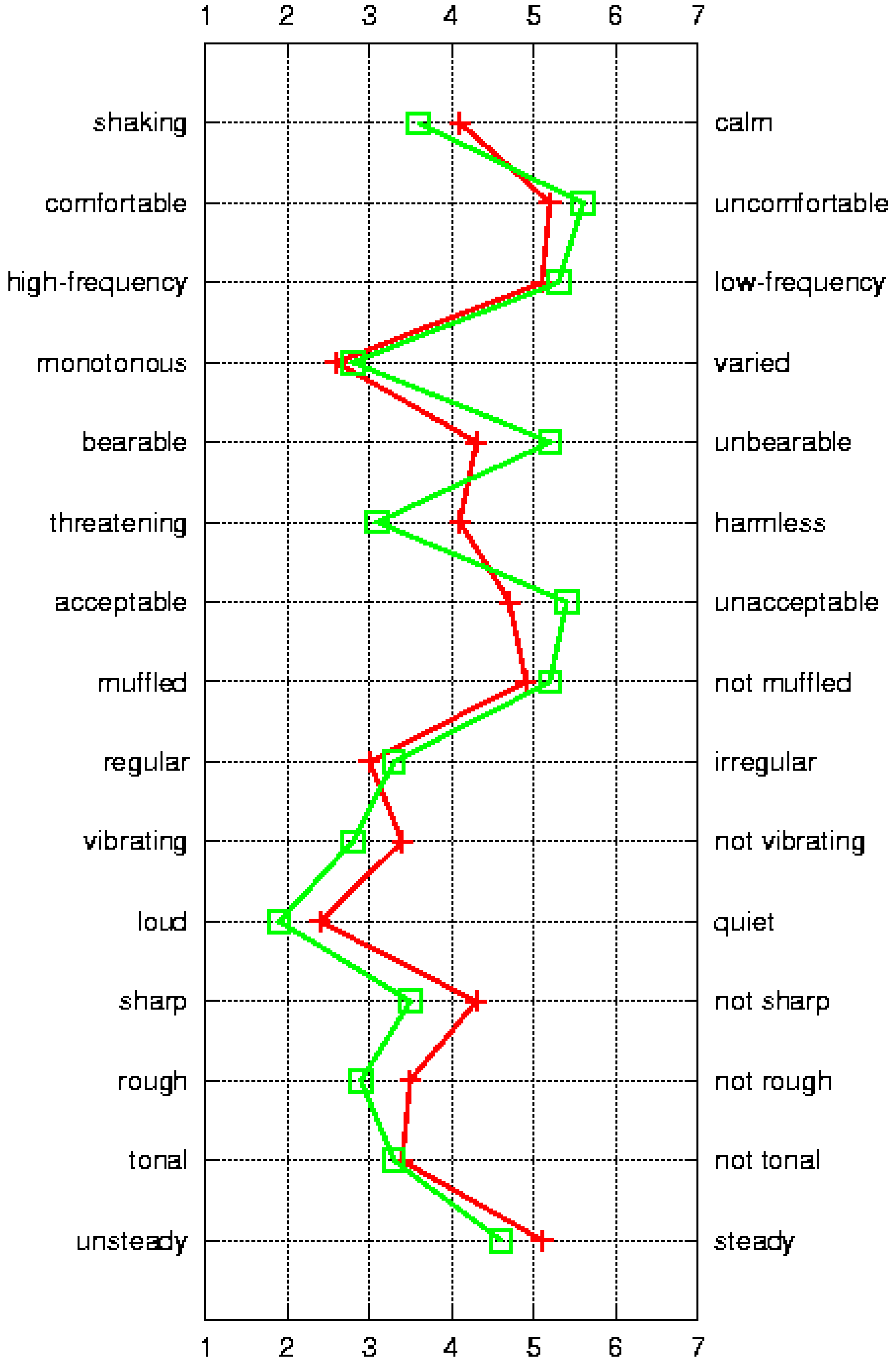


Figure 23: Influence of changes in well-being on the mean evaluation of the aircraft type propeller
(+ = Group 1 (N=68): less experimentally induced changes in well-being;
□ = Group 2 (N=45): more experimentally induced changes in well-being)

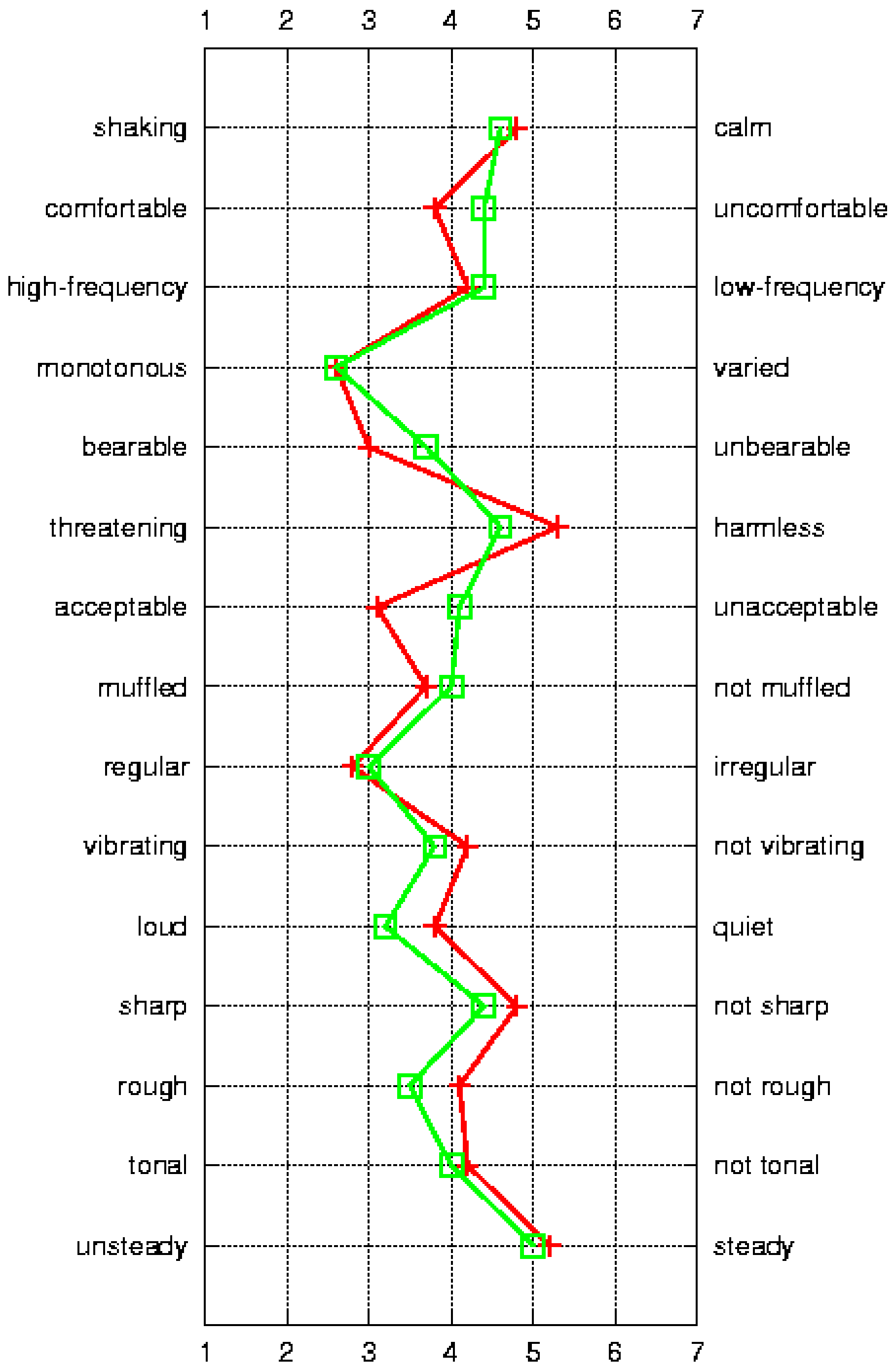


Figure 24: Influence of changes in well-being on the mean evaluation of the aircraft type jet
(+ = Group 1 (N=68): less experimentally induced changes in well-being;
□ = Group 2 (N=45): more experimentally induced changes in well-being)

(B3) Comfort dimension: GROUP analysis regarding differences of experimentally induced subjective mood changes

Differences between GC1 and GC2 regarding experimentally induced subjective mood changes were tested by a 3-factorial (2 x 3 x 2) ANOVA with *subjective mood* (well-being and ill-being) and *times of measurement* as within-subjects factors and with *group* (latent class using a specific cognitive style) as the between-subjects factor. No significant *group* differences with regard to *subjective mood*, $F(1;83) = .021$, $p < .885$, appeared. Only *subjective mood*, $F(1;83) = 132.822$, $p < .0001$, *times of measurement*, $F(1.760;146.079) = 9.563$, $p < .0001$, and their interaction, $F(1.412;117.156) = 18.087$, $p < .0001$, were significant, suggesting that *subjective mood* depended on the *times of measurement*. The two-way interaction between *group* and *subjective mood*, $F(1;83) = 1.340$, $p < .250$, between *group* and *times of measurement*, $F(1.760;146.079) = .058$, $p < .925$, as well as the interaction between all factors, $F(1.412;117.156) = 1.963$, $p < .158$, did not reach significance. Results implied that modifications of *subjective mood* were not determined by the between-subjects factor *group*. T-test comparisons confirmed that differences between GC1 and GC2 regarding well-being and ill-being were not significant. T-tests carried out WITHIN each group only demonstrated significant differences (GC1: $p < .01$; GC2: $p < .02$) between well-being at T1 and T2 as well as at T1 and T3. Only ill-being of GC1 moved significantly ($p < .01$) from T1 to T2 (Figures 25 and 26).

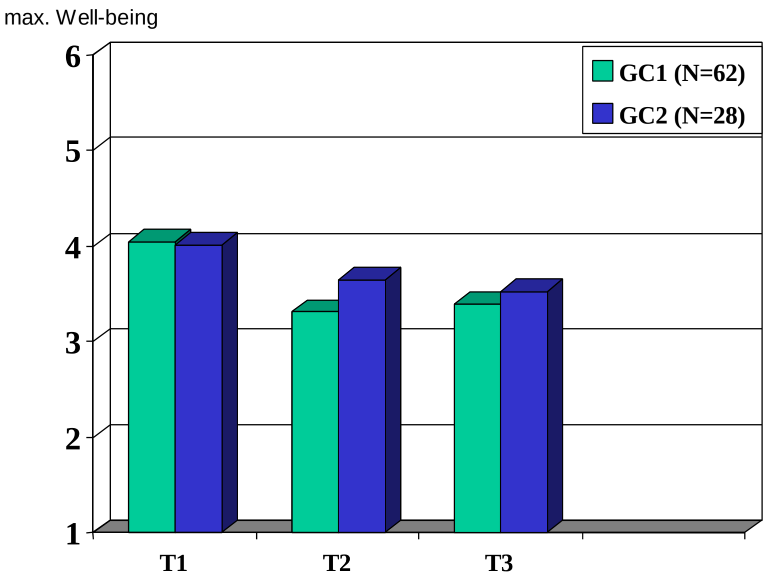


Figure 25: Comfort dimension: well-being (EWL) of GC1 and GC2 at three times of measurement

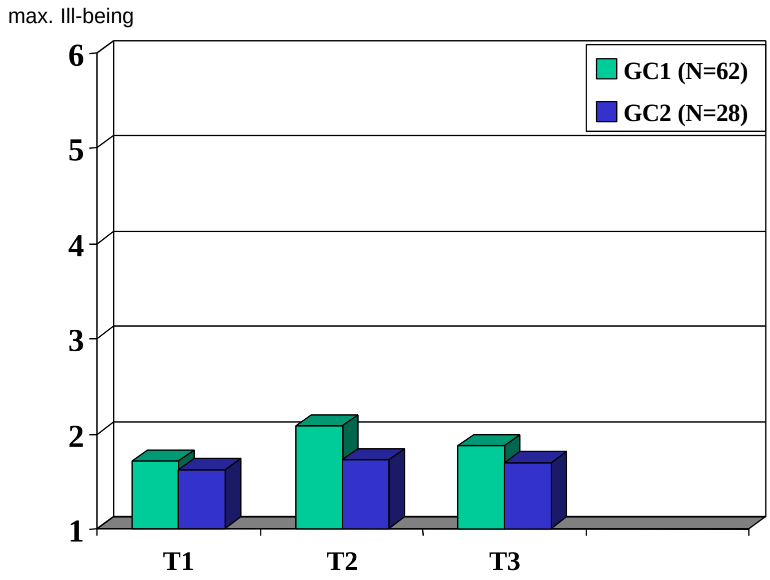


Figure 26: Comfort dimension: ill-being (EWL) of GC1 and GC2 at three times of measurement

(B4) Variation dimension: GROUP analysis regarding differences of experimentally induced subjective mood changes

A similar analysis of variance proved no effect of the between-subjects factor *group*, $F(1,48) = 1.975$, $p < .166$, concerning *subjective mood* (well-being and ill-being). Only *subjective mood*, $F(1;48) = 47.517$, $p < .0001$, *times of measurement*, $F(1.941;93.150) = 13.539$, $p < .0001$, and their interaction were significant, $F(1.480;71.022) = 28.956$, $p < .0001$, indicating that *subjective mood* was dependent on the *times of measurement*. However, significance of the interaction between *group* and *subjective mood*, $F(1;48) = .350$, $p < .557$, between *group* and *times of measurement*, $F(1.941;93.150) = 1.886$, $p < .159$, and of the three-way interaction, $F(1.480;71.022) = 2.259$, $p < .126$, did not appear, suggesting that changes of *subjective mood* were not influenced by the *group* factor. T-test applications revealed significant differences ($p < .05$) between both groups' well-being at T2 and T3. WITHIN each group well-being differed significantly ($p < .01$) between T1 and T2 as well as T1 and T3. Ill-being changed significantly (GV1: $p < .05$; GV2: $p < .01$) from T1 to T2 (Figures 27 and 28).

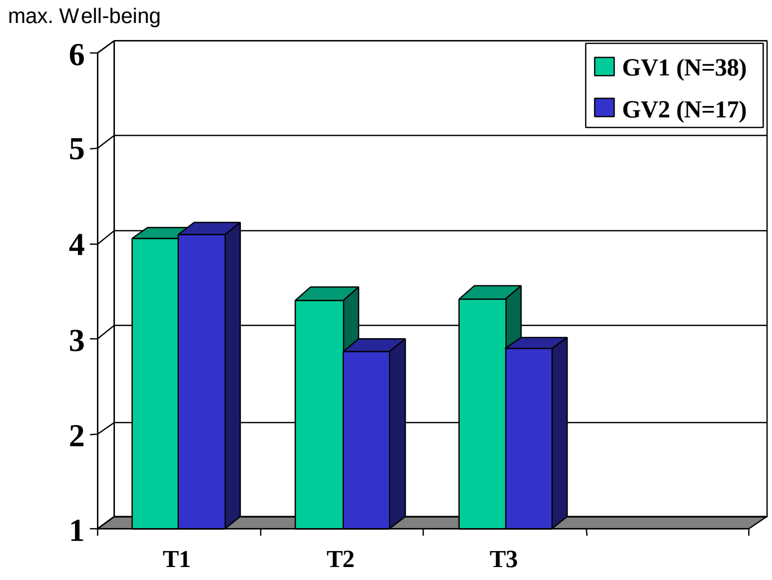


Figure 27: Variation dimension: well-being (EWL) of GV1 and GV2 at three times of measurement

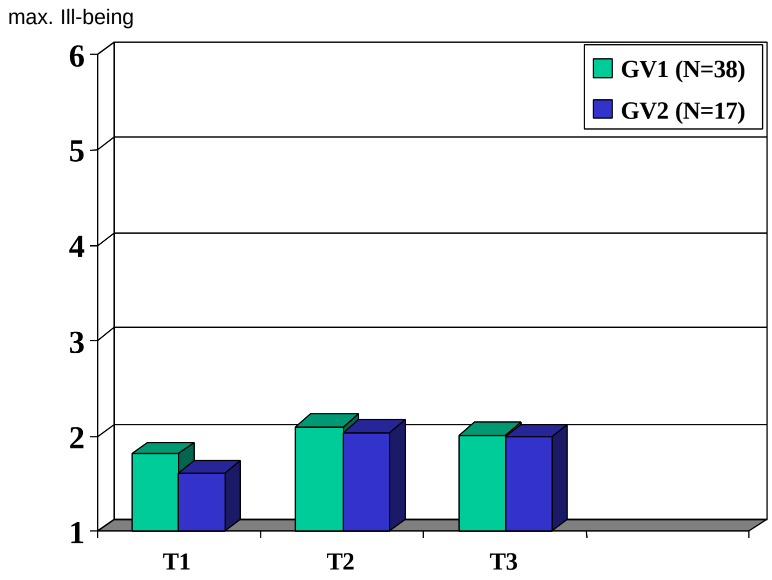


Figure 28: Variation dimension: ill-being (EWL) of GV1 and GV2 at three times of measurement

5.5.3 Qualitative questionnaire analysis

Comments of the subjects on what they <u>dis</u>liked and general remarks to the experiment were divided into the following three categories:

(1) Psychophysical conditions in the mock-up cabin

Subjects mainly claimed the bad air (18 namings), the warmth (9 namings), the uncomfortable seats, respectively, seat positions (3 namings), and the duration of the experiment leading to monotony, boredom, concentration or habituation problems and a so-called „over-exertion" of the ear (12 namings). Three participants perceived a deviation of the laboratory situation from real flight situations which was mainly due to the task of focusing attention to the stimuli.

(2) Characteristics of the presented sound and vibration configurations

Twelve persons remarked the loudness as being too high. From their viewpoint, nine participants found the stimuli rather similar. Four subjects noted failing reality of the presentations due to the high loudness and decreased vibration magnitude. Two persons, on the other hand, emphasised the lifelike atmosphere. On average, the ecological validity of the presentations was rated at 3.82 (median: 4.0; modus: 4.0).

(3) Problems with the questionnaire

Concerning attributes of the SD, only three subjects claimed that the meaning of adjectives were nearly identical and that some polarities were partly not understandable. Unfortunately, qualities which caused problems were not specified. One person reported that the adjective pair „harmless” vs. „threatening” was not applicable to the laboratory situation. Two participants did not understand the meaning of „sharp" in an acoustical sense.

With regard to the EWL, three subjects had difficulties in describing their subjective mood by using adjectives. Attributes were partly unintelligible but they were not named in detail.

102 persons (87.2% of the sample) pointed out a willingness to participate again in such an experiment.

5.6 Discussion

Study 1 focused on the affective components of comfort sensation in aircraft; that is, how individuals react and affectively rate physically differing sound and vibration stimuli. Seven combined interior sound and vibration configurations simulating jet aircraft (N=4) and propeller aircraft cruise flight (N=3) were presented in a so-called mock-up and evaluated by means of 15 polarities of a SD. Results indicated that stimuli gave rise to affective evaluations in terms of the fundamental perceptual dimensions of comfort, variation and tonality. Together, they accounted for about two thirds of the total variance in the data. The established dimensions were in accordance with the factors which have been steadily extracted in psychoacoustic research. They also confirmed the classical EPA structure as a universal semantic feature of language (Osgood et al., 1975; Schick, 1995a, 1996a). The comfort dimension corresponded to a combined evaluation and potency factor denoting aesthetic-evaluative comfort aspects on the one side („comfortable“, „bearable", „acceptable", „muffled”), and power or magnitude (of sound and vibration) on the other („loud”, „threatening”, „rough”, „sharp”, „vibrating”). The attribute „muffled” which emerged in the factor analysis only related to the jet's configurations. This meant that the jets seemed to have a „muffled” character which contributed to comfort sensation. The adjectives „vibrating”, „threatening”, and „sharp” were specific for the propeller's combinations. Generally, the propellers have been assessed to be more „vibrating” and „threatening”, respectively less „comfortable”, than the jets. This is accordance with the physical description of the stimuli. However, the physical sharpness of the propellers was less than the jets’ even though the quality „sharp” only appeared related to the propellers’ judgement. With respect to this finding, a possible explanation is that the subjects may have had problems with this attribute. This was, for example, reported explicitly by two subjects in the qualitative questionnaire interview. The variation dimension can be interpreted as indicating activity related to time characteristics at one end („monotonous”, „regular”) and further vibration properties at the other („unsteady”, „shaking”). The tonality dimension proved that the EPA structure does not generally exhaust the dimensions along which meaningful ratings can be distinguished (Quehl, 1997, 1999; Schäfer, 1983; Schäfer & Fuchs, 1975; Schick, 1979). Rather, indications show that the meaning of dimensions may vary with the kinds of concept being assessed, i.e., with the frame of reference of evaluation. For instance, Bisping (1995) and Chouard and Hempel (1999) found that in addition to an aesthetic-evaluative and a potency dimension, interior car sound can be described by perceptual dimensions such as pitch, sonority and impulsiveness. The authors believed this also holds true for aircraft interior sound.

In the present study, comfort appeared to represent a continuous, bipolar dimension of experience varying from strongly positive (very comfortable) to strongly negative (very discomfortable). This bipolarity may be due to the involvement of affective evaluation; comfort has been felt or vice versa (Richards, 1980). The sensation of discomfort mainly referred to particular sound properties such as perceived loudness or roughness as well as specific vibration features like „vibrating", all denoting the intensity of sound and vibration perception. Accordingly, persons clearly connected loudness with vibration magnitude in the perceptional space. The sensation of combined auditory and vibratory (vibro-acoustic) comfort, on the other hand, was characterised by the applicable semantic attributes „comfortable", „bearable" and „acceptable". They denoted a similar quality representing vibro-acoustic comfort in the three-dimensional, semantic space of perception in which the judgements were made. As a dimension of semantic space, vibro-acoustic comfort corresponded to the reviewed lexical, ergonomic, psychological and everyday comfort (and well-being) definitions and theories (e.g., Becker, 1991; Metzger, 1994; Pineau, 1982; Slater, 1985, Zhang et al., 1996). Comfort was commonly defined as a psychological state of subjective well-being (in the sense of relaxation, pleasantness, ease, satisfaction, convenience, or physical freedom of complaints) induced under optimal conditions; its opposite given by a state of subjective discomfort, stress or pain.

Findings suggested the comfort and variation dimensions significantly correlated with objective descriptions of sound and vibration in terms of acoustic, psychoacoustic and vibration parameters. Factor analysis involving subjects derived for both dimensions two independent clusters of persons („latent classes" according to McAdams et al., 1995; McAdams & Winsberg, 2000) each employing particular evaluation strategies or cognitive styles (e.g., Riding 1997; Riding & Cheema, 1991; Riding & Rayner, 1997, 1998) with regard to representative adjectives (loadings > .70). Factor scores (related to the yielded latent classes) of all stimuli (propellers and jets) were correlated with physical descriptors. It was shown that group 1 of the comfort dimension (GC1) and group 2 of the variation dimension (GV2) homogeneously based their assessment of representative qualities on perceived sound pressure level [in dB, dB(A)], loudness, roughness, fluctuation strength, tonality and vibration magnitude. Almost all correlation coefficients were highly significant ($p < .01$). Besides, most of the physical parameters were highly intercorrelated ($r > .950$) which was due to the physical interdependence of sound pressure level, loudness, roughness, fluctuation strength and vibration level. Altogether, results implied that an increase in sound pressure level, respectively loudness, roughness, fluctuation strength or vibration magnitude induced a subjective decrease in comfort. Negative correlations between tonality and other physical descriptors confirmed that the loudest, roughest, most fluctuating and vibrating stimuli (propeller) were the least tonal.

The interpretation of significant correlations between the latent classes GC1, respectively GV2 and physical descriptions of sound and vibration was based on (a) combined sound and vibration evaluation using the SD, and (b) mood scale analysis (EWL). Sociodemographic information of persons belonging to GC1 and GV2 have not been taken into account since the rating of the stimuli did not appear to be dependent on subjective characteristics. As far as the four vibro-acoustic clusters did not systematically influence the judgement, the study considered all 17 seats of the mock-up. Furthermore, examination focused on the mean evaluation of both aircraft types since both the propeller's and the jet's configurations only differed significantly on average.

(a) Analysis of variance of the SD data proved significant assessment differences between the subject clusters. GC1 evaluated the propeller and jet as being significantly more uncomfortable, vibrating and louder than GC2. GV2 rated the propeller as being more vibrating and sharp than GV1.

(b) Since affective reactions to vehicle environments represent an integral component of the perceived comfort, and both comfort and well-being are closely related concepts, present research assumed that changes of subjective mood (especially subjects' well-being) induced by an experimental setting may influence the comfort rating understood as an intervening or moderating variable (situational, respectively contextual moderator) (Bisping et al., 1990; Blauert & Jekosch, 1997; Evans & Lepore, 1997; Guski, 1997a; Quehl et al., 2000d). Subjective mood was tested at three times (T1-T3) using 46 standardised mood scales of the EWL constituting the mood aspects „well-being" and „fear" (Janke & Debus, 1978). Factor and reliability analysis derived the two orthogonal mood dimensions „well-being" and „ill-being" (Bradburn, 1969; Bradburn & Caplovitz, 1965; Diener, 1984; Diener & Emmons, 1984; Diener et al., 1985; Headey et al., 1984) each represented by five scales. Mood scale analysis involving these dimensions revealed that the experimentally caused changes of subjective mood did not differ significantly between the clusters. However on closer inspection, well-being and ill-being WITHIN each cluster appeared to change more clearly (well-being decreased, ill-being increased) for GC1 and GV2 than for GC2 and GV1 from T1 to T2. As far as both changes in well-being and ill-being of GC1 and GV2 were „worse" than those of GC2 and GV1, it was concluded that the former judged the stimuli significantly more negative with regard to comfort, sound and vibration qualities than the latter. Differences in reaction intensity or susceptibility in terms of induced modifications in well-being may be due to individual variations of experimental reactivity (Strelau, 1970, 1974, 1982, 1983, 1987, 1989, 1991, 1993, 1995, 1999) or general sensitivity to react to ambient „environmental stressors" such as sound and vibration (Höger, 2000; Weinstein, 1980; Winneke et al., 1992, 1996). In other words, persons who were more susceptible to the experimental setting (due to their individual reactivity or sensitivity) experienced stronger alterations in well-being. As long as well-being and comfort sensation are interdependent, significant evaluation differences regarding comfort, sound and vibration attributes of the stimuli resulted.

Data concerning GC1 and GV2 were rather similar because 12 participants of GV2 (70 %) also belonged to GC1.

All in all, results indicated that affective evaluations of combined aircraft interior sound and vibration can be described in terms of the orthogonal perceptional dimensions of comfort, variation and tonality. Comfort appeared to represent a psychological state of subjective well-being; its opposite given by attributes describing the intensity of sound and vibration perception. Factor analysis involving subjects derived two independent „latent classes" each employing particular cognitive styles with regard to representative attributes of the comfort and variation dimensions. Factor scores (related to the latent classes) of all stimuli were correlated with physical descriptors. It was found that participants who were more susceptible to the experimental setting (in terms of induced changes in well-being) homogeneously based their judgements on perceived sound pressure level, loudness, roughness, fluctuation strength, tonality and vibration magnitude. The stronger reaction intensity or susceptibility of these subjects was explained in terms of individual variations of experimental reactivity or general sensitivity to respond to ambient „environmental stressors". Due to the significant intercorrelation of the physical parameters it was not possible to estimate their individual portion regarding the comfort and variation dimensions. In order determine the interaction between sound and vibration level and their specific contribution to affective evaluations on the perceptional dimensions (especially of comfort), a laboratory study was performed. Findings are reported in the next chapters.

STUDY 2: ***Interaction between sound and vibration level regarding the comfort evaluation of aircraft interior stimulus configurations***

Study 2 was conducted to specify the interaction between sound and vibration level and their relative contribution to affective evaluations on the perceptional dimension of (vibro-acoustic) comfort. Since comfort may be viewed as a continuous, bipolar dimension of experience ranging from extreme comfort and well-being to extreme discomfort, stress and pain, concepts of environmental stress research (Cohen, Evans, Stokols & Krantz, 1986) have been used to interpret the interactive effects of the „environmental stressors" sound and vibration.

A. THEORETICAL PART

6.1 Sound and vibration as „environmental stressors"

Throughout the history of its usage the concept of stress has meant different things to different persons. The history and character of the stress concept was reviewed, for instance, by Lazarus (1966). Numerous definitions have been provided that vary to the extent in which they emphasise one of the following categories:

(1) Stress was regarded, perhaps most commonly, as a stimulus; i.e., a new, intense, rapidly changing, sudden or unexpected condition generating a reactive change of some sort.

(2) Stress has often meant the reaction itself, i.e., a response.

(3) Stress has been treated as a combination of stimulus-response patterns, i.e., a transaction between person and environment in which intervening mechanisms such as the person's cognitive and coping appraisal system plays a great role in stress management.

Physical, psychological and social stress conditions of the environment, called environmental stressors (Guski, 2001; Hamilton, 1979; Humphrey, 1984; Lepore & Evans, 1996), can actually cause a stress response. These conditions belong to the stimulus category (1) of the stress concept. Stress responses range from physiological reactions to complex cognitive appraisals of the potential threat or harm of an environmental array (chapter 6.2.2).

Cohen (1980) assumed that environmental stressors interact with many psychological variables which mediate the stressor effects and produce different stress responses.

According to the comfort theories reviewed in section 1, comfort refers to a positive state or the absence of a negative one (discomfort). As far as comfort may be regarded as a continuous, bipolar dimension of experience varying from extreme comfort and well-being to extreme discomfort, stress and pain, the interactive effects of the „environmental stressors" sound and vibration regarding comfort evaluation have been interpreted by leaning towards selected models of environmental stress research.

6.1.1 Characteristics of environmental stressors

Five general types of environmental stressors have been identified (Baum et al., 1982; Campbell, 1983; Evans & Cohen, 1987; Lazarus & Cohen, 1977; Lepore & Evans, 1996):

(1) Cataclysmic events

These stressors are related to sudden, irrevocable, unique, and powerful life events affecting a large number of people (e.g., natural disasters, technological or man-made catastrophes). Cataclysmic events are usually out of an individual's control. They are more or less universally stressful, and require major adaptive responses from all persons directly affected.

(2) Stressful or major life events

They include episodic and often irrevocable events affecting fewer people or a single individual in the same powerful and sudden impact as cataclysmic events, for example, major changes in family status (e.g., birth), or in economic conditions (e.g., loss of job). Some of these events can also be more or less outside individuals control, for instance, terminal illness. Others may be equally dramatic but controlled more by the persons themselves, for example, divorce.

(3) Daily hassles

These stressors are associated with stable, repetitive, or chronic episodes typical of ordinary life which can cause frustration, tension, and irritation. Environmental events (e.g., noisy party), work issues (e.g., job dissatisfaction), and interpersonal problems (e.g., important family decisions) constitute the majority of daily hassles. Daily hassles are generally more common, nonurgent and short-lived than cataclysmic or major life events.

(4) Ambient stressors

They denote continuous, relatively stable (sometimes chronic), and intractable conditions of the physical environment (e.g., traffic noise). The term „ambient" is employed because many of these stressors are background conditions, passing largely unnoticed unless they interfere with some important goals or directly threaten health. Ambient stressors are generally negatively valued because they are often associated with connotations of constraint, annoyance, undesirability, and unpleasantness. Sound and vibration belong to this category.

(5) Role stressors

These stressors refer to ongoing difficulties individuals face in fulfilling role obligations, or problematic interactions with other people they encounter in their role.

Evans and Cohen (1987) suggested eight (interdependent) dimensions along which the quality of the various types of environmental stressors can be specified:

(1) Degree of perceptual salience

This dimension is associated with the extent to which a stressor is easily identifiable or noticeable. Many physical sources of stress, particularly if chronic, of low moderate intensity, and uncontrollable, rapidly become background stimuli due to habituation of sensitivity and general awareness, for instance, ambient stressors.

(2) Type of adjustment

This dimension relates to the type of adjustment required by a stressor. Stressors which are very intense or uncontrollable, for example, are likely to lead to accommodation and emotion-focused coping rather that efforts to deal with a stressor directly.

(3) Significance and value of a stressor

The value of valence and individual significance of a stressor may also have important consequences for stress responses. For instance, some stressors, while demanding major adaptive resources, can be positively valued.

(4) Degree of controllability over a stressor

Control may function as a psychological (appraisal) process that is influenced primarily by the individual disposition (e.g., locus of control) or personal coping resources. Control can also refer to instrumental opportunities to exercise influence on the occurrence or duration of a stressor. In this sense control is associated with characteristics of situational variables. Uncontrollable stressors are typically appraised as more threatening and are frequently associated with negative effects on health and well-being.

(5) Degree of predictability of a stressor

Some stressors may be more predictable than others, which can have consequences for both the way they influence health and the manner in which an individual may choose to cope with them. For example, Glass and Singer (1972) found that predictable or controllable noise exacted smaller costs in adaptation.

(6) Necessity and importance of a stressor

Stressors that are seen as necessary and/or important cause different kinds of reactions than stressors which are perceived as unnecessary and unimportant (e.g., military aircraft vs. civil aircraft) (Guski, 1987; Kastka, 1976).

(7) Influence on behaviour

Related to the importance of a stressor is whether it is tied to human behaviour.

(8) Duration and periodicity of a stressor

Duration has two dimensions: the extent of previous personal history with a stressor and the length of current exposure to it. The term periodicity refers to the regularity or predictability of a stressor as well as its continuity.

Table 15: Effects of environmental stressors (adapted from Evans & Cohen, 1987).

Physiological	Task performance	Affect / Interpersonal behaviour	Observation	Adaptation
Elevated catecholamines	Deficits in rapid detection	Greater self-report of negative affect	Increased speech faults and filled pauses	Habituation in response sensitivity
Elevated corticosteroids	Deficits in sustained attention	Reduced altruism and other forms of social co-operation	Accelerated speech rate	Negative performance after-effects
Elevated blood pressure	Deficits in multiple signal tasks	Greater aggression and hostility	Higher vocal pitch	Reduced altruism and interpersonal sensitivity after-effects
Elevated skin conductance	Deficits in incidental memory	Overly focused and stereotyped decision making	Lexical leakage	Greater susceptibility to learned helplessness
Elevated respiration rate	Increased processing speed in working memory with reduction in capacity		More defensive body postures	Reduced immunogical resistance following chronic exposure
Elevated muscle tension			Reduced eye contact	Higher rates of cardiovascular disorders from chronic exposure
Elevated cardiac output			Greater automanipulative behaviours	Higher rates of psychological symptoms from chronic exposure

Table 15 summarises the effects of environmental stressors on human health and functioning. Evans and Cohen (1987) emphasised that the measures of stress generally did not correlate highly with one another. Furthermore, large inter- and intraindividual differences in both the magnitude and the profile of responses to environmental stressors can occur.

6.2 Basic stress models

Two important stress models will be outlined. They emphasise, respectively, physiological (stress as a response) and psychological (stress as a transaction) processes in the reactions to environmental stressors. It was intended to draw both perspectives together, recognising the importance of the biological context as well as the contribution of cognitive appraisal and coping in the interpretation and management of stressful events.

6.2.1 Stress as a response

Two of the pioneer researchers on stress, Walter Cannon and Hans Selye, developed stress models which centre on the physiological responses of the body to physical and psychological agents or demands, called stressors. In addition, both models concentrate on homeostatic processes. The denotation homeostasis (from Greek homoios, „similar" and stasis, „position", „standing") originates from Cannon (1932). He employed the term for physiological mechanisms with adaptive function in order to maintain the internal state of the body (homeostatic balance), which stressors might have upset. The author assumed that the sympathetic-adrenal medullary axis (see below) is primarily involved in these homeostatic processes.

Selye (1956, 1974, 1976, 1981, 1983, 1991) observed a remarkably consistent pattern of psychophysiological reactivity when laboratory animals were exposed to a variety of widely different stressors (e.g., heat, cold, drugs). He described this as the *„nonspecific response of the body to any demand upon it"* (Selye, 1974, p. 14) which represents the core of any stress response. It appeared to be independent of particular stressor qualities; rather only the extent of response varied depending on stressor intensity. The physiological processes and the reactions involved in the body's stress response were labelled by Selye as the general adaptation syndrome (GAS) consisting of the three stages of alarm reaction, resistance, and exhaustion. The alarm reaction includes the preparation for resistance which is necessary to meet the demands made by a stressor to which the body is suddenly exposed and not adapted (e.g., extreme temperatures). The organism responds by mobilising its adaptive resources. Thus, the hormone output increases rapidly during this stage. This is due to the involvement of the sympathetic-adrenal medullary axis (focus of Cannon's approach) and the anterior pituitary-adrenocortical axis (focus of Selye's approach) (Figure 29). The so-called anterior pituitary-adrenocortical axis contains a stressor induced excitation of the medial-basal cell groups in the hypothalamus which leads to an emission of corticotropin releasing-hormones (CRH). CRH descends to the anterior pituitary gland and causes a discharge of the AdrenoCorticoTropc Hormone (ACTH) into the general blood circulation. Upon reaching the adrenal cortex, ACTH generates an increased hormone corticoid content of the blood, mainly glucocorticoids such as cortisol or corticosterone. Simultaneously, within the so-called sympathetic-adrenal medullary axis, an excitation of the efferent sympathetic nervous system induces a stimulation of the adrenal medullary cells. This in turn leads to the release of the catecholamines adrenaline and noradrenaline into the blood circulation system (Birbaumer & Schmidt, 1996; Pinel, 1997; Schandry, 1988; Schmidt, Thews & Lang, 2000). When the adaptive resources are made available, the body enters the stage of resistance, which typically involves the organism's adaptation to a stressor and the consequent improvement or disappearance of the somatic responses characteristic of the alarm reaction. The hormonal output remains high but stable during this stage. The released glucocorticoids elicit thymus shrinkage, accompanied by many other changes, such as atrophy of the lymph nodes, inhibition of immune responses as well as inflammation, and production of glucose (a readily available source of energy for adaptive reactions). The corticoids also suppress the secretion of ACTH caused by the anterior pituitary gland. Another typical feature of the stress response is the generation of peptic ulcers in the stomach and intestine. Their development is facilitated through an increased level of corticoids in the blood, but the sympathetic nervous system also plays a role in eliciting ulcers. The secreted catecholamines induce an increased heart rate, heart beat volume, and arterial blood pressure due to vasoconstriction of the arterioles of the skin and mucous membranes, as well as vasodilatation of the arterioles of skeletal muscles, and vasodilatation of the bronchia, which all together lead to a greater blood and oxygen supply to the skeletal muscles, heart, and brain. Furthermore, inhibition of inflammatory processes and peptic action occurs, and different gluconeogenic processes take place in the skeletal muscles and liver to make energy available (Birbaumer & Schmidt, 1996; Pinel, 1997; Schandry, 1988; Schmidt, Thews & Lang, 2000). Long-term exposure to same (sufficiently severe) stressors or repeated instances of adaptive demands can deplete the organism's adaptive resources to respond due to its finite adaptability (e.g., the anterior pituitary and the adrenal gland lose their capacity to secrete hormones). Then, the organism enters the stage of exhaustion; signs of the alarm reaction reappear, and if the stress response continues unabated, physiological dysfunction and finally death are ensured .

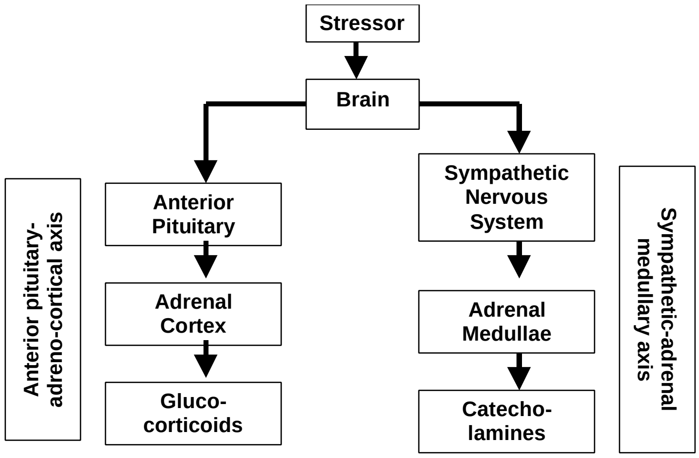


Figure 29: The neuro-hormonal axes of the stress response (adapted from Pinel, 1997).

6.2.2 Stress as a transaction

Psychological stress models differ from physiological approaches when considering how cognitive processes mediate stressor effects. For instance, Hamilton (1979, p. 6) defined environmental stress as the *„aversive effects of an unfavourable physical environment, to the effects of crowding, noise, social and economic deprivations [...]. The experience of these events as unfavourable, aversive or distressing is, in any event, not universal and a cognitive interpretation of the information is required before the human adaptive system react with coping or defensive responses [..] I would argue that environmental stress resides in the head and not in the world around us. A 'transaction' does take place."* From this psychological viewpoint, stress is not viewed as a demanding environmental condition (stressor) or the defensive response to it, rather, it depends on how a relationship to the environment, called transaction, is subjectively perceived and evaluated. Following this tradition, Lazarus' cognitive-phenomenological approach (Lazarus, 1966, 1968, 1969, 1990, 1991) has treated stress as a relational concept which refers to the person's continually cognitive judgements about demands and constraints in ongoing transactions and the individual's resources and options for managing them. Stress is analysed in terms of cognitive appraisal and coping, a sequence of psychological processes each of which serves in its specific fashion to mediate the encounters between the person and the environment:

Primary appraisal relates to the cognitive process of evaluating the significance of actual, imagined, or anticipated transactions with the environment with respect to its significance for the person's well-being (Coyne & Lazarus, 1981; Folkman, Schaefer & Lazarus, 1979; Lazarus, 1990, 1991; Lazarus & Launier, 1978). It comes in three forms:

(1) An irrelevant appraisal means that a transaction is considered to have no personal significance or any implication whatever for well-being and hence may be ignored.
(2) A benign-positive appraisal includes, for example, an evaluation of a transaction as signifying a positive, comfortable state of affairs. Hence, it is beneficial or desirable. No adaptive or coping effort is required and the person feels comfortable.
(3) A stressful appraisal contains a judgement implicating that a transaction involves threat, harm-loss, or challenge. All three comprise some more or less negative evaluation of one's present or future state of well-being. Harm-loss refers to damage that has already occurred, such as illness or loss of significant relationships. Threat concerns harm or loss that has not yet happened but is anticipated. It arises when the demands exceed the individual's felt ability to cope with them. Challenge relates to a judgement that the demands of a transaction may be overcome; i.e. the stressful situation can be dealt with effectively. This may provide an opportunity to grow by drawing upon more than routine resources. The extent to which a transaction will be seen as stressful is dependent upon a constellation of personal and situational factors. Personal factors include generalised beliefs about one's self (e.g., self-efficiency) and environment, the availability of resources (e.g., the person's morale and assessments of health or energy), as well as problem-solving skills. Situational or contextual factors contain characteristics of environmental conditions presented in chapter 6.1.1 such as the magnitude, duration, and controllability.

Once an event has been appraised as stressful and therefore as worthy to respond, coping processes ensue. Secondary appraisal refers to the person's ongoing evaluations concerning coping resources, options, and constraints (Coyne & Lazarus, 1981; Folkman et al., 1979; Lazarus, 1990, 1991; Lazarus & Launier, 1978). Coping consists of cognitive and behavioural efforts to manage environmental demands (external events) and internal demands (individual goals and values) that have been appraised to exceed the individual's adaptive resources (Coyne & Lazarus, 1981; Folkman et al., 1979; Lazarus, 1966, 1968, 1969, 1990, 1991; Lazarus & Folkman, 1984; Lazarus & Launier, 1978). Coping resources involve properties of persons (e.g., self-efficiency, general beliefs and attitudes), their social environment (e.g., social support and networks), and physical environment resources (e.g., privacy) that enable to respond to a stressful situation (Folkman et al., 1979; Lazarus & Launier, 1978). The range of coping processes encompasses four categories (Folkman et al., 1979; Lazarus, 1969, 1990, 1991; Lazarus & Folkman, 1984; Lazarus & Launier, 1978):

(1) An information search which has the instrumental function of providing a basis for action to change the transaction,
(2) Direct action, i.e. dealing with the stressful situation directly,
(3) Inhibition of action to accord with environmental and intrapsychic characteristics, and
(4) Intrapsychic modes including all cognitive processes designed to regulate the stress response by making the person feel better.

These coping processes have two main functions (Coyne & Lazarus, 1981; Folkman et al., 1979; Lazarus, 1990, 1991; Lazarus & Launier, 1978):
(1) Problem-focused or instrumental coping strategies alter ongoing transactions by dealing with the sources of stress, whether by changing one's behaviour to maintain problems or by modifying environmental conditions.
(2) Palliative or intrapsychic coping strategies regulate the stress reaction by changing the way in which the relationship is attended to (e.g., a threat that one avoids thinking about) or interpreted (e.g., a threat that is dealt with by denial or psychological distancing).

After secondary appraisal, reappraisal can occur as a kind of feedback process (Coyne & Lazarus, 1981; Lazarus, 1990, 1991; Lazarus & Launier, 1978). It relates to the changes in a person's evaluative judgements. Reappraisal results when new information about the changing transaction and its significance for well-being is obtained from internal psychological changes, modifications in the environment (often from coping efforts), and from defensive intrapsychic activity.

6.3 Models on the interactive effects of combined environmental stressors

Many sources of environmental stress covary in the natural environment. Sound and vibration, for instance, frequently fluctuate together due to the same physical origin (chapter 6.3.1). A major question of environmental stress research concerns the issue of examining additive and multiplicative effects of combined environmental stressors (Evans & Cohen, 1987; Lepore & Evans, 1996). From a conceptual perspective, the concepts of convergent and divergent validity are applicable. Presupposing that various kinds of changes in physical environment conditions can be conceptualised as stressful, it may be argued that they share some common mechanism or process. If two or more environmental stressors operate by some similar mechanism (e.g., arousal levels), then there should be some measurement convergence reflected by either parallel results between two different stressors or some additive effects when both are combined.[10] Figure 30 illustrates different ways in which combined environmental stressors can influence adjustment outcomes by using a two stressor (A and B) example according to Lepore and Evans (1996). Higher scores represent more adjustment problems, or stronger stress responses. The first two bars show independent or simple main effects of exposure to either stressor A or stressor B. On average, a person who experiences either A or B can be expected to score 10 points on the adjustment problem scale. According to the additive model, the joint effect of stressors A and B on adjustment should be equivalent to the sum of the independent effects of A and B (10 + 10 = 20), as shown in the fourth bar in Figure 30. In other words, the combination produces a greater effect than that of each single stressor, but no more than the sum of the effects of the individual stressors. In statistical terms, the additive model proposes that there are no unique effects of being exposed to both stressor A and B above and beyond their combined independent effects. The third and fifth bars show two different multiplicative effects of combining stressors A and B. Here the combined effects are not equal to the sum of the independent effects. The attenuation model (third bar) indicates that the combination of stressors A and B produces an effect less than it would expected from the additive model. The potentiation or synergistic model (fifth bar) assumes that the joint effect of stressors A and B is greater than the sum of the effects of the individual stressors.

[10]In addition to the reviewed traditional stress models, there has been a less encompassing approach that significantly influenced environmental stress research. Broadbent (1971) suggested that effects of combined stressors are arithmetically additive if the 'internal mechanisms' which they affect are independent. However, if the 'internal mechanisms' are not independent then the effects can be additive, synergistic, or subtractive. The arousal paradigm has often been used in attempts to explain combined effects of environmental stressors (Berlyne, 1960, 1971; Broadbent, 1971; Fiske & Maddi, 1961; Mehrabian & Russell, 1974; Wohlwill, 1974). Arousal models of stress assume that changes in the physical environment can affect the arousal level in the reticular activating system in the brain. These changes are manifested on a behavioural continuum ranging from sleep to high excitement. Based on the Yerkes-Dodson-law (Hebb, 1955; Duffy, 1962; Yerkes & Dodson, 1908) an inverted U-shaped function is postulated between arousal level and measures of comfort and performance: Low and high arousal produce inefficiency, whereas comfort and performance are best at a mediate level of arousal. Consequently, environmental conditions that lower or raise arousal levels beyond some optimal range cause stress. Thus, the arousal paradigm can explain, for instance, how combinations of stressors (e.g., noise causing overarousal plus sleep deprivation inducing reduced arousal) cancel out another's aversive effects (e.g., on mental task performance) in comparison to the individual stressor. Physical variables related to arousal are, for example, the intensity and complexity of stimulation. Noise can be easily incorporated into the arousal model since it increases the amount of physical stimulation in an ambient environment. However, the models' focus on stressor's physical properties and the neglect of psychological processes has often been criticised (Cohen, 1978; Hellbrück, 1993).

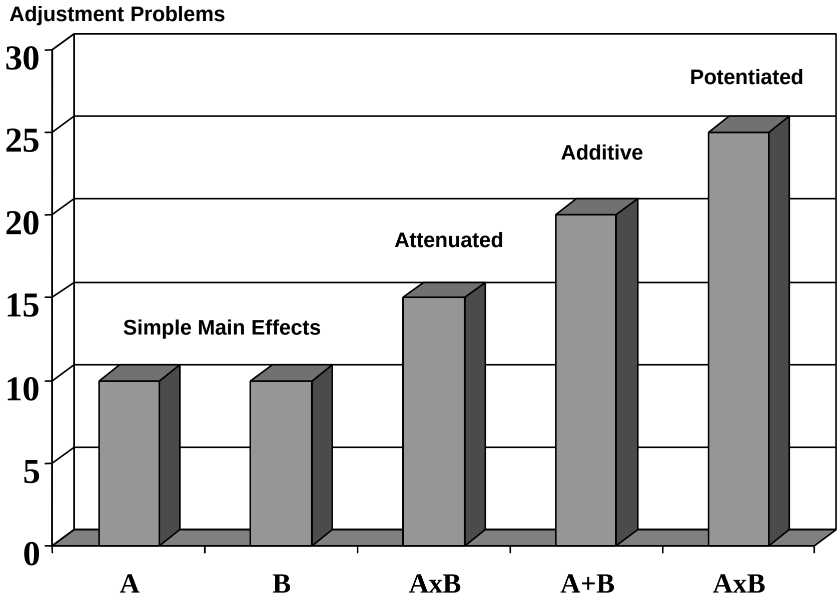


Figure 30: Stressor combinations (adapted from Lepore & Evans, 1996).

6.3.1 Empirical studies on the interactive effects of combined environmental stressors

Environmental stress research has mainly focused on annoyance, discomfort, and disturbance reactions to describe the interactive effects of combined environmental stressors (Koelega, 1987). For example, various investigations have been concerned with the interaction between ambient (e.g., auditory, odour and visual) stressors:
One report (Berglund, Berglund & Lindvall, 1975b) has clearly shown that noise-odour interaction does occur and suggested that interactions shown in a field situation would stem from non-sensory factors, for example, attitudes. Other field studies in which noise and air pollution have been investigated in their disturbing effects on people proved that annoyance was only weakly related to physically measured levels of noise and air pollution but that a strong correlation between annoyance due to noise and air pollution existed. Wanner, Wehrli, Nemecek and Turrian (1977) observed that the frequency of annoyance caused by noise and air pollution was correlated by 0.78 and the intensity of annoyance due to both was correlated by 0.72. The Viennese study of annoyance due to different environmental factors (Wiener Umwelterhebung, 1984) proved that noise was the main factor to which annoyance was attributed (62 %), followed by dust (45 %) and odours (40 %). The correlations between the annoyance caused by the different environmental factors were very strong (all above 0.90). On one hand, this might be due to the fact that the whole group of ambient stressors was

highly interrelated and on the other hand it is possible that the individuals being annoyed by one stressor (e.g., noise) were sensitised to other stressors (e.g., air pollution). Hangartner (1987) reported a correlation of 0.81 for annoyance originating from noise and automobile exhaust. The author concluded that individuals did not distinguish between both stressors and that the self-rating could be regarded to represent an integrated measure of both annoyance factors. In a current study, Meis and Brauchle (2001) found a highly significant interaction between annoyance due to road traffic noise and air pollution. Findings indicated a „compensatory" interaction between both ambient stressors: Increased air pollution significantly decreased the annoyance caused by noise, and vice versa, increased noise level significantly reduced the annoyance evoked by air pollution.
Höfert (1981) showed a significant positive interaction between industrial noise and blinding concerning annoyance. For an analysis of the relation between visual appearance and noise annoyance, Kastka and Noack (1987) sampled visual appearance data and, independently, the noise immission parameters and residential annoyance data in two towns in Germany and Switzerland. It was found that the visual aesthetic context of the environment influenced the effect of the auditory stressor. The same noise level produced more noise annoyance in less attractive environments than in those with a higher visual quality. The difference amounted up to a 5 dB bonus for the more attractive visual environment. The authors concluded that visual aesthetic structures in the environment may compensate for the effect of environmental noise immissions by influencing annoyance via an integration of sensory experiences.

Sound and vibration often covary in the natural environment due to the same physical origin. Because of this physical kinship, Dupuis (1979) suggested that both ambient stressors can interact additively or even potentatively regarding subjective responses. Laboratory experiments concerning the interactive effects of combined noise and vibration on annoyance have been performed by Howarth and Griffin (1990a, 1990b, 1991), Landström, Kjellberg and Lundström (1993), Meloni and Krueger (1990), Paulsen and Kastka (1995), Schust, Seidel, Seidel and Blüthner (1997, 1998), and Seidel (1997). Further studies have been reviewed by Howarth (1989) and Griffin (1990). The presented sound pressure levels of the investigations mentioned above had a stimulus range between 33 and 84 dBA. The vibration exposure has been realised by sinusoidal vibrations of different frequencies, by stochastic vibrations, by measurements of either railway-induced vibrations in buildings nearby railways or real vibrations in different vehicles. Frequently, n_x magnitudes of whole-body, vertical (z-axis) vibration and n_y levels of noise were simultaneously generated in all possible paired combinations by paired combinations by means of different „sound and vibration simulation systems". Cross-modality matching, magnitude estimation, or annoyance category scales were employed to indicate annoyance due to the individual impact of noise or vibration (single rating), and caused by both stressors (composite rating). Besides the laboratory experiments, extensive field studies have been conducted applying questionnaires regarding the exposition of combined noise and vibration at the work place (Splittgerber, Kreuzer & Jansen, 1991) or in buildings nearby railways (Zeichart, 1998; Zeichart, Sinz, Schuemer-Kohrs & Schuemer, 1994a, 1994b). Laboratory and field investigations have been concerned with:

(1) the effect of noise on judgement of vibration,

(2) the effect of vibration on judgement of noise, and

(3) the relative and total annoyance produced by combinations of noise and vibration.

Results regarding the influence of noise on assessment of vibration (1), and vice versa, the impact of vibration on evaluation of noise (2) are not homogeneous. For instance, Paulsen and Kastka (1995) found that the annoyance caused by vibration was largely independent of accompanying noise (see also Landström et al., 1993). On the other side, judgement of noise depended on simultaneously existing vibration, especially at low noise levels. In contrast, Howarth and Griffin (1990a) showed that vibration did not influence the assessment of noise (see also Schust et al., 1997, 1998) but the evaluation of vibration was induced by the presence of noise, depending on the relative magnitude of both stressors.

Data indicated that total annoyance caused by the combination of noise and vibration was generally higher than assigned to their individual impact (Howarth & Griffin, 1990a, 1991; Landström et al., 1993; Paulsen & Kastka, 1995). Both ambient stressors appeared to have a synergetic, mainly additive interaction regarding total annoyance. Total annoyance was commonly dominated by noise, but it was also influenced by accompanying vibration. Howarth and Griffin (1990a) proved, for example, that at all magnitudes of vibration an increase in noise level deteriorated total annoyance, and contrary, that at all levels of noise an increase in vibration magnitude worsened the subjective response. Generally, the additive effect of vibration and noise decreased with increasing noise, respectively vibration level (Howarth & Griffin, 1990b, 1991; Schust et al., 1997, 1998; Seidel, 1997; Splittgerber et al., 1991; Zeichart, 1998; Zeichart et al., 1994a, 1994b). Seidel, Erdmann, Blüthner, Hinz, Bräuer, Arias, & Rothe (1990) performed an experiment to determine levels of noise and vibration which produce equivalent sensations. It was found that an increase in vibration level by 1 dB equalled an increase in noise level by 1.7 dB (see also Fleming & Griffin, 1975; Kjellberg et al., 1985). Howarth and Griffin (1990b) defined a subjective equivalence contour between noise and vibration level which is expressed by the following multiple regression equation:

$$L_{AE} = 29.3 \log_{10} VDV + 89.2$$

L_{AE} refers to the sound exposure level and VDV is the vibration dose value. This relation, which involves the summation of the individual impacts of two stressors, was able to provide a more accurate means of predicting total annoyance for different combinations of noise and vibration than a method based on each single stressor (Howarth & Griffin, 1991).

Altogether, the interaction between the ambient environmental stressors noise and vibration regarding subjective annoyance reactions appears to be very complex. Frequently, an additive interaction occurred which was commonly dominated by noise, but also determined by simultaneous vibration. Both stressors' interaction and relative contribution to annoyance generally depended on their relative magnitudes. Different explanations of this synergetic interaction have been proposed. For instance, Fothergrill (1972) suggested that with low vibration levels, a noise can mask annoyance caused by vibration, while with a high noise level and vibration magnitude the judgement may become a composite rating of both stressors. Meloni and Krueger (1990)[11] advised with a similar „masking hypothesis" according to which high levels of noise raise the perception or disturbance thresholds for vibration. Accordingly, annoyance caused by vibration will not increase with growing magnitude at a simultaneous high noise level. Zeichart et al. (1994a) discussed the „contrast hypothesis" which involves the assumption that the dominating (i.e. more annoying) stressor (noise) tends to divert attention, or even masks the effects of the other (vibration), and hence is generally overestimated concerning the assessment of total annoyance or disturbance.

[11] Meloni and Krueger (1990) showed that perception thresholds of sinus and stochastic vibration stimuli are raised significantly under the influence of high sound level (> 64 dBA) (see also Splittgerber & Hillen, 1991; Treier, 1997; Yamada et al., 1990).

6.4 Method

Subjects. Thirty subjects took part in the experiment, 17 females and 13 males, aged from 17 to 36 years (mean = 24.80; median = 23.50). They were mainly students of psychology. Participants were naive to the experiment, and reported having normal hearing. They were either paid for their participation or received a course credit.
Eighty-seven per cent of the sample flew once a year, 13 % had never flown before. The main reason for flying was pleasure (83.3 %). Eighty-eight per cent normally travelled by economy class.

Design. The experimental design was a 2 (*aircraft types*) x 3 (*sound pressure levels*) x 3 (*vibration magnitudes*) factorial design (Table 16). Subjects took part in two experimental blocks, each containing the exposure to combinations of three sound and vibration levels (original, low, strong) of either jet 1 or propeller 2 also presented in study 1. The duration of each stimulus was 60 seconds. All were evaluated by means of 15 bipolar qualities of the SD for aeroplanes. The order of both aircraft types was counterbalanced over the participants. For each experimental block subjects were randomly assigned to one of five presentation sequences. Between both blocks there was a five minute break. The whole experiment took approximately 50 minutes, including the break.

Table 16: Schematic diagram of the experimental design

	Factor A: Aircraft types					
	Propeller			**Jet**		
	Factor B: Sound pressure levels			**Factor B:** Sound pressure levels		
Factor C: Vibration magnitudes	Original	+ 3 dB	- 3 dB	Original	+ 3 dB	- 3 dB
Original	P1	P2	P3	J1	J2	J3
+ 4 dB	P4	P5	P6	J4	J5	J6
- 4 dB	P7	P8	P9	J7	J8	J9

Material and set-up. Study 2 focused on physical variations of sound and vibration level of jet 1 and propeller 2 presented in study 1. Stimuli were reproductions of vertical (z-axis) aircraft interior vibration presented together with sound. They were generated by simultaneously varying the original sound pressure level and vibration magnitude, keeping all other physical aspects of the configurations constant.[12] The sound was presented at three levels combined with three magnitudes of vibration (Table 16). Based on a laboratory pretest, these levels were defined in terms of the sensitivity index d' (> 2.0) according to the signal detection theory (Macmillan & Creelman, 1991) (Appendix IX). Correspondingly, the sound pressure levels (in dB re $2x10^{-5}$ N/m^2) of the jet were 73 dB(A) (- 3dB SPL), 76 dB(A) (Original SPL), and 79 dB(A) (+ 3dB SPL), and 78 dB(A) (- 3dB SPL), 81 dB(A) (Original SPL), 84 dB(A) (+ 3dB SPL) for the propeller. The vibration levels (in dB re 10^{-6} m/s^2), measured at the panel of the SVRS, were 95.8 dB (- 4 dB VL), 99.8 dB (Original VL), and 103.8 dB (+ 4 dB VL) for the jet, and 108.3 dB (- 4 dB VL), 112.3 dB (Original VL), and 116.3 dB (+ 4 dB VL) for the propeller.

In order to avoid a reassuring „massage effect" of short vibration exposures (25 seconds; chapter 5.3) as well as an exhaustion in persons due a too lengthy stimulus duration (120 seconds; chapter 5.5.3), it was decided to present all combinations for 60 seconds including a one second rise/fall time. Each configuration was announced by a 0.5 sec chirping signal at 440 Hz followed by an one second break. To prevent sequence effects, combinations of both aircraft types were copied on a Compact Disk (CD) in five randomised orders to which participants were randomly assigned. Furthermore, the order of the aircraft types was balanced over the subjects.

The experiments took place in a semi-anechoic chamber (iac) with a reflecting ground surface at the Institute for Research into Man-Environment-Relations at the University of Oldenburg. The surrounding sound level measured at the persons' ear was 16 $L_{eq(A)}$. The experimenter was sitting in a control room outside the laboratory and could see the participant via a videosystem. The participant sat on the „sound and vibration reproduction system" (SVRS) also applied to the laboratory pretests (chapter 5.3). For reproducing the recorded vibrations a real aircraft passenger seat was mounted on a rigid plate with a size of 0.9 m x 1.2 m and a thickness of 8 cm. The plate was placed on a elastic bearing and driven by electrodynamic actuators in the vertical direction (z-axis) in the frequency range from 10 to 150 Hz (low pass limited) with a maximum ac-

[12]Table 9 in chapter 5.4 gives psychoacoustic and vibration parameters of jet 1 and propeller 2. Psychoacoustic parameters were computed from the recorded time series with the analysis system BAS 4.0 (HEAD acoustics GmbH). Third octave band sound pressure levels (in dB re $2x10^{-5}$ N/m^2) were calculated in accordance with ISO 532B (1975). Vibration levels (acceleration levels in dB re 10^{-6} m/s^2) resulted from the frequency weighting Wk and energy summation of the recorded acceleration data according to ISO 2631-1 (1997).

celeration of 1 m/s^2 (120 dB vibration level). The sounds were given via two loudspeakers situated in a stereophonic arrangement at a distance of 1.5 m on the left and right in front of the subject. The set-up of the SVRS is illustrated by Figure 31.

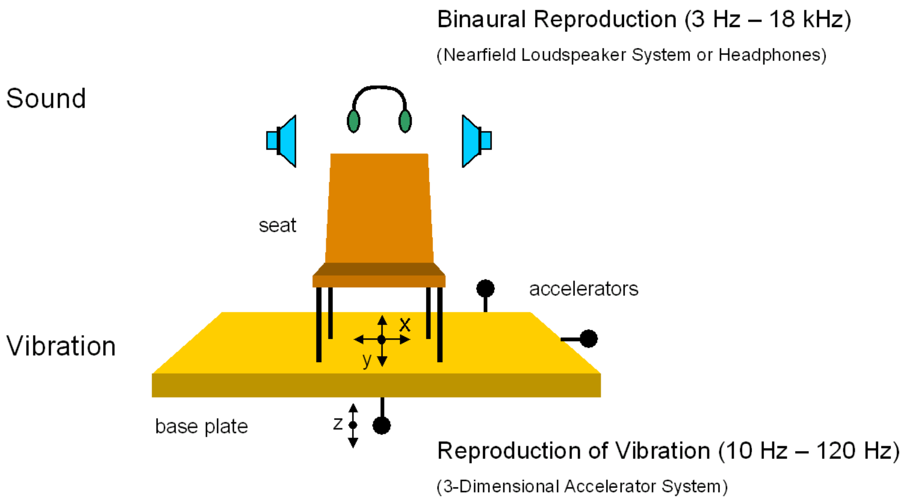


Figure 31: A schematic representation of the sound and vibration reproduction system (SVRS)

Variables. The experimental variables were *aircraft types*, *sound pressure levels*, and *vibration magnitudes*. The dependent variable was *evaluation* of physically varied sound and vibration configurations of two aircraft types using 15 qualities of the SD, each enclosing seven categories. The judgements were performed to specify the interaction between sound and vibration level and their individual contribution to affective ratings, especially on the perceptional dimension of (vibro-acoustic) comfort. For each stimulus a randomised sequence of the adjectives was employed. The combinations were announced as „flight situations". During the practice an overview of the stimulus range was given. After practice, participants spontaneously marked the category they thought appropriate for expressing their perception of each attribute.

Persons' *subjective mood* was measured at three times by means of 10 mood scales (monopolar 6-point adjectives) of the EWL (Janke & Debus, 1978) composing the orthogonal mood dimensions „well-being" and „ill-being" derived in study 1 (chapter 5.5.2.1.2). At each time a randomised sequence of the mood scales was applied. The EWL allows the measurement of subjective mood changes depending on environmental conditions. The intention was to study the impact of experimentally caused alterations of subjective mood on (comfort) assessment in the sense of a situational or contextual moderator variable.

Procedure. Thirty subjects were exposed individually to two experimental blocks. Each block contained nine combined sound and vibration level variations of either jet 1 or propeller 2 presented in study 1. The sequence of both aircraft types was counterbalanced over the participants. Within each block subjects were randomly assigned to one of five presentation orders. Between both blocks there was a five minute break during which the persons left the laboratory. The study was performed in the native language of the subjects (German). At the beginning of the experiment the participants' seat posture was specified on the SVRS. They were requested to adopt an upright posture with their back supported by the backrest, to place their feet on the floor and to positionate feet and upper legs horizontally and lower legs vertically throughout the experiment. Then, subjects were instructed by the experimenter to describe the different tasks required (Appendix X-1 and X-4). To prevent „anchor" or „ceiling" effects the participants exercised using the SD before each block begun Appendix X-2 and X-3). For this purpose, all stimuli were played five seconds and rated by the adjective pair „beautiful" vs. „ugly". After training, subjects were asked to evaluate the sound and vibration configurations on 15 attributes of the SD. Each combination was given for 60 seconds. Fifteen seconds after the presentation's beginning a flash light in front of the SVRS indicated to start the judgement. After each presentation a break of 30 seconds gave the opportunity to continue the assessment. Finally, all persons answered the questions of a qualitative questionnaire on general remarks to the experiment, the ecological validity of the presentations (measured on a six-point scale ranging from „not realistic" to „very realistic"), willingness to participate again as well as the subjective understanding of the term comfort and a comfortable flight situation (Appendix XI-1 and XI-2).

Subjects' subjective mood was measured using 10 mood scales of the EWL before the experiment started, between the first and second block, and at the end.

The whole experiment lasted approximately 50 minutes, including the break between both blocks.

6.5 Results

6.5.1 Inference statistics

(A) General evaluation differences between both aircraft types

Differences between evaluations due to both aircraft types were tested by a 3-factorial (15 x 9 x 2) ANOVA. Within-subjects factors were given by *adjectives of the SD, sound and vibration configurations,* and *aircraft types*.

Highly significant effects of the factors *adjectives of the SD*, $F(2.874;83.349) = 8.958$, $p < .0001$, and *sound and vibration configurations*, $F(6.214;180.205) = 14.085$, $p < .0001$, were found. *Aircraft types* did not reach significance, $F(1;29) = .747$, $p < .395$. The interaction between *sound and vibration configurations* and *aircraft types* was also not significant, $F(5.930;171.969) = 1.166$, $p < .327$. *Adjectives of the SD* interacted significantly with *sound and vibration configurations*, $F(13.327;386.495) = 19.998$, $p < .0001$, as well as with *aircraft types*, $F(6.691;194.027) = 5.065$, $p < .0001$. Important for the present discussion was the significant three-way interaction, $F(18.212;528.155) = 1.722$, $p < .032$, suggesting that both *aircraft types* differed considerably concerning the judgement of their *sound and vibration configurations* by using *adjectives of the SD*. With respect to this finding, decisions to separately analyse the propeller's and jet's ratings were made.

(B) Influence of personal characteristics on general evaluation

In order to examine the influence of subjects’ personal characteristics on evaluation, two similar 3-factorial (15 x 9 x 2) ANOVAs were carried out with *gender* as the between-subjects factor and *age* as a covariate. Due to the sample's homogeneous composition the impact of other personal variables was not taken into account. Data showed no differences between judgements due to persons' *age* ($F(15;14) = .569$, $p < .855$), or *gender* ($F(1;28) = .275$, $p < .604$). Additionally, the interaction between all factors was not significant, indicating that assessment of the stimuli was not influenced by individual attributes. Therefore, no particular analysis involving specific sample subgroups was performed.

(C) Influence of sound and vibration level on general evaluation

Two separate 3-factorial (15 x 3 x 3) ANOVAs were conducted for each aircraft type to determine significant differences between evaluations on 15 polarities due to the physical sound and vibration level variations. Within-subjects factors were *adjectives of the SD, sound pressure levels,* and *vibration magnitudes*.

Regarding the propeller, analysis of variance proved significant effects of the factors *adjectives of the SD*, $F(3.329;96.548) = 9.185$, $p < .0001$, and *vibration magnitudes*, $F(1.902;55.145) = 24.737$, $p < .0001$. Significance of *sound pressure levels* was not obtained, $F(1.910;55.397) = .825$, $p < .439$. The significant two-way interaction between *adjectives of the SD* and *sound pressure levels*, $F(10.044;291.281) = 22.837$, $p < .0001$, between *adjectives of the SD* and *vibration magnitudes*, $F(7.085;205.462) = 19.490$, $p < .0001$, as well as the interaction between all experimental variables, $F(11.782; 341.688) = 1.895$, $p < .035$, reflected that the judgement of propeller's *sound pressure levels, vibration magnitudes* and their combination was dependent on *adjectives of the SD*. The only insignificant interaction occurred between *sound pressure levels* and *vibration magnitudes*, $F(3.558;103.187) = .160$, $p < .946$.

Concerning the jet, significant effects of the factors *adjectives of the SD*, $F(2.949;85.515) = 7.850$, $p < .0001$, and *vibration magnitudes*, $F(1.931;56.011) = 29.027$, $p < .0001$, were found. Significant differences between *sound pressure levels* did not appear, $F(1.870;54.241) = 1.944$, $p < .156$. The significant two-way interaction between *adjectives of the SD* and *sound pressure levels*, $F(7.264;210.668) = 24.185$, $p < .0001$, as well as between *adjectives of the SD* and *vibration magnitudes*, $F(6.508;188.731) = 16.434$, $p < .0001$, suggested that the rating of either *sound pressure levels* or *vibration magnitudes* was dependent on *adjectives of the SD*. Finally, there was no significant interaction between *sound pressure levels* and *vibration magnitudes*, $F(3.196;92.690) = 1.106$, $p < .353$, or between all main factors, $F(14.003;406.086) = 1.449$, $p < .127$. The latter meant that the assessment of the jet's sound and vibration level combinations was not dependent on *adjectives of the SD.*

6.5.2 Principal component analysis

Inferential statistical analyses have shown that the judgement of both experimental variables depended on attributes of the SD. However, it did not seem practicable to test evaluation differences on each single polarity due to the 3 x 3 experimental design. Instead of deciding on T-test applications, so-called „aggregated" dependent variables were defined by means of factor analysis (varimax rotated principal component analysis) of the polarities' correlations. Basically, these aggregated dependent variables corresponded to the perceptional dimensions of study 1. Factor analyses were carried out for the ratings of:

(1) both aircraft types together, and

(2) each aircraft type's configurations separately.

Applying the criterion of eigenvalues > 1, three „aggregated" dependent variables or perceptual dimensions were derived. Together, they accounted for approximately two thirds of the observed variance in the judgements. Component diagrams related to both analyses are given in Appendix XII-1 to XII-3. The factor matrix resulting from the evaluation of both aircraft types (factor analysis 1) is presented in Table 17. Qualities of the SD representing the rotated factors are listed in descending order of their loadings. Dimensions were interpreted by clusters of adjectives loaded at least > .50 on each. The yielded factorial structure was rather similar to that of study 1. F1 carrying more than 40% of the variance represented a comfort dimension associated with the perception of aircraft interior sound properties, for instance, loudness and sharpness. One pole was described by the strongly clustered features „comfortable", „bearable", „acceptable", and „muffled". The other pole was related to the terms „loud", „sharp", „threatening", and „rough". F2 had high loadings for attributes connected with vibration at one end („vibrating", „shaking", „unsteady") and characteristics of time at the other („monotonous", „regular"). Since the item „vibrating" loaded on F2 instead of F1 (study 1), it was interpreted as a vibration dimension. Finally, F3 corresponded to the sensation of tonality.

Table 17: Rotated factor matrix involving the evaluation of the configurations of both aircraft types (factor analysis 1)

	Component		
	F1 (43.9%)	F2 (12.0%)	F3 (8.1%)
acceptable	-,868	-,147	-5,988E-02
comfortable	-,853	-,269	-1,155E-02
bearable	-,837	-,207	-,115
loud	,834	2,600E-02	-,146
sharp	,732	,104	-,131
threatening	,724	,289	,275
rough	,668	,364	3,258E-02
muffled	-,608	-,231	,388
monotonous	6,558E-02	-,766	,306
regular	-,128	-,749	,185
unsteady	,355	,720	,179
vibrating	,260	,692	,148
shaking	,518	,675	,171
high frequency	-,399	7,002E-02	-,206
tonal	,281	,113	,796

The interaction between sound and vibration level regarding the derived „aggregated" dependent variables was analysed by calculating mean values at any sound and vibration configuration. For this purpose, the assessments on the representative adjectives of the comfort and vibration dimensions (loadings of at least > .60) were averaged. Furthermore, these attributes were rotated similarly. Concerning the comfort dimension, the attributes „acceptable", „bearable", „comfortable", and „muffled" changed to „unacceptable", „unbearable", „uncomfortable", and „not muffled"; regarding the vibration dimension „monotonous" and „regular" became „varied" and „irregular". The tonality dimension has not been taken into account since it explained less than 10% of the data's variance.

6.5.3 Interaction between sound and vibration level and their relative contribution to comfort and vibration evaluation

2-factorial (3 x 3) within-subjects ANOVAs were applied separately to each aircraft type's ratings in order to specify the interaction between sound and vibration level and their relative contribution to comfort and vibration evaluation. *Sound pressure levels* and *vibration magnitudes* were within-subjects factors. Additionally, T-tests were applied to each sound pressure level and each vibration magnitude to test differences between assessments due to the variations of vibration magnitude and sound pressure level.

(A) Interaction between sound and vibration level and their relative contribution to comfort evaluation

Analysis of the propeller's comfort evaluation showed significant effects of *sound pressure levels*, $F(1.758;50.996) = 82.576$, $p < .0001$, of *vibration magnitudes*, $F(1.883;54.607) = 18.400$, $p < .0001$, and of their interaction, $F(2.887;83.723) = 3.848$, $p < .013$. *Sound pressure levels*, $F(1.229;35.629) = 75.747$, $p < .0001$, *vibration magnitudes*, $F(1.526;44.252) = 10.665$, $p < .001$, and the two-way interaction, $F(3.287;95.328) = 2.269$, $p < .046$, also reached significance regarding the jet's comfort evaluation. T-test comparisons for the propeller's comfort evaluation indicated significant differences ($p < .02$) between <u>all</u> *vibration magnitudes* at + 3 dB SPL and – 3 dB SPL as well as between <u>all</u> *sound pressure levels* at <u>all</u> *vibration magnitudes*. Concerning the jet's comfort evaluation, significant differences ($p < .02$) between + 4 dB VL and – 4 dB VL at <u>all</u> *sound pressure levels*, between the Orig. VL and – 4 dB VL at – 3 dB SPL, and between the Orig. VL and + 4 dB VL at the Orig. SPL were found. Furthermore, <u>all</u> *sound pressure levels* differed significantly at <u>all</u> *vibration magnitudes*. All in all, results implied that both aircrafts' comfort evaluation was influenced by *sound pressure levels* and *vibration magnitudes* as well as their specific interaction. For a better view, the interaction between both experimental variables is graphed in Figures 32 and 33. Z-axes are ranging from 1 (minimal „comfortable", respectively maximal „discomfortable") to 7 (maximal „comfortable", respectively minimal „discomfortable").

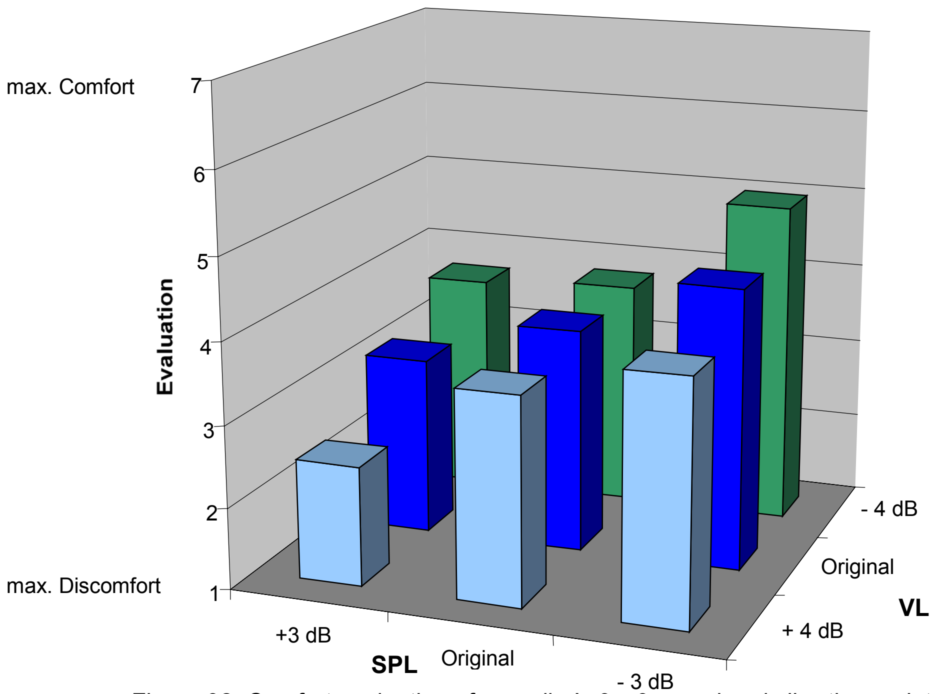


Figure 32: Comfort evaluation of propeller's 3 x 3 sound and vibration variations

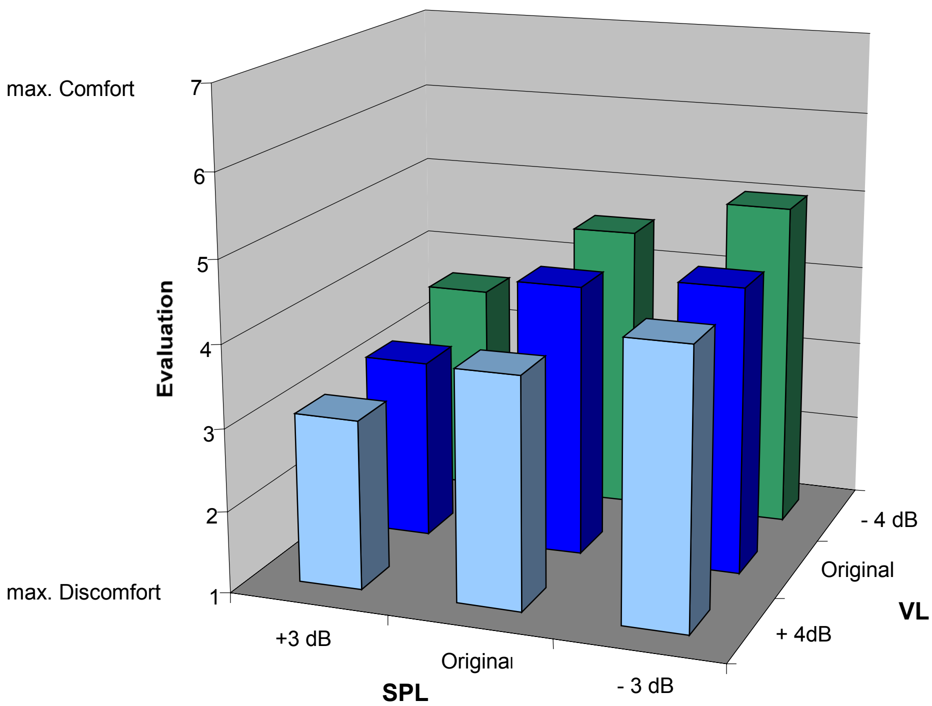


Figure 33: Comfort evaluation of jet's 3 x 3 sound and vibration variations

(B) Interaction between sound and vibration level and their relative contribution to vibration evaluation

Regarding the propeller's vibration evaluation, significant effects of *sound pressure levels*, $F(1.883;54.616) = 3.259$, $p < .049$, and of *vibration magnitudes*, $F(1.519;44.059) = 64.552$, $p < .0001$, emerged. However, the interaction between the main factors was not significant, $F(3.438;99.705) = 1.811$, $p < .142$. Significance of *sound pressure levels*, $F(1.925;55.816) = 5.603$, $p < .007$, and of *vibration magnitudes*, $F(1.810;52.493) = 56.190$, $p < .0001$, also appeared concerning the jet's vibration evaluation. Outcomes again proved no significant two-way interaction, $F(3.228;93.605) = 2.039$, $p < .109$. Application of T-tests revealed significant differences ($p < .02$) between the Orig. SPL and – 3 dB SPL at the Orig. VL of the propeller, and between + 3 dB SPL and – 3 dB SPL at + 4 dB VL and – 4 dB VL of the jet. Altogether, it was concluded that the vibration evaluation of both aeroplanes was dependent on *sound pressure levels* and *vibration magnitudes* but did not seem to be influenced by their interaction. The interaction between both variables is depicted in Figures 34 and 35. Z-axes are ranging from 1 (maximal „vibrating”) to 7 (minimal „vibrating”).

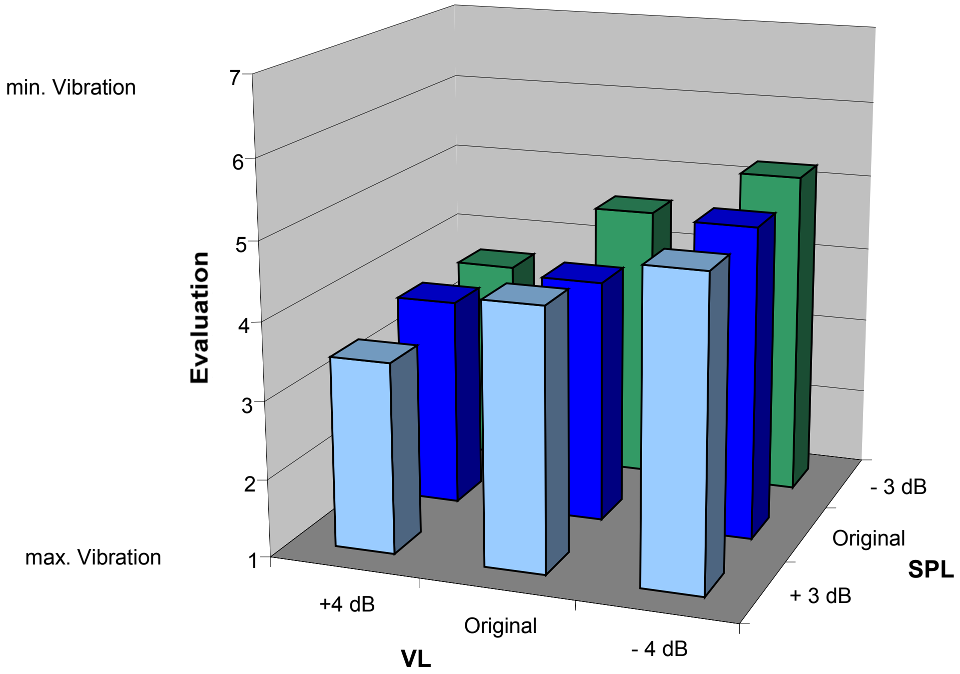


Figure 34: Vibration evaluation of propeller's 3 x 3 sound and vibration variations

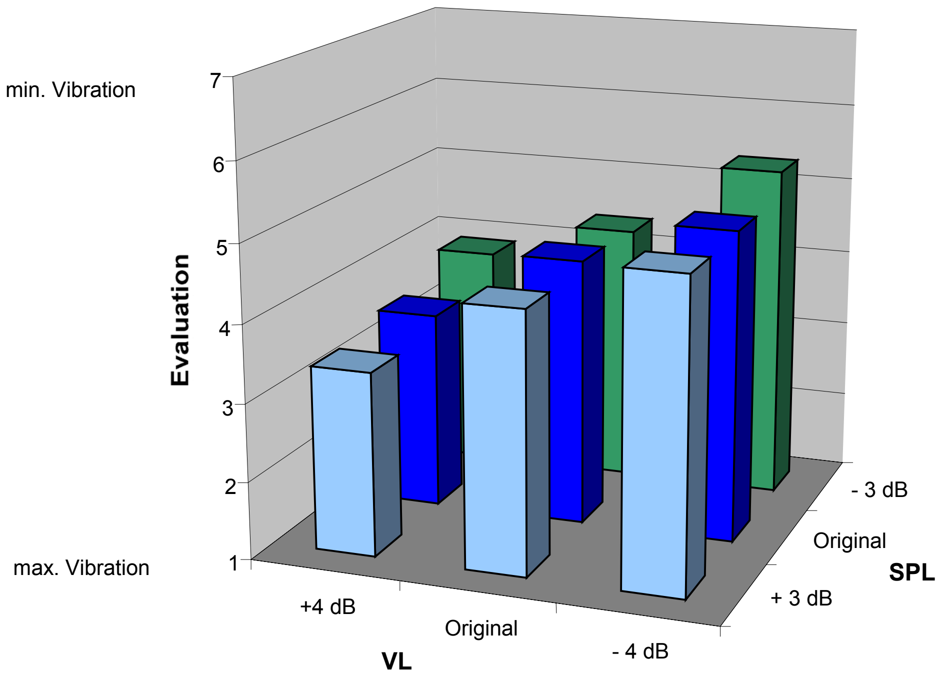


Figure 35: Vibration evaluation of jet's 3 x 3 sound and vibration variations

6.5.4 Mood scale analysis

The influence of subjective mood changes caused by the experimental setting on (comfort) rating of the stimuli was studied by measurements of participants' subjective mood at three times (T1-T3). For this aim, 10 mood scales of the EWL (Janke & Debus, 1978) composing the empirically derived mood dimensions „well-being" and „ill-being" (chapter 5.5.2.1.2) were used.

(A) Influence of experimentally induced changes of subjective mood on stimulus evaluation

A 2-factorial (2 x 3) within-subjects ANOVA was performed over the mean values of well-being and ill-being scales measured at three times. *Subjective mood* (well-being and ill-being) and *times of measurement* were within-subjects factors. Data analysis proved highly significant effects of both *subjective mood*, $F(1;29) = 37.807$, $p < .0001$, and *times of measurement*, $F(1.718;49.827) = 8.423$, $p < .001$. The significant interaction, $F(1.581;45.853) = 4.733$, $p < .020$, reflected that *subjective mood* depended on the *times of measurement*. T-tests accordingly revealed significant differences ($p < .01$) between *well-being* at T1 and T2 as well as at T1 and T3. Significant differences regarding *ill-being* did not appear.

Subsequent analysis focused on the influence of experimentally evoked modifications in well-being on assessment. Difference scores between T1 and T2 were calculated, and a median split of the sample was carried out. The median of well-being was .40. The hypothesis was that well-being in persons with difference scores under the median was influenced less by the experimental setting (group 1: N = 17) than well-being in persons with differences larger than the median (group 2: N = 13). Since theoretical and empirical data proved that well-being and comfort are closely related, it was assumed that both groups should differ at least in comfort evaluation.

For each aircraft type, separate 3-factorial (3 x 3 x 2) ANOVAs were performed together for group 1 and group 2 with *sound pressure levels* and *vibration magnitudes* as within-subjects factors and *group* (according to the mediansplit of the sample regarding changes in well-being) as the between-subjects factor. In addition, T-tests were applied to each sound pressure level and each vibration magnitude to determine group specific differences between ratings due to the variations of vibration magnitude and sound pressure level.

(A1) Influence of experimentally induced changes in well-being on comfort evaluation

Effect of *group* concerning the propeller's comfort evaluation was not obtained, $F(1;28) = 1.769$, $p < .194$. No significant interaction between *group* and *vibration magnitudes,* respectively *sound pressure levels,* and between all factors appeared. This suggested that experimentally induced alterations in well-being did not effect the comfort evaluation neither of propeller's sounds and vibrations nor of their combination. Only *sound pressure levels,* $F(1.747;48.915) = 78.844$, $p < .0001$, and *vibration magnitudes,* $F(1.907;53.401) = 17.007$, $p < .0001$, reached significance. Their significant two-way interaction, $F(2.877;80.550) = 3.655$, $p < .017$, confirmed that the propeller's comfort evaluation was influenced by the interaction between *sound pressure levels* and *vibration magnitudes*. Regarding the jet's comfort evaluation, *group* was not significant, $F(1;28) = 1.385$, $p < .249$. Data revealed a significant two-way interaction between *group* and *vibration magnitudes*, $F(1.524;42.680) = 3.918$, $p < .038$, suggesting that the comfort evaluation of jet's *vibration magnitudes* was dependent on experimentally evoked changes in well-being. Significance of the interaction between *sound pressure levels* and *group*, $F(1.220;34.170) = .109$, $p < .793$, and of the three-way interaction, $F(3.356;93.957) = 1.329$, $p < .267$, was not found implying that neither the sounds' nor the combined sound and vibration comfort evaluation was effected by modifications in well-being. *Sound pressure levels,* $F(1.220;34.170) = 73.420$, $p < .0001$, and *vibration magnitudes,* $F(1.524;42.680) = 11.738$, $p < .0001$, reached significance, and interacted significantly, $F(3.356;93.957) = 2.776$, $p < .048$. This established the result that the jet's comfort evaluation was determined by the interaction between *sound pressure levels* and *vibration magnitudes*. Concerning the propeller's comfort evaluation, T-tests carried out WITHIN both groups showed significant differences ($p < .02$) between the Orig. SPL and – 3 dB SPL at – 4 dB VL, between the Orig. SPL and + 3 dB SPL at + 4 dB VL, and between + 3 dB SPL and – 3 dB SPL at <u>all</u> *vibration magnitudes*. Significant differences appeared between + 4 dB VL and – 4 dB VL as well as between the Orig. VL and - 4 dB VL at - 3 dB SPL. Furthermore, all *vibration magnitudes* differed significantly at + 3 dB SPL. At the Orig. SPL significant differences were not found at all. Regarding the jet's comfort evaluation, significant differences ($p < .02$) emerged WITHIN both groups between <u>all</u> *sound pressure levels* at each *vibration magnitude.* T-tests only proved significant differences ($p < .02$) for group 1 between the Orig. VL and - 4 dB VL as well as between + 4 dB VL and – 4 dB VL at <u>all</u> *sound pressure levels*. Besides, the Orig. VL and + 4 dB VL differed significantly at the Orig. SPL. On closer examination, it was noticeable that group 2, whose well-being was more induced by the experimental setting than group 1's, generally judged all stimuli as being more discomfortable, especially those combinations with – 4 dB VL. The interaction between both experimental variables is illustrated by Figures 36 to 39.

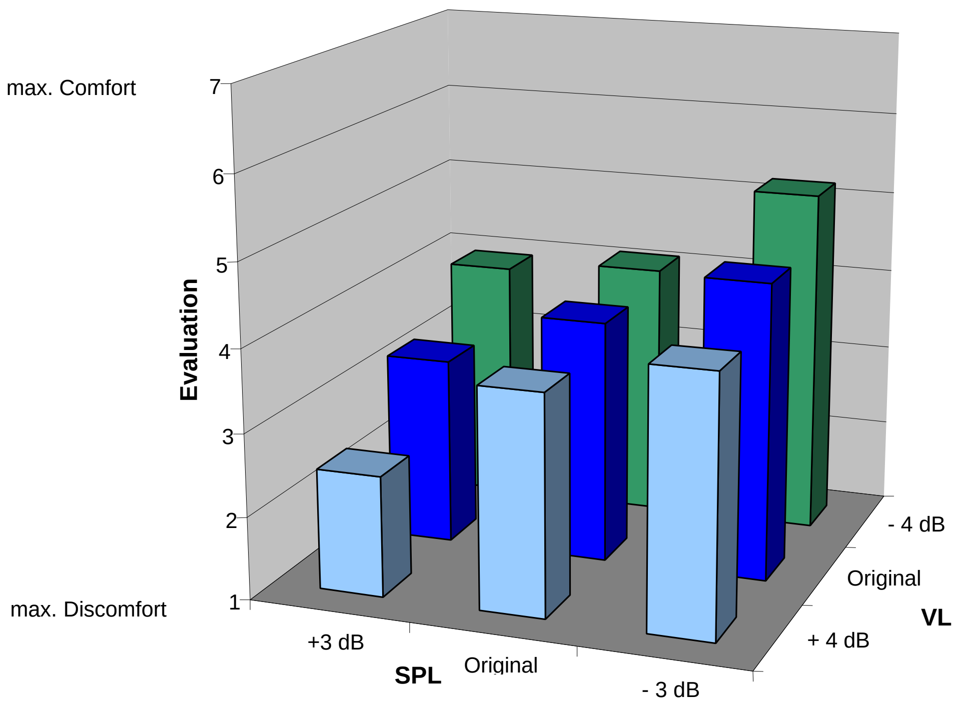


Figure 36: Group 1's comfort evaluation of propeller's 3 x 3 sound and vibration variations

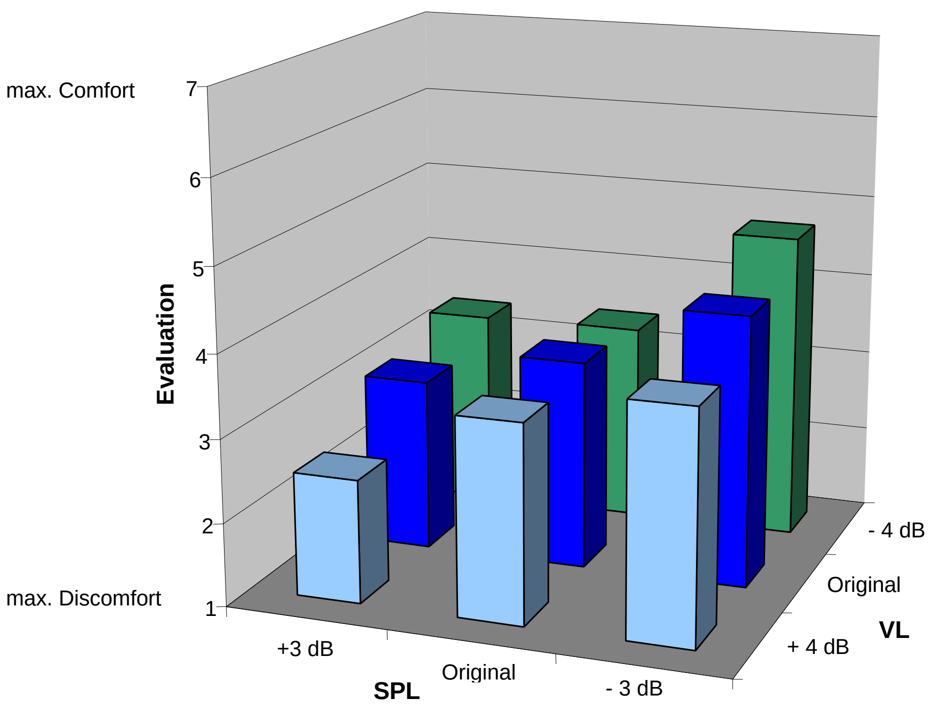


Figure 37: Group 2's comfort evaluation of propeller's 3 x 3 sound and vibration variations

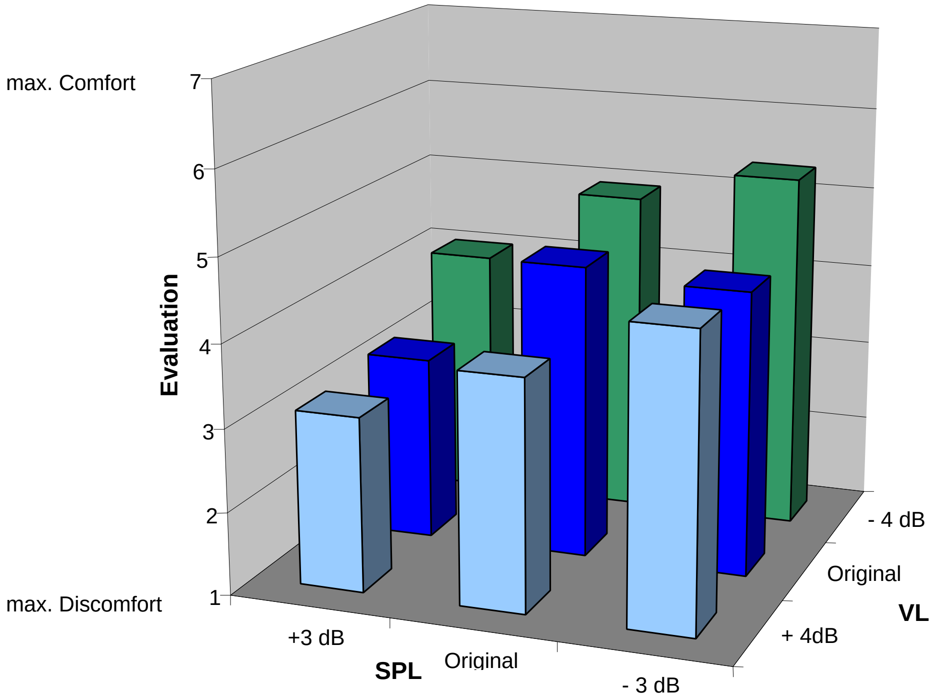


Figure 38: Group 1's comfort evaluation of jet's 3 x 3 sound and vibration variations

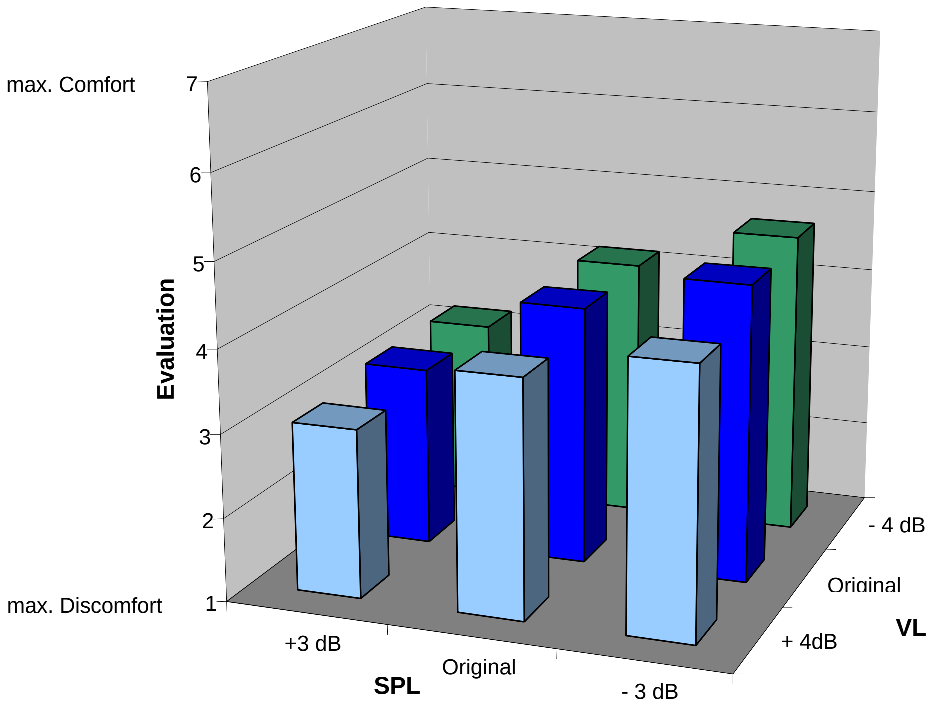


Figure 39: Group 2's comfort evaluation of jet's 3 x 3 sound and vibration variations

(A2) Influence of experimentally induced changes in well-being on vibration evaluation

Regarding the propeller's vibration evaluation, the between-subjects factor was not significant, $F(1;28) = .906$, $p < .349$. Effects of *sound pressure levels*, $F(1.922;53.819) = 3.813$, $p < .030$, and of *vibration magnitudes* , $F(1.542;43.178) = 61.739$, $p < .0001$, were found. *Group* did not approach significance related to the jet's vibration evaluation, $F(1;28) = .070$, $p < .793$. *Sound pressure levels,* $F(1.924;53.880) = 5.420$, $p < .008$, and *vibration magnitudes,* $F(1.767;49.472) = 58.418$, $p < .0001$, were highly significant. For both aircraft types significant interactions did not appear at all which confirmed the outcomes of analysis involving the whole sample. Altogether, results suggested that induced changes in well-being did not influence the vibration evaluation of the stimuli. T-test comparisons conducted WITHIN both groups demonstrated almost no significant evaluation differences due to the variations of *sound pressure levels* and *vibration magnitudes*. However on closer inspection, group 2 generally rated the stimuli as being more vibrating than group 1 did, particularly those combinations with – 4 dB VL (Figures 40 to 43).

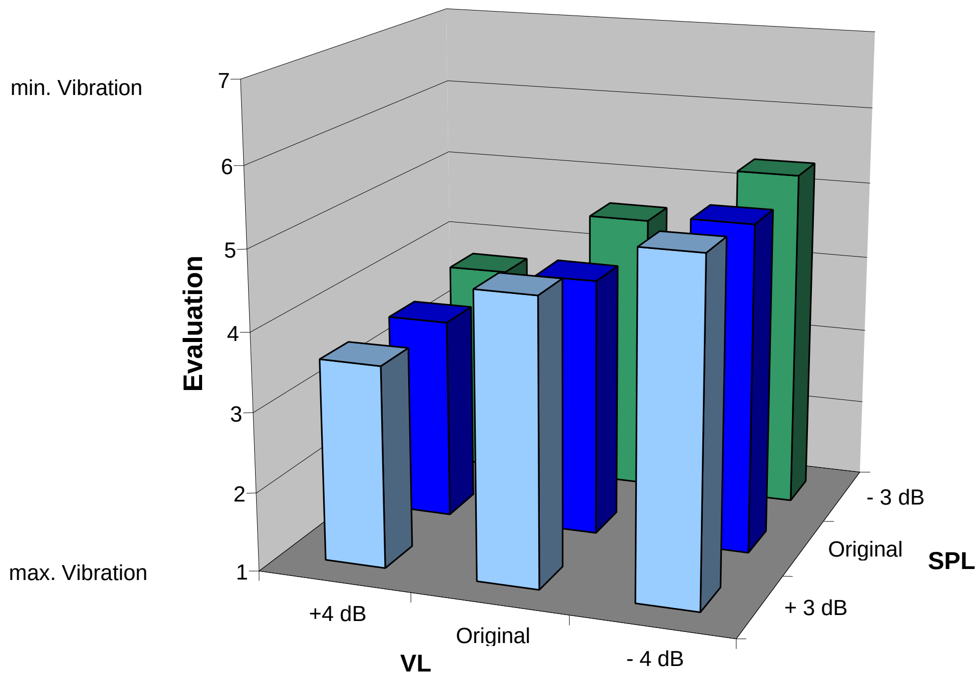


Figure 40: Group 1's vibration evaluation of propeller's 3 x 3 sound and vibration variations

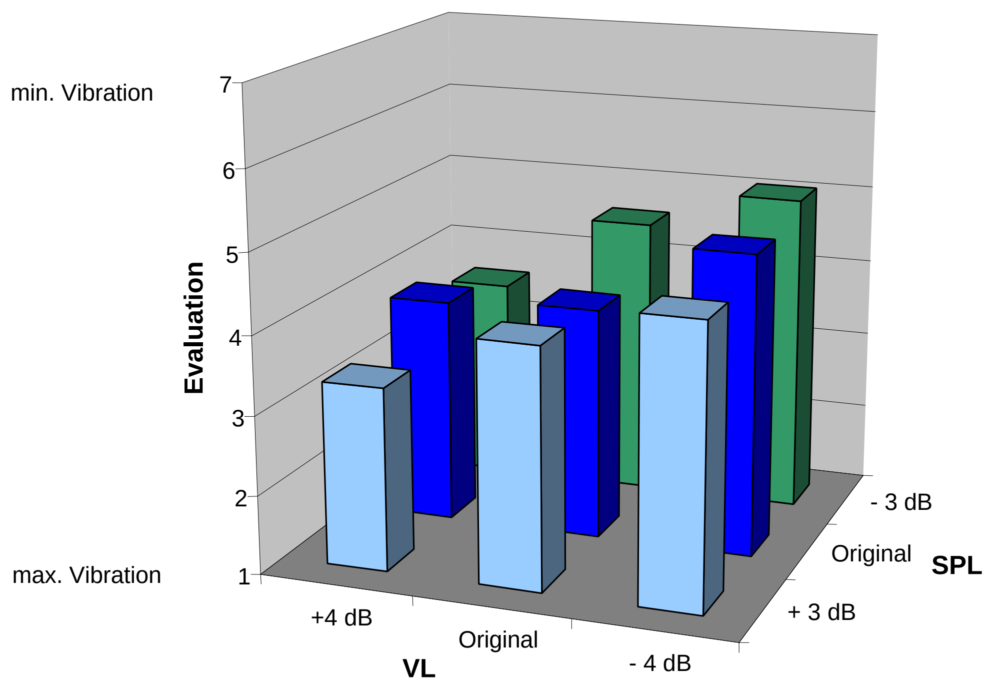


Figure 41: Group 2's vibration evaluation of propeller's 3 x 3 sound and vibration variations

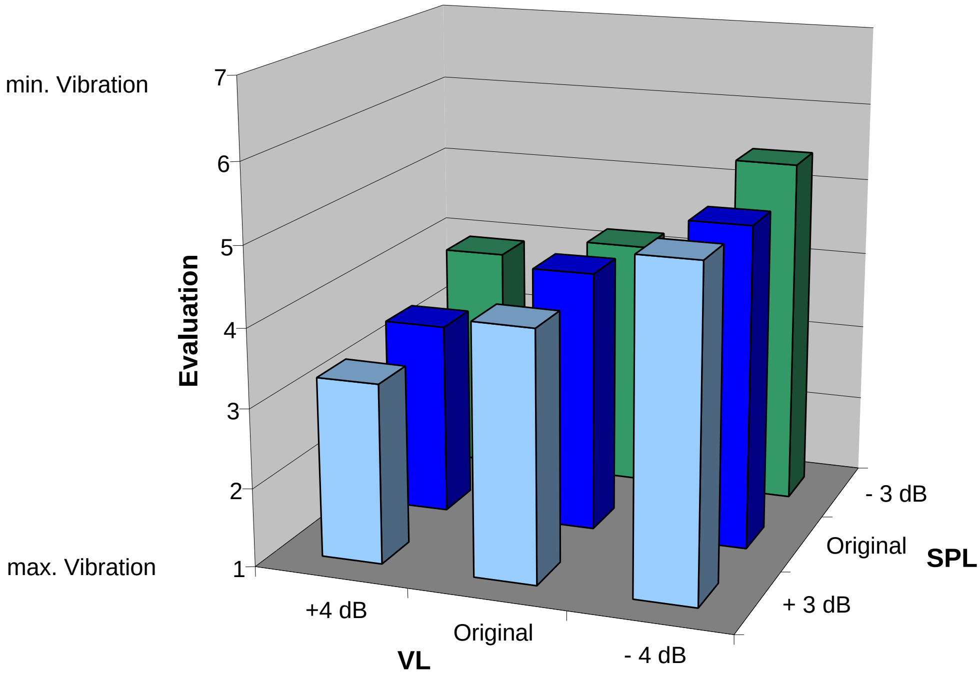


Figure 42: Group 1's vibration evaluation of jet's 3 x 3 sound and vibration variations

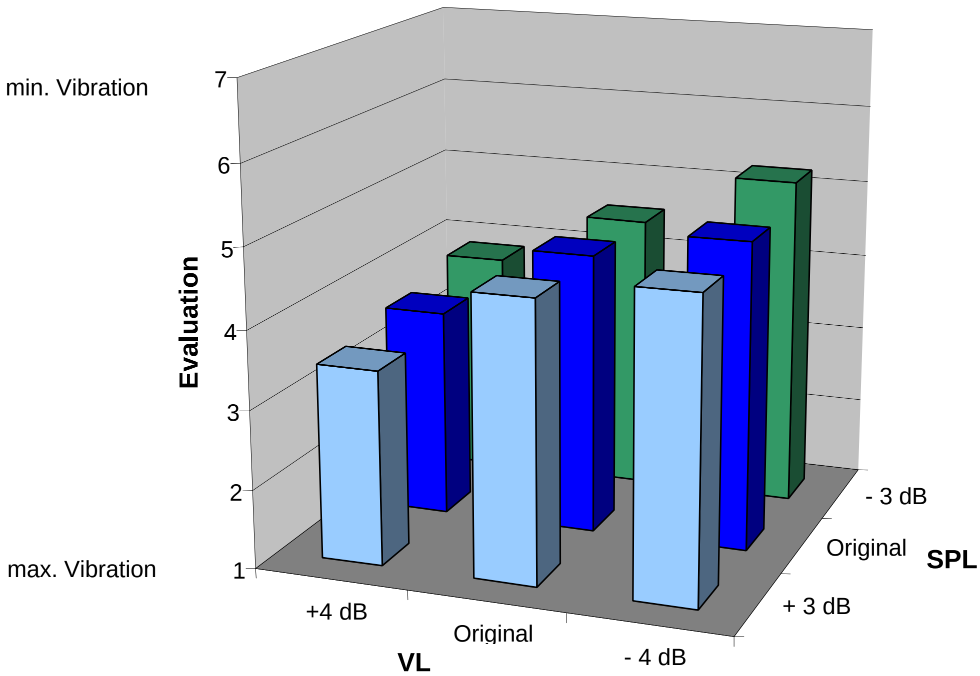


Figure 43: Group 2's vibration evaluation of jet's 3 x 3 sound and vibration variations

(B) Differences between the comfort and vibration evaluation due to vibration sensitivity

Altogether, mood scale analysis have shown that group 2 (who reacted more clearly to the experimental setting in terms of induced changes in well-being from T1 to T2) generally evaluated stimuli, in particular configurations with – 4 dB VL, as being more discomfortable and vibrating than group 1 did. A significant interaction between *group* and jet's *vibration magnitudes* was found, suggesting that the comfort evaluation of jet's *vibration magnitudes* was influenced by experimentally caused alterations in well-being. Furthermore, T-tests indicated that group 2 did not consider variations of *vibration magnitude* in the comfort evaluation of the jet's sounds. With respect to these findings, a possible explanation is that subjects differed in their sensitivity to react to ambient „environmental stressors". This might have found its expression in individual varying degrees of a so-called vibration sensitivity. In order to test this assumption, mean values of each vibration magnitude were calculated by averaging their assessments over all sound pressure levels. 2-factorial (3 x 2) ANOVAs were applied separately to both aircrafts' rating with *mean vibration magnitudes* as the within-subjects factor and *group* as the between-subjects factor.

The *group* factor was not significant concerning the comfort and vibration evaluation of the propeller [comfort evaluation: $F(1;28) = 1.768$, $p < .194$; vibration evaluation: $F(1;28) = .906$, $p < .349$]. Results showed significance of the propeller's *mean vibration magnitudes* concerning the comfort evaluation, $F(1.907;53.402) = 17.008$, $p < .0001$, and vibration evaluation, $F(1.542;43.178) = 61.739$, $p < .0001$. No two-way interaction occurred at all [comfort evaluation: $F(1.907;53.402) = 1.702$, $p < .347$; vibration evaluation: $F(1.542;43.178) = 1.349$, $p < .266$]. Regarding the jet's comfort and vibration evaluation, no significance of *group* emerged [comfort evaluation: $F(1;28) = 1.385$, $p < .249$; vibration evaluation: $F(1;28) = .070$, $p < .793$]. *Mean vibration magnitudes* differed significantly related to comfort evaluation, $F(1.524;42.680) = 11.738$, $p < .0001$, and regarding vibration evaluation, $F(1.767;49.472) = 58.418$, $p < .0001$. Furthermore, both factors interacted significantly concerning comfort evaluation, $F(1.524;42.680) = 3.918$. T-test comparisons proved significant differences ($p < .05$) between group 1 and group 2 related to the comfort evaluation of both aircraft types at – 4 dB VL. Findings are illustrated by Figures 44 and 45.

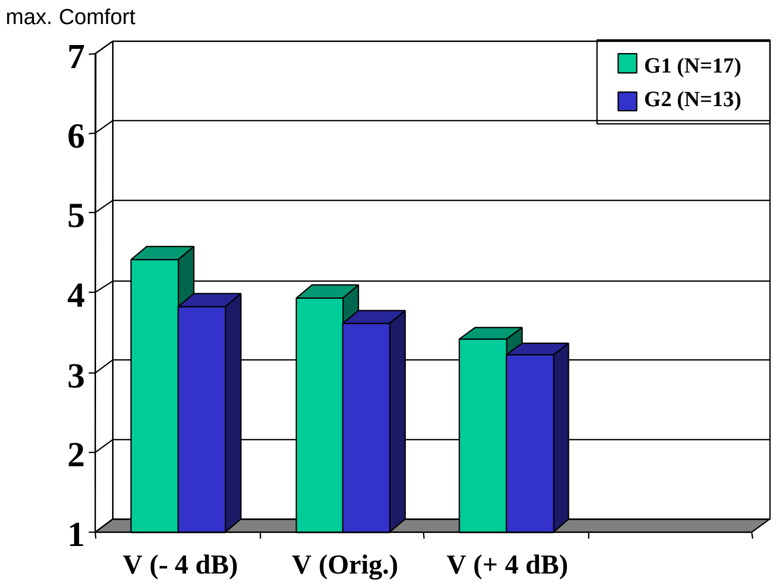


Figure 44: Group 1’s and group 2’s comfort evaluation of the propeller's mean vibration magnitudes (each averaged over three sound pressure levels)

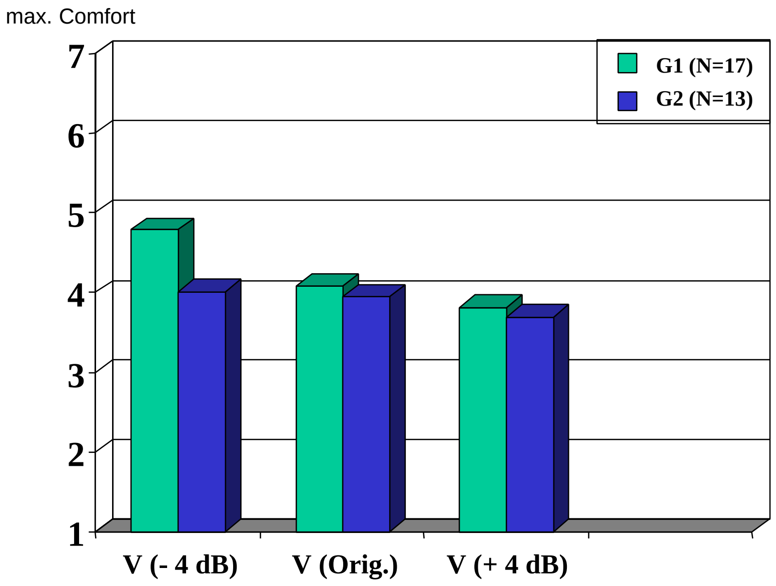


Figure 45: Group 1’s and group 2’s comfort evaluation the of jet's mean vibration magnitudes (each averaged over three sound pressure levels)

6.5.5 Qualitative questionnaire analysis

Remarks of the subjects on what they dis liked and general comments were divided into the following three categories:

(1) Psychophysical conditions in the laboratory

One person claimed the air in the laboratory was bad. One participant disliked the uncomfortable seat position. However, another person emphasised the comfort of the aircraft seat.

(2) Characteristics of the presented sound and vibration configurations

Three subjects disliked the sounds (especially of the propeller). Four participants noticed a strong similarity of the stimuli within each experimental block. Five persons described the loudness as being too high. On average, the ecological validity of the presentations was rated at 4.13 (median: 4.0, modus: 5.0).

(3) Problems with the questionnaire

Regarding the SD, only two subjects claimed that the adjectives were partly difficult to understand. Unfortunately, both did not name the adjectives which caused them problems. Another participant reported having had difficulties with the term „sharp".

Twenty-nine subjects (96.7% of the sample) stated a willingness to participate in a comparable experiment.

Participants’ answers concerning their individual conception of the term comfort and a comfortable flight situation have been presented in chapters 1.1 and 1.2.

6.6 Discussion

Study 2 focused on the interaction between sound and vibration level and their relative contribution to affective evaluations on the perceptional dimension of (vibro-acoustic) comfort. Jet 1 and propeller 2 also presented in study 1 were systematically varied in sound pressure level and vibration magnitude (3 x 3 design) and implemented as stimuli in a laboratory experiment using the „sound and vibration reproduction system" (SVRS). Each configuration was assessed by means of the SD also used in study 1. Results indicated that affective evaluations on the comfort dimension appeared to be dependent on the specific interaction between both ambient „environmental stressors" (Baum et al., 1982; Campbell, 1983; Evans & Cohen, 1987; Guski, 2001; Hamilton, 1979; Humphrey, 1984; Lazarus & Cohen, 1977; Lepore & Evans, 1996). In contrast, ratings on the perceptional dimension of vibration were not influenced by the interaction between sound and vibration. Rather, they were mainly determined by vibration magnitude and only slightly by simultaneously occurring sound. T-test comparisons revealed that at the same sound pressure level (or vibration magnitude) the three magnitudes of vibration (or sound pressure levels) gave rise to significant different comfort judgements. This was an important indication for the suitability of the chosen physical variations of sound and vibration level. An increased sound pressure level combined with an increased vibration magnitude received the least favourable assessments. A decreased sound pressure level combined with a decreased vibration magnitude caused the most comfortable ratings. At almost all sound pressure levels and all vibration magnitudes, an increase in vibration magnitude, respectively sound pressure level decreased comfort as compared to the original levels. This validated the empirical findings regarding the interactive effects of noise and vibration on subjective annoyance responses (Howarth & Griffin, 1990a; 1990b, 1991; Paulsen & Kastka, 1995; Schust et al., 1997, 1998; Seidel, 1997; Splittgerber et al., 1991; Zeichart, 1998; Zeichart et al., 1994a, 1994b). All in all, a synergetic, additive interaction between sound and vibration level concerning the comfort evaluation of combined aircraft interior sound and vibration configurations was found. According to the „masking hypothesis" supposed by Meloni and Krueger (1990), high levels of noise may raise the perception or disturbance thresholds for vibration. Hence, annoyance reactions caused by vibration did not increase with growing magnitude at a simultaneous high noise level. In contrast to this hypothesis, the interaction between sound and vibration level regarding comfort evaluation appeared to be independent of the relative magnitude of both physical parameters. The additive effect of increasing vibration magnitude and sound pressure level was observed at each sound pressure level and each vibration magnitude. As far as the interaction concerns logarithmic quantities, it should be interpreted as being a „multiplicative" one from a linear point of view.

A method that can be used to assess the combined effects of total environments is the employment of multiple regression techniques to provide a model that combines environmental components. This has been performed, for example, to predict the comfort of aircraft passengers (e.g., Jacobson & Richards, 1976, 1978; Jacobson et al., 1978, 1980). In the present study, however, regression analysis could not be not conducted due to the presence of multicollinearity in the data.[13] Instead, the specific contribution of sound pressure level and vibration magnitude to comfort evaluation was estimated by considering the variance explained by each experimental variable. With regard to the propeller, sound pressure level accounted for 74.0 %, and vibration magnitude carried 25.8 % of the variance in the ratings. Concerning the jet, sound pressure level explained 72.3 %, and vibration magnitude carried 26.9 % of the variance. Altogether, results proved that the comfort evaluation of aircraft interior sound and vibration combinations was determined by the sound pressure level at about 70 % and by the vibration magnitude at around 30 %. This was in accordance with the commonly reported dominance of noise regarding subjective annoyance responses. The present findings might be explained in terms of the „contrast hypothesis" (Zeichart et al., 1994a) according to which the dominating (i.e. more negatively valued) „stressor" (sound) tends to divert attention, or masks the effects of vibration, and hence dominates subjective reactions and evaluations. This was supported by the qualitative questionnaire analysis which indicated that participants mainly disliked the sounds (especially of the propeller) due to the high loudness. Accordingly, low, pleasant loudness appeared to represent an important (unfulfilled) comfort need (chapter 1.2).

Since affective responses to vehicle environments represent an integral component of the perceived comfort, and both comfort and well-being are closely related concepts, present research assumed that modifications of subjective mood (especially subjects' well-being) induced by an experimental setting may influence the comfort rating re-

[13]Multicollinearity is given when predictors in regression analysis are highly intercorrelated (Backhaus et al., 1996; Bortz, 1993; Lunneborg & Abbott, 1983; Montgomery & Peck, 1982). This generally creates large standard errors of the regression coefficients and can seriously disturb the least squares fit. Pearson's product-moment correlation coefficients calculated from the vibration magnitudes and sound pressure levels of jet 1 and propeller 2 were uniformly $r = 1.000$ and highly significant ($p < .0001$). Possible solutions of multicollinearity are either to create a new predictor that is simply a composite of the highly correlated predictors or to use only one of the predictors in the set of the intercorrelated variables. In the present study, only two physical predictors were given. Since the individual contribution of sound and vibration level on comfort evaluation should be specified they could not be summarised or selected.

garded as a situational, respectively contextual moderator (Bisping et al., 1990; Blauert & Jekosch, 1997; Evans & Lepore, 1997; Guski, 1997a; Quehl et al., 2000d). Subjective mood was measured at three times (T1-T3) by means of 10 mood scales of the EWL (Janke & Debus, 1978) composing the orthogonal mood dimensions „well-being" and „ill-being" defined in study 1. It was shown that persons who reacted more clearly to the experimental setting (in terms of evoked changes in well-being from T1 to T2) generally judged the stimuli, especially combinations with the decreased vibration magnitude, as being more discomfortable and vibrating than other subjects did. Mood scale analysis revealed a significant interaction between experimentally caused alterations in well-being and the comfort evaluation of the jet's vibration magnitudes. Only the more effected subjects did not consider variations of jet's vibration magnitude in the sounds' comfort evaluation. Interindividual differences in reaction intensity might be explained in terms of a experimental reactivity (Strelau, 1970, 1974, 1982, 1983, 1987, 1989, 1991, 1993, 1995, 1999) or a general sensitivity to respond to ambient „environmental stressors" such as sound and vibration (Höger, 2000; Weinstein, 1980; Winneke et al., 1992, 1996). In the current study, the sensibility towards ambient „stressors" found its expression in an individual varying degree of a so-called vibration sensitivity. Accordingly, it was proved that more and less effected persons differed significantly regarding the vibrations' comfort evaluation (averaged over all sound pressure levels) at the decreased magnitude. More sensitive subjects assessed the low magnitude vibration as being more discomfortable. Since the low magnitude vibration (especially of the jet) has been rated more negatively, no significant comfort evaluation differences between the jet's vibration magnitudes at each sound pressure level appeared because they have been adapted in their level of perceived (dis)comfort.

All in all, findings implied that sound and vibration level additively interacted regarding affective evaluations on the perceptional dimension of (vibro-acoustic) comfort. The interaction appeared to be independent of the relative magnitude of both physical parameters. With respect to the logarithmic nature of both physical parameters, the interaction was interpreted as being a „multiplicative" one from a linear point of view. Mood scale analysis indicated an influence of experimentally induced changes in well-being on comfort and vibration evaluation. Persons who reacted more clearly to the experimental setting generally judged the combinations with the decreased vibration magnitude as being more discomfortable and vibrating than others. This has been explained in terms of an individual differing degree of a vibration sensitivity.

7. SUMMARY AND CONCLUSION

The consideration of comfort is paramount in ensuring user acceptance and economic survival of any modern air transportation technology. The sensation of comfort is influenced by a large variety of physical and psychological factors. Most previous comfort studies were concerned with the impact of physical parameters in transportation. Interior sound and vibration appeared to be among the known main physical determinants. Even though comfort seemed to be a complex function of both sound and vibration, the majority of investigations analysed auditory or vibratory comfort separately. Only a few attempts have been made to systematically relate subjective responses to physical descriptions of vehicle environments. Where mainly discomfort and annoyance reactions were examined, results were limited to their application to combined auditory and vibratory (denoted as vibro-acoustic) comfort optimisation.

The current research which originated from the BRITE EURAM project IDEA PACI (BE97-4056) simultaneously addressed the perception of combined aircraft interior sound and vibration. In order to adjust aircrafts to the subjective comfort needs of the passengers, the way they perceive combined sound and vibration stimuli (particularly with regard to aspects relevant to vibro-acoustic comfort) must be understood. Thus, the nature of the underlying perceptual dimensions and physical correlates distinguishing combined aircraft interior sound and vibration has been studied to approximate passengers' conception of vibro-acoustic comfort and to define desirable physical properties for aircraft's comfort design from their viewpoint (study 1). The interaction between sound and vibration level and their relative contribution to the comfort evaluation of aircraft interior sound and vibration stimuli has been analysed in study 2. A common technique for establishing dimensions of perception is the application of the semantic differential (SD) which measures the aspects of any object's connotative meaning (i.e. emotive, affective and evaluative factors). It offered the possibility to comprehensively characterise auditory and vibratory sensations on the level of semantic descriptors (Schick, 1979, 1995a, 1996a) which were then assigned to physical quantities. Since there was only little known about the perceptual dimensions related to aircraft interior sound and vibration up to now, a concept-specific SD for aircraft interior (sound and vibration) environments has been developed covering 15 semantic descriptors for the perception of interior sound and vibration, for comfort and well-being, and for conventional psychoacoustic parameters (Zwicker, 1999; Zwicker & Fastl, 1999). The major innovations of the constructed SD were the combination of sound and vibration, the novelty of the semantic attributes, and the incorporation of traditional psychoacoustic quantities. Since affective reactions to vehicle environments represent an integral component of the perceived comfort, and both comfort and well-being are closely related concepts, current research additionally examined the relationship between changes of subjective mood (especially subjects' well-being), induced by an experimental setting understood as a situational or contextual moderator variable (Bisping et al., 1990; Blauert & Jekosch, 1997; Evans & Lepore, 1997; Guski, 1997a; Quehl et al., 2000d), and the comfort rating of combined aircraft interior sound and vibration. For this purpose, standardised mood scales of the German Eigenschaftswörterliste (EWL) (Janke & Debus, 1978) constituting the mood aspects „well-being and „fear" have been applied.

Results of the first empirical study proved that affective evaluations of combined aircraft interior sound and vibration can be described by the three fundamental perceptional dimensions of comfort, variation and tonality. Comfort appeared to be a continuous, bipolar dimension of experience ranging from very comfortable to very discomfortable. This bipolarity resulted from the involvement of affective evaluation; comfort has been felt or vice versa (Richards, 1980). Discomfort was mainly related to the intensity of sound and vibration perception such as the experienced loudness or roughness and specific vibration attributes like „vibrating". Thus, persons clearly associated loudness with vibration magnitude in the perceptional space. Vibro-acoustic comfort in aircraft, on the other side, was described by the clustered adjectives „comfortable", „bearable" and „acceptable", denoting a similar quality in the three-dimensional, semantic space of perception. Altogether, vibro-acoustic comfort corresponded to the reviewed lexical, ergonomic, psychological and everyday comfort (and well-being) definitions and theories (e.g., Becker, 1991; Metzger, 1994; Pineau, 1982; Slater, 1985, Zhang et al., 1996). Comfort was commonly defined as a psychological state of subjective well-being (in the sense of relaxation, pleasantness, ease, satisfaction, convenience, or physical freedom of complaints) induced under optimal conditions.
Furthermore, it was shown that the affective evaluations on the perceptional dimensions of comfort and variation were significantly correlated with acoustic, psychoacoustic and vibration parameters. Factor analysis involving subjects derived two independent „latent classes" (McAdams et al., 1995; McAdams & Winsberg, 2000) each employing particular cognitive styles (e.g., Riding 1997; Riding & Cheema, 1991; Riding & Rayner, 1997, 1998) with regard to representative attributes of both dimensions. Factor scores (related to the latent classes) of all stimuli were correlated with physical descriptors. It was found that participants who were more susceptible to the experimental setting (in terms of evoked modifications in well-being)

homogeneously based their judgements on perceived sound pressure level, loudness, roughness, fluctuation strength, tonality and vibration magnitude. An increase in sound pressure level, respectively loudness, roughness, fluctuation strength or vibration magnitude caused a subjective decrease in comfort. The stronger reaction intensity or susceptibility of these persons has been explained in terms of individual variations of experimental reactivity (Strelau, 1970, 1974, 1982, 1983, 1987, 1989, 1991, 1993, 1995, 1999) or general sensitivity to react to ambient „environmental stressors“ such as sound and vibration (Höger, 2000; Weinstein, 1980; Winneke et al., 1992, 1996). As long as well-being and comfort sensation are interdependent, significant assessment differences regarding comfort attributes emerged between the more and less induced subjects.

Findings of the second empirical study indicated that the affective evaluations on the perceptional dimension of (vibro-acoustic) comfort depended on the additive interaction between the ambient „environmental stressors” (Baum et al., 1982; Campbell, 1983; Evans & Cohen, 1987; Guski, 2001; Hamilton, 1979; Humphrey, 1984; Lazarus & Cohen, 1977; Lepore & Evans, 1996) sound and vibration. The interaction was independent of the relative magnitude of both physical parameters. The sound pressure level contributed approximately 70 % and the vibration magnitude about 30 % to the comfort evaluation. This was in accordance with the commonly reported dominance of noise regarding subjective annoyance responses (Howarth & Griffin, 1990a; 1990b, 1991; Paulsen & Kastka, 1995; Schust et al., 1997, 1998; Seidel, 1997; Splittgerber et al., 1991; Zeichart, 1998; Zeichart et al., 1994a, 1994b). With respect to the logarithmic nature of both quantities, the interaction was denoted as „multiplicative” from a linear point of view. Data have been explained in terms of the „contrast hypothesis” (Zeichart et al., 1994a) according to which the dominating and more negatively valued sound generally tends to divert attention, or masks the effects of vibration, and hence dominates subjective reactions and evaluations.
Mood scale analysis revealed that persons who reacted more clearly to the experimental setting (in terms of evoked changes in well-being) rated the combinations with decreased vibration magnitude as being more discomfortable and vibrating than the less induced participants. This has been explained in terms of a so-called vibration sensitivity.

In the research reported here the analysis of combined auditory and vibratory (vibro-acoustic) comfort in aircraft integrated both affective components involved in comfort sensation and physical descriptions of aircraft interior sound and vibration stimuli. As a dimension of semantic, perceptional space, vibro-acoustic comfort (such as comfort in

general) represented a kind of subjective well-being induced under optimal conditions; its opposite given by qualities characterising the intensity of sound and vibration perception which appeared to be closely related. The optimal physical conditions underlying vibro-acoustic in aircraft comfort included low levels of sound (at 70 %) and vibration (at 30 %). Accordingly, from the passengers' viewpoint comfort design for aircraft can still profit by efforts towards a general sound and vibration level reduction following the idea that „less is more".
Results proved an influence of experimentally caused changes in well-being on rating of comfort. Thus, not only affective evaluations but also affective reactions to real or artificial vehicle environments should be considered in defining standards of comfort optimisation. Affective reactions entail a reference to the self as reacting to stimuli, whereas affective evaluations concern the analysis of the affective qualities of stimuli. It has been shown that both concepts clearly overlap, i.e. affective reaction (I feel uncomfortable) is related to the evaluation (the stimulus is uncomfortable). In the current studies, affective reactions seemed to have the status of a situational, respectively contextual moderator and hence should be taken into account in any study regarding the subject of „comfort".

The present research is limited in several aspects. First, it was specifically related to sound and vibration in fixed-wing aircraft (propeller and jet aeroplanes). Consequently, the research was constrained to the variation of the derived perceptual dimensions discriminating aircraft interior sound and vibration. The studies dealt with restricted physical gradations of the stimuli with regard to acoustic, psychoacoustic and vibration quantities. Furthermore, the research was limited to simulated vibrations reproduced in the lateral axis. In a real aircraft the vibration pattern is more complex consisting of lateral, vertical, fore-an-aft as well as rotational vibrations. Future research could gain from investigating affective evaluations of and reactions to complex vibrations combined with complex sound environments. All in all, an enlargement of the physical stimulus range is needed to verify the empirically derived multidimensional, semantic space of perception of aircraft interior sound and vibration. It is believed that the chosen approach and methodology is valid for the study of a variety of auditory and vibratory stimuli. It may also be applied to other means of transportation than solely aircraft. Moreover, besides sound and vibration other physical environmental parameters also exhibiting importance for a supportive vehicle environment should be taken into account (e.g., temperature, ventilation, seating and spatial arrangements). Research integrating multi-modal perception and subjective evaluations would advance the knowledge on the fundamentals of comfort sensation in transportation. To achieve a high degree of ecological validity, human comfort responses should be investigated during conditions closely resembling real transportation settings. Besides the application of realistic mock-ups and other experimental set-ups such as sound and vibration reproduction systems, another possibility is to use „virtual reality" technology to simulate real vehicle environments with respect to experiences in different sensory modalities in a lifelike and appropriate manner.

REFERENCES

Abe, K., Ozawa, K., Suzuki, Y. & Sone, T. (1998). Evaluation of environmental sounds using adjectives describing sound quality, emotional state, and information carried by sounds. *Journal of the Acoustical Society of Japan, 54*, 343-350.

Abe, K., Ozawa, K., Suzuki, Y. & Sone, T. (2000). The factors for perceiving sound environments and the influence/effects of visual and verbal information on the factors. In: Schick, A., Meis, M. & Reckhardt, C. (Eds.). Contributions to psychological acoustics. Results of the eighth Oldenburg symposium on psychological acoustics. Oldenburg: bis.

Abele-Brehm, A. & Brehm, W. (1986). Zur Konzeptualisierung und Messung von Befindlichkeit. Die Entwicklung der "Befindlichkeitsskalen" (BFS). *Diagnostica, 32*, 209-228.

American Standard Association (1960). Acoustical terminology. New York: American Standard Association.

Andresen, J. & Moller, H. (1984). Equal annoyance contours for infrasonic frequencies. In: Moller, H. (Ed.). Effects of infrasound on man. A monograph of research carried out at Aalborg University. Institute of Electronic Systems (AUC). Aalborg: University Press.

Armelang, M. & Bartussek, D. (1997). Differentielle Psychologie und Persönlichkeitsforschung. Stuttgart: Kohlhammer.

Aspinall, D.T. (1966). An empirical investigation of low frequency wind noise in motor cars. MIRA Report No. 1966/2. Nuneaton: Motor Industry Research Association.

Aures, W. (1985). Ein Berechnungsverfahren der Rauhigkeit. *, 58*, 268-281.

Backhaus, K., Erichson, B., Plinke, W. & Weiber, R. (1996). Multivariate Analysemethoden. Eine anwendungsorientierte Einführung. Berlin: Springer.

Backteman, O. (1987). Why is low frequency noise annoying? In: Proceedings of the Inter-noise '87, 1025-1028.

Backteman, O., Köhler, J. & Sjöberg, L. (1983a). Infrasound-tutorial review: part 1. *Journal of Low Frequency Noise and Vibration, 2*, 1-31.

Backteman, O., Köhler, J. & Sjöberg, L. (1983b). Infrasound-tutorial review: part 2. *Journal of Low Frequency Noise and Vibration, 2*, 176-210.

Baird, J.C., Harder, K. & Preis, A. (1997). Annoyance and community noise: psychophysical model of dose-response relationships. *Journal of Environmental Psychology, 17*, 333-343.

Baum, A., Singer, J.E. & Baum, C.S. (1982). Stress and the environment. In: Evans, G.W. (Ed.). Environmental stress. Cambridge: Cambridge University Press.

Baumann, U. & Dittrich, A. (1972). Überprüfung der deutschen Version eines Polaritätenprofils zur Erfassung der Befindlichkeit. *Zeitschrift für klinische Psychologie, 1*, 335-350.

Becker, P. (1988). Ein Strukturmodell der emotionalen Befindlichkeit. *Psychologische Beiträge, 30*, 514-536.

Becker, P. (1991). Theoretische Grundlagen. In: Abele, A. & Becker, P. (Hg.). Wohlbefinden. Theorie. Empirie. Diagnostik. Weinheim: Juventa.

Békésy, G. v. (1936). Über die Hörschwelle und Fühlgrenze langsamer sinusförmiger Luftdruckschwankungen. *Annalen der Physik*, *26*, 554-556.

Bell, P.A., Fisher, J.D., Baum, A. & Greene, T.C. (1990). Environmental psychology. Fort Worth: Holt, Rinehart and Winston.

Bellmann, M.A., Mellert, V., Reckhardt, C. & Remmers, H. (2000). Experimente zur Wahrnehmung von Vibrationen. In: Fortschritte der Akustik - DAGA 2000, 494-495.

Bellmann, M.A., Mellert, V., Remmers, H. & Weber, R. (2000). Experiments on the perception of whole-body vibration. Presented at the 35th UK Group Meeting on Human Response to Vibration, Southampton, 2000.

Beran, V., Girg, J. & Ledvionvá, M. (1992). Messung und Bewertung des Infraschallpegels in verschiedenen Verkehrsmitteln. In: Proceedings of the 17th International Association against Noise Congress, Prague, 234-237.

Bergler, R. (Hg., 1975). Das Eindrucksdifferential. Bern: Huber.

Berglund, B., Berglund, U. & Lindvall, T.H. (1975a). Scaling loudness, noisiness and annoyance of aircraft noise. *Journal of the Acoustical Society of America, 57*, 930-934.

Berglund, B., Berglund, U. & Lindvall, T.H. (1975b). On perceptual interaction of noise and odor. The University of Stockholm, Reports from the Department of Psychology, 445, 1-10.

Berglund, B., Hassmén, P. & Job, R.F.S. (1996). Sources and effects of low-frequency noise. *Journal of the Acoustical Society of America, 99*, 2985-3002.

Berglund, B. & Job, R.F.S. (1994). Psychological factors and physiological responses to environmental noise. In: Proceedings of 23rd International Congress of Applied Psychology, Abstracts, 117, SY ENV(2)1.

Berglund, B. & Nilsson, M.E. (1997). Empirical issues concerning annoyance models for combined community noises. In: Proceedings of the Inter-noise ‘97, 1053-1058.

Berlyne, D.E. (1960). Conflict, curiosity and arousal. New York: McGraw-Hill.

Berlyne, D.E. (1971). Aesthetics and psychobiology. New York: Appleton-Century-Crofts.

Bieri, J. (1971). Cognitive structures in personality. In: Schroder, H.M. & Suedfeld, P. (Eds.). Personality theory and information processing. New York: Ronald Press Company.

Birbaumer, N. & Schmidt, R.F. (1996). Biologische Psychologie. Berlin: Springer.

Bismarck, G. v. (1972). Extraktion und Messung von Merkmalen der Klangfarbenwahrnehmung stationärer Schalle. Dissertation an der TU München.

Bismarck, G. v. (1974a). Timbre of steady sounds: a factorial investigation of its verbal attributes. *Acustica, 30*, 146-158.

Bismarck, G. v. (1974b). Sharpness as an attribute of the timbre of steady sounds. *Acustica, 30*, 159-192.

Bisping, R. (1994). Digital generation of acoustical target for car sound engineering based on psychometrical data. In: Proceedings of the Inter-noise ‘94, 869-874.

Bisping, R. (1995). Emotional effect of car interior sounds: pleasantness and power and their relation to acoustic key features. *SAE paper 951284*, 1203-1209.

Bisping, R. (1997). Car interior sound quality: experimental analysis by synthesis, *Acta Acustica, 83*, 813-818.

Bisping, R., Steingrüber, H.J., Oltmann, W. & Wenk, C. (1990). Adult’s tolerance of cries: an experimental investigation of acoustic features. *Child Development, 61*, 1218-1229.

Bjarne, K. & Moller, H. (1981). Loudness and annoyance of infrasound. In: Proceedings of the Inter-noise ‘81, 761-764.

Blauert, J. & Jekosch, U. (1997). Sound quality evaluation – a multi-layered problem. *Acta Acustica, 83*, 747-753.

Bock, M., Lazarus, H. & Höge, H. (1985). Über die Gefahrenbedeutung akustischer Betriebssignale. *Zeitschrift für Lärmbekämpfung, 32*, 9-17.

Boemak, N. (1994). Bewertung von Motorgeräuschen durch subjektiven Vergleich im Akustiklabor. *Zeitschrift für Lärmbekämpfung, 41*, 84-88.

Borchers, I.U., Rohde, T., Klöppel, V., Emborg, U., Ligu, C., Gleine, W. & Sollo, A. (1998). The passenger environment: internal noise. In: Proceedings of the 3rd Aero Days Post-Conference, 130-132.

Bortz, J. (1993). Statistik. Für Sozialwissenschaftler. Berlin: Springer.

Borucki, H. (1989). Einführung in die Akustik. Mannheim: BI Wissenschafts-Verlag.

Bradburn, N.M. (1969). The structure of psychological well-being. Chicago: Aldine.

Bradburn, N.M. & Caplovitz, D. (1965). Reports on happiness. A pilot study of behavior related to mental health. Chicago: Aldine.

Bradley, M.M. & Lang, P.J. (2000). Affective reactions to acoustic stimuli. *Psychophysiology, 37*, 204-215.

Branton, P. (1966). The comfort of easy chairs. *Furniture Industry Research Association Report No. 22*.

Branton, P. (1969). Behaviour, body mechanics and discomfort. *Ergonomics, 12*, 316-327.

Branton, P. & Grayson, G. (1967). An evaluation of train seats by observation of sitting behaviour. *Ergonomics, 10*, 35-51.

Bregman, A.S. (1990). Auditory scene analysis. Cambridge: MIT.

Broadbent, D.E. (1971). Decision and stress. New York: Academic.

Broadbent, D.E. (1972). Individual differences in annoyance by noise, *Sound, 6,* 56-61.

Broner, M. (1978a). Low frequency and infrasonic noise in transportation. *Applied Acoustics, 11*, 129-145.

Broner, M. (1978b). The effects of low frequency noise on people - a review. *Journal of Sound and Vibration, 58*, 483-500.

Broner, M. & Leventhall, H.G. (1980). A modified PNdB for assessment of low frequency noise. *Journal of Sound and Vibration, 73*, 271-277.

Broner, M. & Leventhall, H.G. (1983). Low frequency noise annoyance assessment by low frequency noise rating. *Journal of Low Frequency Noise and Vibration, 2*, 20-28.

Bryan, M.E. (1976a). Low frequency noise annoyance. In: Tempest, W. (Ed.). Infrasound and low frequency vibration. London: Academic.

Bryan, M.E. (1976b). A tentative criterion for acceptable noise levels in passenger vehicles. *Journal of the Acoustical Society of America,48*, 525-535.

Bryan, M.E., Tempest, W. & Williams, D. (1978). Vehicle noise and the passenger. *Applied Ergonomics, 9*, 151-154.

Campbell, J. (1983). Ambient stressors. *Environment and Behaviour, 15*, 355-380.

Cannon, J. (1932). The wisdom of the body. New York: Norton.

Carp, F.M. & Carp, A. (1984). A complementary/congruence model of well-being of mental health for community elderly. In: Altman, I., Lawton, M.P. & Wohlwill, J.F. (Eds.). Elderly people and the environment. Human behavior and the environment. Advances in theory and research, Vol. 7. New York: Plenum.

Carpentier, E.F. Le (1969). Easy chair dimensions for comfort - a subjective approach. *Ergonomics, 12*, 328-337.

Chemnitz, S. (1990). Von Leisetretern und Konzertsälen. Akustik bei Mercedes-Benz. Stuttgart: Daimler Benz AG.

Chouard, N. & Hempel, T. (1999). A semantic differential design especially developed for the evaluation of interior car sounds. *Acta Acustica, 85*, 229.

Clarke, M.J. (1979). A study of the available evidence on duration effects on comfort and task proficiency under vibration. *Journal of Sound and Vibration, 65*, 107-123.

Cohen, S. (1978). Environmental load and allocation of attention. In: Baum, A., Singer, J.E. & Valins, S. (Eds.). Advances in environmental psychology, Vol. 1. The urban environment. Hillsdale: Lawrence Erlbaum.

Cohen, S. (1980). After-effects of stress on human performance and social behaviour: a review of research and theory. *Psychological Bulletin, 88*, 82-108.

Cohen, S., Evans, G.W., Stokols, D. & Krantz, D.S. (1986). Behavior, health, and environmental stress. New York: Plenum.

Collier's dictionary (1994). A to J. New York: P.F. Collier.

Corlett, E.N. & Bishop, R.P. (1976). A technique for assessing postural discomfort. *Applied Ergonomics, 19*, 175-182.

Coyne, J.C. & Lazarus, R.S. (1981). Cognitive style, stress perception, and coping. In: Kutash, I.L. & Schlesinger, L.B. (Eds.). Handbook of stress and anxiety. San Francisco: Jossey-Bass.

Daniel, P. & Weber, R. (1997). Psychoacoustical roughness: implementation of an optimized model. *Acta Acustica, 83*, 113-123.

Dempsey, T.K., Leatherwood, J.D. & Clevenson, S.A. (1976). Noise and vibration ride comfort criteria. NASA Technical Reports, TM-X-73975.

Dempsey, T.K., Leatherwood, J.D. & Drezek, A.B. (1976). Passenger ride quality within noise and vibration environment. NASA Technical Reports, TM-X-72841.

Dempsey, T.K., Leatherwood, J.D. & Sherman, A.C. (1978). Development of noise and vibration ride comfort criteria. *Journal of the Acoustical Society of America, 65*, 124-132.

Diener, E. (1984). Subjective well-being. *Psychological Bulletin, 95*, 542-575.

Diener, E. & Emmons, R.A. (1984). The independence of positive and negative affect. *Journal of Personality and Social Psychology, 47*, 1104-1117.

Diener, E., Larsen, R.J., Levine, S. & Emmons, R.A. (1985). Frequency and intensity: the underlying dimensions of positive and negative affect. *Journal of Personality and Social Psychology, 48*, 1253-1265.

DIN 1320 (1997). Akustik. Begriffe. Berlin: Beuth.

DIN 45681 (1992). Bestimmung der Tonhaltigkeit von Geräuschen und Ermittelung eines Tonzuschlages für die Beurteilung von Geräuschemissionen, Entwurf. Berlin: Beuth.

Duffy, E. (1962). Activation and behavior. New York: Wiley.

Dupuis, H. (1979). Lärm und andere physikalische Einflußfaktoren. *Zeitschrift für Arbeitswissenschaft, 33*, 23-26.

Eade, P.W. & Hardy, E.J. (1977). Railway vehicle internal noise. *Journal of Sound and Vibration, 51*, 403-415.

Ebe, K. & Griffin, M.J. (2000a). Qualitative models of seat discomfort including static and dynamic factors. *Ergonomics, 43*, 771-790.

Ebe, K. & Griffin, M.J. (2000b). Quantitative prediction of overall seat discomfort. *Ergonomics, 43*, 791-806.

Edworthy, J., Hellier, E. & Hards, R. (1995). The semantic associations of acoustic parameter commonly used in the design of auditory information and warning signals. *Ergonomics, 38*, 2341-2361.

Ertel, S. (1964). Die emotionale Natur des „semantischen“ Raumes. *Psychologische Forschung, 8*, 1-32.

Ertel, S. (1965). Standardisierung eines Eindrucksdifferentials. *Zeitschrift für experimentelle und angewandte Psychologie, 12*, 21-58.

Evans, G.W. & Cohen, S. (1987). Environmental stress. In: Stokols, D. & Altman, I. (Eds.). Handbook of environmental psychology, Vol. 1. New York: Wiley.

Evans, G.W. & Lepore, S.J. (1997). Moderating and mediating processes in environment-behavior research. In: Moore, G.T. & Marans, R.W. (Eds.). Advances in environment, behavior, and design. Vol. 4. Towards the integration of theory, methods, research, and utilization. New York: Plenum.

Evans, M.J. & Tempest, W. (1972). Some effects of infrasound noise in transportation. *Journal of Sound and Vibration, 22*, 19-24.

Evans, M.J. & Yeowart, N.S. (1974). Thresholds of audibility for very low-frequency pure tones. *Journal of the Acoustical Society of America, 55*, 814-818.

Fastl, H. (1990). Gehörbezogene Lautstärke. Messverfahren in der Musik. *Das Orchester, 38*, 1-6.

Fastl, H. (1997). The psychoacoustics of sound-quality evaluation. *Acta Acustica, 83*, 754-764.

Fastl, H. & Widmann, U. (1990). Subjective and physical evaluation of aircraft noise. *Noise Control Engineering Journal, 35*, 61-63.

Fiedler, K. (1985). Kognitive Strukturierung der sozialen Umwelt: Untersuchungen zur Wahrnehmung kontingenter Ereignisse. Göttingen: Hogrefe.

Fields, J.M. (1993). Effects of personal and situational variables on noise annoyance in residential areas. *Journal of the Acoustical Society of America, 93*, 2753-2763.

Fields, J.M. & Walker, J.G. (1982). Comparing the relationships between noise level and annoyance in different surveys: a railway noise vs. aircraft and road traffic comparison. *Journal of Sound and Vibration, 81*, 51-80.

Fields, J.M. & Walker, J.G. (1983). Annoyance due to railway noise and road traffic noise: a further comparison. *Journal of Sound and Vibration*, *88*, 275-281.

Fink, W.F. (1987). Kognitive Stile, Informationsverhalten und Effizienz in komplexen betrieblichen Beurteilungsprozessen: theoretische Ansätze und ihre empirische Prüfung. Frankfurt am Main: Peter Lang.

Finke, H.-O., Guski, R. & Rohrmann, B. (1980). Betroffenheit einer Stadt durch Lärm. Bericht über eine interdisziplinäre Untersuchung. Berlin: Umweltbundesamt-Texte.

Fischer, M. (1991). Umwelt und Wohlbefinden. In: Abele, A. & Becker, P. (Hg.). Wohlbefinden. Theorie - Empirie - Diagnostik. Weinheim: Juventa.

Fiske, D. & Maddi, S. (1961). Functions of varied experience. Homewood: Dorsey.

Fisseni, H.-J. (1998). Persönlichkeitspsychologie. Auf der Suche nach einer Wissenschaft. Ein Theorienüberblick. Göttingen: Hogrefe.

Flade, A. (1978). Die Beurteilung umweltpsychologischer Konzepte mit einem konzeptspezifischen und einem universellen semantischen Differential. *Zeitschrift für experimentelle und angewandte Psychologie, 15,* 367-378.

Fleischer, G. (1990). Lärm - Der tägliche Terror. Stuttgart: Thieme.

Flemming, D.B. & Griffin, M.J. (1975). A study of the subjective equivalence of noise and whole-body vibration. *Journal of Sound and Vibration, 42*, 453-461.

Flindell, I.H. (1983). Pressure L_{eq} and multiple noise sources: a comparison of exposure-response relationships for railway noise and road traffic noise. *Journal of Sound and Vibration, 87*, 327-330.

Flindell, I.H. (1997). Noise assessment methodology in multisource environments. In: Proceedings of the Inter-noise '97, 1037-1040.

Floyd, A. (1976). Cognitive styles. Milton Keynes: Open University Press.

Folkman, S., Schaefer, C. & Lazarus, R.S. (1979). Cognitive processes as a mediation of stress and coping. In: Hamilton, V. & Warburton, D.M. (Eds.). Human stress and cognition. An information processing approach. New York: Wiley.

Fothergrill, L.C. (1972). A study of subjective response to whole-body vibration. M.Sc. Thesis, University of Southampton.

Friedlein, J. (1989). "Subjektive Akustik" - Ein objektives Mittel der Geräuschbeurteilung? Stuttgart: Daimler Benz AG.

Fuchs, G.L. (1993). Low frequency noise and vibration. In: Proceedings of the International Noise and Vibration Control Conference 1993, St. Petersburg, 29-34.

Gabrielsson, A. & Lindström, B. (1985). Perceived sound quality of high-fidelity loudspeakers. *Journal of the Audio. Eng. Society, 33*, 33-53.

Gabrielson, T.B. (1997). Infrasound. In: Crocker, M. J. (Ed.). Encyclopaedia of acoustics. Vol. 1. New York: Wiley.

Gavreau, V. (1968). Infrasound. *Science Journal, Jan. 1968*, 33-37.

Geisser, S. & Greenhouse, S. W. (1958). An extension of Box's results on the use of the F-distribution in multivariate analysis. *Annals of Mathematical Statistics, 29*, 885-891.

Genuit, K. (1994). Sound engineering of vehicle noise. In: Proceedings of the Internoise '94, 875-880.

Genuit, K. (1997). Background and practical examples of sound design. *Acta Acustica, 83*, 805-812.

Gierke, H.E. v. & Nixon, C.W. (1976). Effects of intense infrasound on man. In: Tempest, W. (Ed.). Infrasound and low frequency vibration. London: Academic.

Gierke, H.E. v. & Parker, D.E. (1976). Infrasound. In: Keidel, W. D. & Neff, W. D. (Eds.). Handbook of sensory physiology, Vol. V/3. Berlin: Springer.

Gifford, R. (1987). Environmental psychology. Principles and practice. Boston: Allyn and Bacon.

Glass, D.C. & Singer, J.E. (1972). Urban stress. Experiments on noise and social stressors. New York: Academic.

Goldstein, K.M. & Blackman, S. (1978). Cognitive style: 5 approaches and relevant research. New York: Wiley.

Grandjean, E. (1980). Sitting posture of car drivers from the point of view of ergonomics. In: Oborne, D.J. & Levis, J.A. (Eds.). Human factors in transport research, Vol. 2, user factors: comfort, the environment and behaviour. New York: Academic.

Grandjean, E. (1984). Postural problems at office machine workstations. In: Grandjean. E. (Ed.). Ergonomics and health in modern offices. London: Taylor & Francis.

Grey, J.M. (1975). An exploration of musical timbre. Ph.D. Dissertation, Department of Psychology, Stanford University.

Grey, J.M. (1977). Multidimensional perceptual scaling of musical timbres. *Journal of the Acoustical Society of America, 61*, 1270-1277.

Grey, J.M. (1978). Timbre discrimination in musical patterns. *Journal of the Acoustical Society of America, 64*, 467-472.

Grey, J.M. & Gordon, J.W. (1978). Perceptual effects of spectral modifications on musical timbres. *Journal of the Acoustical Society of America, 63*, 1493-1500.

Grey, J.M. & Moorer, J.A. (1977). Perceptual evaluation of synthesized musical instrument tones. *Journal of the Acoustical Society of America, 62*, 454-462.

Griffin, M.J. (1990). Handbook of human vibration. London: Academic.

Griffin, M.J. (1992). Vibration. In. Griffin, M.J. (Ed.). Handbook of human performance, Vol. 1. London: Academic.

Griffin, M.J. (1997). Vibration and motion. In: Salvendy, G. (Ed.). Handbook of human factors. New York: Wiley.

Griffin, M.J. & Whitham, E.M. (1976). Duration of whole-body vibration exposure: its effect on comfort. *Journal of Sound and Vibration, 48*, 333-339.

Grob, A., Lüthi, R., Kaiser, F.G., Flammer, A., Mackinnon, A. & Wearing, A.J. (1991). Berner Fragebogen zum Wohlbefinden Jugendlicher (BFW). *Diagnostica, 37*, 66-75.

Gross, C.M., Gooenetilleke, R.S., Menon, K.K., Banaag, J.C. & Nair, C.M. (1992). New developments in the biomechanical assessment and prediction of seat comfort. Melville: Biomechanics Corp. of America.

Guski, R. (1984). Eine Voruntersuchung zur Bedeutung der Begriffe *„Ruhe“* und *Lärm“*. In: Schick, A. & Walcher, K.P. (Hg.). Beiträge zur Bedeutungslehre des Schalls, Ergebnisse des 3. Oldenburger Symposiums zur Psychologischen Akustik. Frankfurt am Main: Peter Lang.

Guski, R. (1987). Lärm - Wirkungen unerwünschter Geräusche. Bern: Hans Huber.

Guski, R. (1997a). Psychische Wirkungen von Umweltfaktoren. In: Wichmann, G., Schlipköter, H.-W. & Fülgraff, G. (Hg.). Handbuch der Umweltmedizin. Landsberg/Lech: ecomed.

Guski, R. (1997b). Psychological methods for evaluating sound quality and assessing acoustic information. *Acta Acustica, 83*, 765-774.

Guski, R. (1999). Personal and social variables as co-determinants of noise annoyance. *Environment and Behavior, 32*, 270-286.

Guski, R. (2001). Environmental stress and health. In: Smelser, N.J. & Baltes, P.B. (Eds.). The international encyclopaedia of the social and behavioral sciences. Oxford: Elsevier.

Guski, R., Schuemer, R. & Felscher-Suhr, U. (1999). The concept of noise annoyance: how international experts see it. *Journal of Sound and Vibration, 223*, 513-527.

Habsburg, S. & Middendorf, L. (1977). What is really connecting in seating comfort? Studies of correlates of static seat comfort. *SAE Paper 770247*. Warrendale: Society of Automotive Engineers.

Habsburg, S. & Middendorf, L. (1980). Calibrating comfort: systematic studies of human responses to seating. In: Oborne, D.J. & Levis, J.A. (Eds.). Human factors in transport research, Vol. 2, user factors: comfort, the environment and behaviour. New York: Academic.

Hamilton, V. (1979). Human stress and cognition: problems of definition, analysis, and integration. In: Hamilton, V. & Warburton, D.M. (Eds.). Human stress and cognition. An information processing approach. New York: Wiley.

Hammond, C.E., Hollenbaugh, D.D., Clevenson, S.A. & Leatherwood, J.D. (1981). An evaluation of helicopter noise and vibration ride qualities criteria. NASA Technical Reports, TM-83251.

Handmann, U. & Bodden, M. (1995). Psychoakustische Untersuchungen an Fahrzeuginnengeräuschen. In: Fortschritte der Akustik - DAGA ‘95, 879-882.

Hangartner, M. (1987). Evaluation of annoyance caused by motor traffic. In: Koelega, H. (Ed.). Environmental annoyance: characterization, measurement and control. Proceedings of the International Symposium on Environmental Annoyance at the Conference Centre Winschoten. Amsterdam: Elsevier Science.

Hanson, D.B. (1979). The influence of propeller design parameters of farfield harmonic noise in forward flight. *AIAA paper 79-0609*.

Harvey, O.J. (1963). Authoritarianism and conceptual functioning in varied conditions. *Journal of Personality, 31*, 462-470.

Harvey, O.J. (1966). System structure, flexibility, and creativity. In: Harvey, O.J. (Ed.). Experience, structure and adaptability. New York: Springer.

Harvey, O.J. (1971). Conceptual complexity and personality organization. In: Schroder, H.M. & Suedfeld, P. (Eds.). Personality theory and information processing. New York: Ronald Press Company.

Harvey, O.J., Hunt, D.E. & Schroder, H.M. (1961). Conceptual systems and personality organization. New York: Wiley.

Hashimoto, T. (1994). Die japanische Forschung zur Bewertung von Innengeräuschen im Pkw. *Zeitschrift für Lärmbekämpfung, 41*, 69-71.

Hawel, W. (1967a). Kategorien psychologischer Schallbewertung. In: Merz, F. (Hg.). Bericht über den 25. Kongreß der Deutschen Gesellschaft für Psychologie. Göttingen: Hogrefe.

Hawel, W. (1967b). Untersuchungen eines Bezugssystems für die psychologische Schallbewertung. *Arbeitswissenschaft, 6*, 50-53.

Headey, B., Holmström, E. & Wearing, A. (1984). Well-being and ill-being: different dimensions? *Social Indicators Research, 14*, 115-139.

Hebb, D.O. (1955). Drives in the CNS (Conceptual Nervous System). *Psychological Review, 62*, 243-254.

Hecheltjen, K.-G. & Mertesdorf, F. (1973). Entwicklung eines mehrdimensionalen

Stimmungsfragebogens. *Gruppendynamik, 40*, 110-122.

Helander, M.G., Czaja, S.J., Drury, C.G., Cary, J.M. & Burri, G. (1987). An ergonomic evaluation of office chairs. *Office Technology and People, 3*, 246-262.

Hellbrück, J. (1993). Gültigkeit Mittelungspegel-orientierter Lärmbewertungsverfahren. Im Auftrag des Umweltbundesamtes. Forschungsbericht 105 01 999/01.

Hellbrück, J. & Fischer, M. (1999). Umweltpsychologie. Ein Lehrbuch. Göttingen: Hogrefe.

Helmholtz, H. v. (1863). Die Lehre von den Tonempfindungen als psychologische Grundlage für die Theorie der Musik. Braunschweig: Vieweg.

Heron, K.H. (1973). Boundary layer induced cockpit noise. *Proceedings of the British Acoustical Society, 2*, Paper No. 73ANA6.

Hertzberg, H.T.E. (1972). The human buttock in sitting: pressures, patterns, and palliatives. *American Automobile Transactions, 72*, 39-47.

Hiramatsu, K. & Griffin, M.J. (1984). Predicting the subjective response to nonsteady vibration based on summation of the subjective magnitude. *Journal of the Acoustical Society of America, 76*, 1080-1089.

Höfert, W. (1981). Lärm und Blendung: zu einigen Effekten kombinierter Umgebungsstressoren. In: Schick, A. (Hg.). Akustik zwischen Physik und Psychologie. Ergebnisse des 2. Oldenburger Symposiums zur psychologischen Akustik. Stuttgart: Klett-Cotta.

Höger, R. (1999). Theoretische Ansätze und Ergebnisse der psychologisch orientierten Lärmwirkungsforschung. *Umweltpsychologie, 3*, 6-20.

Höger, R. (2000). Cognitive aspects of noise sensitivity. In: Schick, A., Meis, M. & Reckhardt, C. (Eds.). Contributions to psychological acoustics. Results of the eighth Oldenburg symposium on psychological acoustics. Oldenburg: bis.

Hofstätter, P.R. (1957). Psychologie. Frankfurt am Main: Fischer.

Hofstätter, P.R. (1969). Einführung in die Sozialpsychologie. Stuttgart: Kröner.

Holmberg, K., Landström, U. & Kjellberg, A. (1997). Low frequency noise level variations and annoyance in working environments. *Journal of Low Frequency Noise, Vibration and Active Control, 16*, 81-87.

Hood, R.A. & Leventhall, H.G. (1971). Field measurement of infrasonic noise. *Acustica, 25*, 10-13.

Howard, D.M. & Angus, J. (1996). Acoustics and Psychoacoustics. Oxford: Focal.

Howarth, H.V.C. (1989). Annoyance caused by railway vibration and noise and buildings. Ph.D. Thesis, University of Southampton.

Howarth, H.V.C. & Griffin, M.J. (1990a). Subjective response to combined noise and vibration: summation and interaction effects. *Journal of Sound and Vibration,* *143*, 443-454.

Howarth, H.V.C. & Griffin, M.J. (1990b). The relative importance of noise and vibration from railways. *Applied Ergonomics, 21*, 129-134.

Howarth, H.V.C. & Griffin, M.J. (1991). The annoyance caused by simultanous noise and vibration from railways. *Journal of the Acoustical Society of America, 89*, 2317-2323.

Humphrey, J.H. (1984). Profiles in stress. Stress in modern society. No. 2. New York: AMS Press, Inc.

Ingvarsson, A. & Västfjäll, D. (1999). A study on human response to aircraft vibrations in-flight. *AIAA paper 99-1982*.

International Organization for Standardization (ISO) (1975). Acoustics - Methods for calculating loudness level, ISO/DIS 532B. Geneva: International Organization for Standardization.

International Organization for Standardization (1983). Acoustics - Preferred reference quantities for acoustic levels. ISO/DIS 1683. Geneva: International Organization for Standardization.

International Organization for Standardization (ISO) (1995). Acoustics - Frequency weighting characteristic for infrasound measurements, ISO 7196. Geneva: International Organization for Standardization.

International Organization for Standardization (1997). Mechanical vibration and shock - Evaluation of human exposure to whole-body vibration - Part 1: General requirements. ISO 2631(E). Geneva: International Organization for Standardization.

International Organization for Standardization (ISO) (1999). Acoustics - Measurement of airborne noise emitted by computer and business equipment, ISO 7779. Geneva: International Organization for Standardization.

Ising, H. (1983). Effects of 8h exposure to infrasound in man. In: Proceedings of the Fourth International Congress on Noise as a Public Health Problem. Milano: Amplifon.

Ising, H., Markert, B., Shenoda, F.B. & Schwarze, C. (1982). Infraschallwirkungen auf den Menschen. HdA-Reihe, Düsseldorf: VDI.

Ising, H. & Schwarze, C. (1982). Infraschallwirkungen auf den Menschen. *Zeitschrift für Lärmbekämpfung, 29*, 79-82.

Iverson, P. & Krumhansl, C.L. (1993). Isolating the dynamic attributes of musical timbre. *Journal of the Acoustical Society of America, 94*, 2595-2603.

Jacobson, I.D. & Martinez, J. (1974). The comfort and satisfaction of air travelers: basis for a descriptive model. *Human Factors, 16*, 46-55.

Jacobson, I.D. & Richards, L.G. (1976). Ride quality evaluation II: modelling of airline passenger comfort. *Ergonomics, 19*, 1-10.

Jacobson, I.D. & Richards, L.G. (1978). Ride quality evaluation IV: models of subjective reaction to aircraft motion. *Ergonomics, 21*, 521-529.

Jacobson, I.D., Richards, L.G. & Kuhlthau, A.R. (1978). Models of human reaction to vehicle environments. *Applied Ergonomics, 9*, 169-172.

Jacobson, I.D., Richards, L.G. & Kuhlthau, A.R. (1980). Models of human comfort in vehicle environments. In: Oborne, D.J. & Levis, J.A. (Eds.). Human factors in transport research, Vol. 2, user factors: comfort, the environment and behaviour. New York: Academic.

Janke, W. & Debus, G. (1978). Die Eigenschaftswörterliste: EWL. Eine mehrdimensionale Methode zur Beschreibung von Aspekten des Befindens. Göttingen: Hogrefe.

Janke, W. & Kallus, K.W. (1995). Reaktivität. In: Armelang, M. (Hg.). Enzyklopädie der Psychologie, Serie 8, Differentielle Psychologie und Persönlichkeitsforschung, Band 2, Verhaltens- und Leistungsunterschiede. Göttingen: Hogrefe.

Jianghong, Z. & Long, T. (1994). An evaluation of comfort of a bus seat. *Applied Ergonomics, 25*, 386-392.

Job, R.F.S. (1988). Community response to noise: a review of factors influencing the relationship between noise exposure and reaction. *Journal of the Acoustical Society of America, 83*, 991-1001.

Job, R.F.S. (1993). Psychological factors of community reaction to noise. In: Vallet, M. (Ed.). Noise as a public health problem. Arcueil, France: INRETS, Vol. 3, 48-70.

Johnson, D.L. (1980). The effects of high level infrasound. In: Proceedings of the Conference on Low Frequency Noise and Vibration, Aalborg, 47-60.

Jones, D.M. & Davies, D.R. (1984). Individual and group differences in the response to noise. In: Jones, D.M. & Chapman, A.J. (Eds.). Noise and society. Chichester: Wiley.

Jong, R.G. de (1983). Some developments in community response research since the second international workshop on railway and tracked transit system noise in 1978. *Journal of Sound and Vibration, 87*, 297-309.

Jost, E. (1967). Akustische und psychometrische Untersuchungen an Klarinettenklängen. Köln: Volk.

Kagan, J., Moss, H.A. & Sigel, I.E. (1963). Psychological significance of styles of conceptualization. In: Wright, J.C. & Kagan, J. (Eds.). Basic cognitive process in children. *Monographs of the Society for Research in Child Development, 28*, Serial No. 86.

Kagan, J., Rosman, B., Day, D., Albert, J. & Philips, W. (1964). Information processing in the child: significance of analytic and reflective attitudes. *Psychological Monographs, 78,* Whole No. 578.

Kalivoda, M.T. (1998). Akustische Grundlagen. In: Kalivoda, M.T. & Steiner, J.W. (Hg.). Taschenbuch der Angewandten Psychoakustik. Wien: Springer.

Kasmar, J.V. (1970). The development of a usable lexicon of environmental descriptors. *Environment and Behavior, 2*, 153-169.

Kastka, J. (1976). Untersuchungen zur Belästigungswirkung der Umweltbedingungen Verkehrslärm und Industriegerüche. In: Kaminski, G. (Hg.). Umweltpsychologie. Perspektiven - Probleme - Praxis. Stuttgart: Klett-Cotta.

Kastka, J. (1981). Psychologische Indikatoren der Verkehrslärmbelästigung. In: Schick, A. (Hg.). Akustik zwischen Physik und Psychologie. Ergebnisse des 2. Oldenburger Symposiums zur psychologischen Akustik. Stuttgart: Klett-Cotta.

Kastka, J. & Noack, R. (1987). On the interaction of sensory experience, causal attributive cognitions and visual context in noise annoyance. In: Koelega, H. (Ed.). Environmental annoyance: characterization, measurement and control. Proceedings of the International Symposium on Environmental Annoyance at the Conference Centre Winschoten. Amsterdam: Elsevier Science.

Kempfert, O. (1998). Arbeitsplatz Auto. Bewertung und Relevanz von Komfort. Dissertation am Fachbereich Erziehungswissenschaften, Psychologie und Sportwissenschaft der Freien Universität Berlin.

Kendall, R.A. & Carterette, E.C. (1991). Perceptual scaling of simultaneous wind instruments timbres. *Music Perception, 8*, 369-404.

Kendall, R.A. & Carterette, E.C. (1993). Verbal attributes of simultaneous wind instruments timbres: I. von Bismarck's adjectives. *Music Perception, 10*, 445-468.

Kerrick, J.S., Nagel, D.C. & Bennett, R.L. (1969). Multiple ratings of sound stimuli. *Journal of the Acoustical Society of America, 45*, 1014-1017.

Kjellberg, A. & Wirkström, B.O. (1985a). Whole-body vibration: exposure time and acute effects - a review. *Ergonomics, 28*, 535-544.

Kjellberg, A. & Wirkström, B.O. (1985b). Subjective reactions to whole-body vibration of short duration. *Journal of Sound and Vibration*, 99, 415-424.

Kjellberg, A., Wirkström, B.O. & Dimberg, U. (1985). Whole-body vibration: exposure time and acute effects. Experimental assessment of discomfort. *Ergonomics, 28*, 545-554.

Kleeman, W. Jr. (1991). Interior design of the electronic offices: the comfort and productivity payoff. New York: Van Nostrand Reinhold.

Koelega, H. (Ed., 1987). Environmental annoyance: characterization, measurement and control. Proceedings of the International Symposium on Environmental Annoyance at the Conference Centre Winschoten. Amsterdam: Elsevier Science.

Kraemer, S.D. (1973). Annoyance of low frequency sounds. M. Sc. Dissertation. London: Chelsea College.

Krampen, M. (1991). Environmental meaning. In: Zube, E.H. & Moore, G.T. (Eds.). Advances in environment, behavior, and design, Vol. 3. New York: Plenum.

Krimphoff, J., McAdams, S. & Winsberg, S. (1994). Caractérisation du timbres des sons complexes. II: analyses acoustiques et quantification psychophysique. *Journal de Physique, 4*, 625-628.

Krist, R. (1994). Modellierung des Sitzkomforts. Eine experimentelle Studie. Weiden: Schuch.

Krumhansl, C.L. (1989). Why is timbre so hard to understand? In: Nielzen, S. & Olsson, O. (Eds.). Structure and perception of electroacoustic sound and music. Amsterdam: Elsevier.

Kruskal, J.B. (1964a). Multidimensional scaling by optimizing goodness of fit to a nonmetric hypothesis. *Psychometrika, 29*, 1-27.

Kruskal, J.B. (1964b). Nonmetric multidimensional scaling: a numerical method. *Psychometrika, 29*, 115-129.

Kryter, K.D. (1985). The effects of noise on man. New York: Academic.

Kubicek, R. (1989). Vorkommen, Messung, Wirkung und Bewertung von extrem tieffrequentem Schall einschließlich Infraschall in der kommunalen Umwelt. Dissertation an der TH Zwickau.

Kuwano, S., Kaku, J., Kato, T. & Namba, S. (1997). The experiment on loudness in field and laboratory: an examination of the applicability of $L_{eq(A)}$ to mixed sound sources. In: Proceedings of the Inter-noise ‘97, 1089-1094.

Kuwano, S., Namba, S. & Miura, H. (1989). Advantages and disadvantages of A-weighted sound pressure level in relation to subjective impression of environmental noises. *Noise Control Engineering, 33*, 107-1115.

Kuwano, S., Namba, S., Hato, T., Matui, M., Miura, H. & Imai, H. (1993). Psychological evaluation of noise in passenger cars. Analysis of different group of subjects in nationality, age and gender. In: Schick, A. (Ed.). Contributions to psychological acoustics. Results of the sixth Oldenburg symposium on psychological acoustics. Oldenburg: bis.

Kuwano, S., Namba, S., Hato, T., Matui, M. & Imai, H. (1994). Psychologische Bewertung von Lärm in Personenwagen: Analyse nach Nationalität, Alter und Geschlecht. *Zeitschrift für Lärmbekämpfung, 41*, 78-83.

Lambert, J. (1997). Valuing transportation noise annoyance: overview of the methods, the results and their applications. In: Proceedings of the Inter-noise ‘97, 1191-1194.

Lambert, J., Champelovier, P. & Vernet, I. (1996). Annoyance from high speed train noise: a social survey. *Journal of Sound and Vibration, 193*, 21-28.

Lambert, J., Champelovier, P., Vernet, I., Annequin, C. & Baez, D. (1994). Community response to high speed train noise in France. In: Proceedings of the Inter-noise ‘94, 125-128.

Landström, U. (2000). Human effects of infrasound. In: Proceedings of the Inter-noise 2000, 723-728.

Landström, U., Jundström, R. & Byström, M. (1983). Exposure to infrasound – perception and changes in wakefulness. *Journal of Low Frequency Noise and Vibration, 2*, 1-11.

Landström, U., Kjellberg, A. & Lundström, R. (1993). Combined effects of exposure to noise and whole-body vibrations in dumpers, helicopters and railway engines. *Journal of Low Frequency Noise and Vibration, 12*, 75-85.

Landström, U. & Pelmear, P.L. (1993). Infrasound. A short review. *Journal of Low Frequency Noise and Vibration, 12*, 72-74.

Langdon, F.J. (1985). Noise annoyance. In: Tempest, W. (Ed.). The noise handbook. London: Academic.

Lazarus, H. & Höge, H. (1986). Industrial safety: acoustic signals for danger situations in factories. *Applied Ergonomics, 17*, 41-46.

Lazarus, R.S. (1966). Psychological stress and the coping process. New York: Wiley.

Lazarus, R.S. (1968). Emotions and adaptation: conceptual and empirical relations. In: Arnold, W.J. (Ed.). Nebraska symposium on motivation. Lincoln: University of Nebraska Press.

Lazarus, R.S. (1969). Patterns of adjustment and human effectiveness. New York: McGraw-Hill.

Lazarus, R.S. (1990). Streß und Streßbewältigung - Ein Paradigma. In: Filipp, S.H. (Hg.). Kritische Lebensereignisse. München: Psychologie Verlags Union.

Lazarus, R.S. (1991). Emotion and adaptation. New York: Oxford University Press.

Lazarus, R.S. & Cohen, J.B. (1977). Environmental stress. In: Altman, I. & Wohlwill, J.F. (Eds.). Human behavior and the environment: current theory and research. Vol. 2. New York: Plenum.

Lazarus, R.S. & Folkman, S. (1984). Stress, appraisal, and coping. Berlin: Springer.

Lazarus, R.S. & Launier, R. (1978). Stress-related transactions between person and environment. In: Pervin, L.A. & Lewis, M. (Eds.). Perspectives in interactional psychology. New York: Plenum.

Lazarus-Mainka, G. & Raschdorf, D. (1985). Sprechweise, Sprachverständlichkeit und Geräuschintensität als Faktoren der erlebten Belästigung. *Zeitschrift für Lärmbekämpfung, 32*, 135-140.

Leatherwood, J.D. (1974). Annoyance response to simulated advanced turboprop aircraft interior noise containing tonal betas. NASA Technical Reports # 17.

Leatherwood, J.D. (1979). Human discomfort response to noise combined with vertical vibration. NASA Technical Reports, TP-1374.

Leatherwood, J.D. (1984). Combined effects of noise and vibration on passenger acceptance. NASA TM-86284.

Leatherwood, J.D., Clevenson, S.A. & Hollenbaugh, D.D. (1984). Evaluation of ride quality prediction methods for helicopter interior noise and vibration environments. NASA Technical Reports, TP-2261.

Leatherwood, J.D. & Dempsey, T.K. (1976). Psychophysical relationships characterizing human response to whole-body sinusoidal vertical vibration. NASA Technical Reports, TN-D-8188.

Leatherwood, J.D., Dempsey, T.K. & Clevenson, S.A. (1980). A design tool for estimating passenger comfort ride discomfort within complex ride environments. *Human Factors, 22*, 291-312.

Lepore, S.J. & Evans, G.W. (1996). Coping with multiple stressors in the environment. In: Zeidner, M. & Endler, N. (Eds.). Handbook of coping: theory, research and applications. New York: Wiley.

Letens, U. (1991). Einführung in die Methoden der subjektiven und objektiven Geräuschbeurteilung bei der Entwicklung von Kraftfahrzeugen. Stuttgart: Daimler Benz AG.

Leventhall, H.G. (1980). Annoyance caused by low frequency/low level noise. In: Proceedings of the Conference on Low Frequency Noise and Vibration, Aalborg, 113-120.

Leventhall, H.G. & Kyriakides, K. (1976). Environmental infrasound: its occurrence and measurement. In: Tempest, W. (Ed.). Infrasound and low frequency vibration. London: Academic.

Levis, J.A. (1978). The seated bus passenger - a review. *Applied Ergonomics, 9*, 143-150.

Lichte, W.H. & Gray, R.F. (1955). The influence of overtone structure on the pitch of complex tones. *Journal of Experimental Psychology, 49*, 431-436.

Licklider, J.C.R. (1951). Basic correlates of the auditory stimulus. In: Stevens, S.S. (Ed.). Handbook of experimental psychology. New York: Wiley.

Lindberg, S. & Backteman, O. (1988). Loudness of impulse community noises. *Journal of Low Frequency Noise and Vibration, 7*, 98-103.

Lueder, R.K. (1983). Seat comfort: a review of the construct in the office environment. *Human Factors, 25*, 701-711.

Lunneborg, C.E. & Abbott, R.D. (1983). Elementary multivariate analysis for the behavioral sciences. Applications of basic structure. New York: North-Holland.

Macmillan, N.A. & Creelman, C.D. (1991). Detection theory: a user's guide. Cambridge: University Press.

Manenica, I. & Corlett, E.N. (1973). A model of vehicle comfort and a method of its assessment. *Ergonomics, 16*, 849-854.

Maslow, A.H. (1954). Motivation and personality. New York: Harper.

Maslow, A.H. (1977). Motivation und Persönlichkeit. Olten: Walter.

Mayr, R. (1959). Comfort in railway travel. *Railway Gazette, 912*, 266-269.

Mayring, P. (1987). Subjektives Wohlbefinden im Alter. Stand der Forschung und theoretische Weiterentwicklung. *Zeitschrift für Gerontologie, 20*, 367-376.

Mayring, P. (1991). Die Erfassung subjektiven Wohlbefindens. In: Abele, A. & Becker, P. (Hg.). Wohlbefinden. Theorie - Empirie - Diagnostik. Weinheim: Juventa.

McAdams, S. (1989). Psychological constraints on form-bearing dimensions in music. *Contemporary Music Review, 4*, 181-198.

McAdams, S. (1993). Recognition of sound sources and events. In: McAdams, S. & Bigand, E. (Eds.). Thinking in sound. The cognitive psychology of human audition. Oxford: Oxford University Press.

McAdams, S. & Winsberg, S. (2000). Psychophysical quantification of individual differences in timbre perception. In: Schick, A., Meis, M. & Reckhardt, C. (Eds.). Contributions to psychological acoustics. Results of the eighth Oldenburg symposium on psychological acoustics. Oldenburg: bis.

McAdams, S., Winsberg, S., Donnadieu, S., De Soete, G. & Krimphoff, J. (1995). Perceptual scaling of synthesized musical timbre: common dimensions, specifities, and latent subject classes. *Psychological Research, 58*, 177-192.

McCurdy, D.A. (1986). Advanced turboprop aircraft noise annoyance: a review of recent NASA research. *AIAA paper 86-1959*.

McKennell, A.C. (1963). Aircraft noise annoyance around Heathrow airport. London: Her Majesty's Stationary Office.

Mehrabian, A. & Russell, J.A. (1974). An approach to environmental psychology. Cambridge: MIT.

Meis, M. & Brauchle, G. (2001). Die Wirkung kombinierter Schall- und Geruchsexposition: Belästigungsscreening der Bevölkerung um die Abfallbeseitungsanlage in Kreyenbrück/Oldenburg. In: Fortschritte der Akustik - DAGA ‘01, in print.

Meloni, T. & Krueger, H. (1990). Wahrnehmung und Empfindung von kombinierten Belastungen durch Lärm und Vibration. *Zeitschrift für Lärmbekämpfung, 37*, 170-175.

Messick, S. (1976). Personality consistencies in cognition and creativity. In: Messick, S. et al. (Eds.). Individuality in learning. San Francisco: Jossey-Bass.

Messik, S. (1996). Cognitive styles and learning. In: DeCorte, E. & Weinert, F.E. (Eds.). International encyclopaedia of developmental and instructional psychology. Oxford: Pergamon.

Metzger, P. (1994). Komfortverständis bei Kraftfahrern. Diplomarbeit an der Freien Universität Berlin.

Michalos, A.C. (1985). Multiple discrepancy theory (MDT). *Social Indicators Research, 16,* 347-413.

Miedema, H.M.E. & Vos, H. (1999). Demographic and attitudinal factors that modify annoyance from transportation noise. *Journal of the Acoustical Society of America, 105*, 3336-3344.

Miller, J.R. & Carterette, E.C. (1975). Perceptual space for musical structures. *Journal of the Acoustical Society of America, 58*, 711-720.

Miller, R. (1986). Einführung in die Ökologische Psychologie. Opladen: Leske.

Möhler, U. (1988). Community response to railway noise: a review of social surveys. *Journal of Sound and Vibration, 120*, 321-332.

Moller, H. & Andresen, J. (1984). Loudness of pure tones at low and infrasonic frequencies. *Journal of Low Frequency Noise and Vibration, 3*, 78-87.

Moller, H., Henningsen, P. & Andresen, J. (1984). Annoyance from infrasound - alone and in combination with audio frequency noise. In: Proceedings of the Inter-noise ‘84, 911-916.

Montgomery, D.C. & Peck, E.A. (1982). Introduction to linear regression analysis. New York: Wiley.

Moore, B.C. (1982). An introduction to the psychology of hearing. London: Academic.

Moreira, M.N. & Bryan, M.E. (1972). Noise annoyance susceptibility. *Journal of Sound and Vibration, 21*, 449-462.

Morfey, C.L. (1973). Rotating blades and aerodynamic sound. *Journal of Sound and Vibration, 28*, 587-617.

Mzali, M., Dubois, D., Polack, J.-D., Letourneaux, F. & Posson, F. (2000). Auditory comfort on board trains: passengers' point of view. In: Proceedings of the Inter-noise 2000, 397-402.

Nakamura, S. & Tokita, Y. (1981). Frequency characteristics of subjective responses to low frequency sound. In: Proceedings of the Inter-noise ‘81, 739-742.

Namba, S. (1992). Loudness and timbre of non-steady state noise. In: Proceedings of the 14th International Congress on Acoustics, P10.

Namba, S. (1993). The creation of comfortable sound environment. Selected Paper of International Symposium ‘93 on Design Amenity. Fukuoka, Japan, 5-9 October.

Namba, S. (1994). Noise. Quantity and quality. In: Proceedings of the Inter-noise ‘94, 171-218.

Namba, S. & Kuwano, S. (1984). Psychological study on L_{eq} as a measure of loudness of various kinds of noises. *Journal of the Acoustical Society of Japan (E), 5*, 135-148.

Namba, S. & Kuwano, S. (1990). Temporal change of noisiness of helicopter noise. In: Proceedings of the Inter-noise ‘90, 1171-1176.

Namba, S., Kuwano, S., Hato, T. & Kato, M. (1991). Assessment of musical performance by using the method of continuous judgment by selected description. *Music Perception, 8*, 251-276.

Namba, S., Kuwano, S. & Koyasu, M. (1993). The measurement of temporal stream of hearing by continuos judgement. In the case of the evaluation of helicopter noise. *Journal of the Acoustical Society of Japan (E), 14*, 341-352.

Neumann, E.S., Romansky, M.L. & Plummer, R.W. (1978). Passenger car comfort and travel decisions: a physiological study. *Journal of Transport Economics and Policy, 12*, 231-243.

Nitsch, J.R. (1976). Die Eigenzustandsskala (EZ-Skala). Ein Verfahren zur hierarchisch-mehrdimensionalen Befindlichkeitsskalierung. In: Nitsch, J.R. & Udris, I. (Hg.). Beanspruchung im Sport. Beiträge zur psychologischen Analyse sportlicher Leistungssituationen. Bad Homburg: Limpert.

Oborne, D.J. (1975). Questionnaire surveys of passenger comfort. *Applied Ergonomics, 6*, 97-103.

Oborne, D.J. (1976a). A critical assessment of studies relating whole-body vibration to passenger comfort. *Ergonomics, 19*, 751-774.

Oborne, D.J. (1976b). Examples of the use of rating scales in ergonomics research. *Applied Ergonomics, 7*, 201-204.

Oborne, D.J. (1977). Vibration and passenger comfort. *Applied Ergonomics, 8*, 97-101.

Oborne, D.J. (1978a). Passenger comfort – an overview. *Applied Ergonomics, 9*, 131-136.

Oborne, D.J. (1978b). Techniques available for the assessment of passenger comfort. *Applied Ergonomics, 9*, 45-49.

Oborne, D.J. (1978c). Vibration and the passenger comfort: can data from subjects be used to predict passenger comfort? *Applied Ergonomics, 9*, 155-161.

Oborne, D.J. & Clarke, M.J. (1973). The development of questionnaire surveys for the investigation of passenger comfort. *Ergonomics, 16*, 855-869.

Oborne, D.J. & Clarke, M.J. (1974). The determination of equal comfort zones for whole-body vibration. *Ergonomics, 17*, 769-782.

Osgood, C.E. (1952). The nature and measurement of meaning. *Psychological Bulletin, 49*, 197-237.

Osgood, C.E. (1962). Studies on the generality of affective meaning systems. *American Psychologist, 17*, 10-28.

Osgood, C.E. (1964). Semantic differential technique in the comparative study of cultures. *American Anthropologist, 66*, 171-200.

Osgood, C.E. (1971). Exploration in semantic space: a personal diary. *Journal of Social Issues, 27*, 5-64.

Osgood, C.E. (1972). The semantic differential – evaluation and applications. In: Houston, S.H. (Ed.). A survey of psycholinguistics. Mouton: The Hague.

Osgood, C.E. (1976). Focus on meaning. Explorations in semantic space. The Hague: Mouton.

Osgood, C.E., May, W.H. & Miron, M.S. (1975). Cross cultural universals of affective meaning. Urbana: University of Illinois.

Osgood, C.E. & Suci, G.J. (1952). A measure of relation determined by both difference and profile information. *Psychological Bulletin, 49*, 251-262.

Osgood, C.E. & Suci, G.J. (1955). Factor analysis of meaning. *Journal of Experimental Psychology, 50*, 325-338.

Osgood, C.E, Suci, G.J. & Tannenbaum, P.H. (1957). The measurement of meaning. Urbana: University Press of Illinois.

Osgood, C.E., Suci, G.J. & Tannenbaum, P.H. (1961). The logic of semantic differentiation. In: Saporta, S. & Bastian, J.R. (Eds.). Psycholinguistics: a book of readings. New York: Holt, Rinehart & Winston.

Paulsen, R. & Kastka, J. (1995). Effects of combined noise and vibration on annoyance. *Journal of Sound and Vibration, 181*, 295-314.

Pawlow, I.P. (1953-1955). Sämtliche Werke. Berlin: Akademie.

Pepler, R.D., Sussman, E.D. & Richards, L.G. (1980). Passenger comfort in ground vehicles. In: Oborne, D.J. & Levis, J.A. (Eds.). Human factors in transport research, Vol. 2, user factors: comfort, the environment and behaviour. New York: Academic.

Persson Waye, K. (1995). On the effects on environmental low frequency noise. Department of Environmental Medicine, Goteborg University Publication.

Persson, K. & Rylander, R. (1988). Disturbance from low-frequency noise in the environment: a survey among the local environmental health authorities in Sweden. *Journal of Sound and Vibration, 121*, 339-345.

Persson, K., Björkman, M. & Rylander, R. (1990). Annoyance, loudness and dBA in evaluating low frequency sounds. In: Proceedings of the Inter-noise '90, 1319-1322.

Pervin, L.A. (1980). Personality: theory, assessment, and research. New York: Wiley.

Pineau, C. (1982). The psychological meaning of comfort. *International Review of Applied Psychology, 31*, 271-283.

Pinel, J.P. (1997). Biopsychologie. Eine Einführung. Heidelberg: Spektrum.

Pitt, M.A. & Crowder R.G. (1992). The role of spectral and dynamic cues in imagery for musical timbre. *Journal of Experimental Psychology. 18*, 728-738.

Plomp, R. (1970). Timbre as multidimensional attribute of complex tones. In: Plomp, R. & Smoorenburg, G.F. (Eds.). Frequency analysis and periodicity detection in hearing. Leiden: Sijthoff.

Plomp, R. (1976). Aspects of tone sensation. A psychophysical study. New York: Academic.

Plomp, R. & Steeneken, H.J.M. (1969). Effect of phase on the timbre of complex tones. *Journal of the Acoustical Society of America, 46*, 409-421.

Plomp, R., Pols, L.W.C. & van der Geer, J.P. (1966). Dimensional analysis of vowel spectra. *Journal of the Acoustical Society of America, 41*, 707-712.

Pols, L.W.C., van der Kamp, L.J.Th. & Plomp, R. (1969). Perceptual and physical space of vowel sounds. *Journal of the Acoustical Society of America, 46*, 458-467.

Pope, L.D., Wilby, E.G., Willis, C.M. & Mayes, W.H. (1983). Aircraft interior noise models: sidewall trim, stiffened structures and cabin acoustics with floor partition. *Journal of Sound and Vibration, 89*, 371-415.

Pratt, R.L. & Doak, P.E.A. (1976). A subjective rating scale for timbre. *Journal of Sound and Vibration, 45*, 317-328.

Preis, A. (1996). Measurement of annoyance components. In: Proceedings of the Inter-noise '96, 2289-2294.

Quehl, J. (1997). Psychoakustische Untersuchungen zur Beurteilung und Wirkung von Geräuschen der Magnetschnellbahn Transrapid. Diplomarbeit an der Carl-von-Ossietzky Universität Oldenburg.

Quehl, J. (1999). Schienenbonus für Transrapid? Eine psychoakustische Studie zur Übertragbarkeit des Schienenbonus auf die Magnetschnellbahn. *Zeitschrift für Lärmbekämpfung, 5*, 163-174.

Quehl, J., Schick, A., Mellert, V., Schulte-Fortkamp, B. & Remmers, H. (1998). Passenger comfort: a review of involved factors and research techniques available for its assessment. In: Proceedings of the Second CEAS-ASC Workshop: Aircraft Interior Noise Control. Friedrichshafen: Daimler-Benz Aerospace Dornier.

Quehl, J., Schick, A., Mellert, V., Schulte-Fortkamp, B. & Remmers, H. (2000a). Evaluation of combined aircraft interior sound and vibration effects on passengers‘ well-being and comfort sensation: the elaboration of a concept-specific methodological instrument. In: Schick, A., Meis, M. & Reckhardt, C. (Eds.). Contributions to psychological acoustics. Results of the eighth Oldenburg symposium on psychological acoustics. Oldenburg: bis.

Quehl, J., Schick, A., Mellert, V. & Schulte-Fortkamp, B. (2000b). Dimensions of combined acoustic and vibration perception in aircraft derived by factor analysis of semantic differential data. In: Proceedings of the Inter-noise 2000, 465-470.

Quehl, J., Schick, A., Mellert, V., Schulte-Fortkamp, B. & Remmers, H. (2000c). Hauptdimensionen einer kombinierten Geräusch- und Vibrationswahrnehmung in Flugsituationen: Auswertungen zum semantischen Differential. In: Fortschritte der Akustik - DAGA 2000, 198-199.

Quehl, J., Schick, A., Mellert, V. & Schulte-Fortkamp, B. (2000d). Evaluation of combined acoustic and vibration perception in aircraft cabins using semantic differential and multidimensional mood scales. In: Proceedings of the Second Congress of Slovenian Acoustical Society, 303-310.

Quehl, J., Schick, A., Mellert, V. & Remmers, H. (2001). Interaction of sound and vibration on comfort evaluation of aircraft flight situations. In: Fortschritte der Akustik - DAGA ‘01, in print.

Rahlfs, V. (1966). Psychometrische Untersuchungen zur Wahrnehmung musikalischer Klänge. Dissertation, Universität Hamburg.

Random house compact unabridged dictionary (1996). New York: Random House.

Rao, B.K.N. & Ashley, C. (1976). Subjective effects of vibration: In: Tempest, W. (Ed.). Infrasound and low frequency vibration. London: Academic.

Rayman, R.B. (1997). Passenger safety, health and comfort: a review. *Aviation, Space, Environmental Medicine, 68*, 432-440.

Rayner, S. & Riding, R. (1997). Towards a categorisation of cognitive styles and learning styles. *Educational Psychology, 17*, 5-28.

Rebiffé, R. (1980). General reflections on the postural comfort of the driver and passengers; consequences on seat design. In: Oborne, D.J. & Levis, J.A. (Eds.). Human factors in transport research, Vol. 2, user factors: comfort, the environment and behaviour. New York: Academic.

Richards, L.G. (1980). On the psychology of passenger comfort. In: Oborne, D.J. & Levis, J.A. (Eds.). Human factors in transport research, Vol. 2, user factors: comfort, the environment and behaviour. New York: Academic.

Richards, L.G. & Jacobson, I.D. (1975). Ride quality evaluation I. Questionnaire studies of airline passenger comfort. *Ergonomics, 18*, 129-150.

Richards, L.G. & Jacobson, I.D. (1977). Ride quality assessment III. Questionnaire results of a second flight programme. *Ergonomics, 20*, 499-519.

Richards, L.G., Jacobson, I.D. & Kulthau, A.R. (1978). What the passenger contributes to passenger comfort. *Applied Ergonomics, 9*, 137-142.

Riding, R. (1997). On the nature of cognitive style. *Educational Psychology, 17*, 29-50.

Riding, R. & Cheema, I. (1991). Cognitive styles: an overview and integration. *Educational Psychology, 11*, 193-215.

Riding, R. & Rayner, S. (1998). Cognitive styles and learning strategies. Understanding style differences in learning and behaviour. London: David Fulton.

Rinalducci, E.J. (1980). Effects of aircraft motion on passengers' comfort rating and response times. *Perceptual and Motor Skills, 50*, 91-97.

Saldanha, E.L. & Corso, J.F. (1964). Timbre cues and the identification of musical instruments. *Journal of the Acoustical Society of America, 36*, 2021-2026.

Schäfer, B. (1983). Semantische Differential Technik. In: Feger, H. & Bredenkamp, J. (Hg.). Datenerhebung. Enzyklopädie der Psychologie, Themenbereich B, Methodologie und Methoden, Serie I, Forschungsmethoden der Psychologie. Göttingen: Hogrefe.

Schäfer, B. & Fuchs, A. (1975). Kriterien und Techniken der Merkmalsselektion bei der Konstruktion eines Eindrucksdifferentials. In: Bergler, R. (Hg.). Das Eindrucksdifferential. Bern: Huber.

Schandry, R. (1988). Lehrbuch der Psychophysiologie. Körperliche Indikatoren psychischen Geschehens. Weinheim: Psychologie Verlags Union.

Schick, A. (1968). Der Einfluß systematischer Skalenauswahl auf die Verlaufsähnlichkeit von Polaritätsprofilen. *Zeitschrift für experimentelle und angewandte Psychologie, 15*, 147-160.

Schick, A. (1979). Schallwirkung aus psychologischer Sicht. Stuttgart: Klett-Cotta.

Schick, A. (1992). Die Behandlung der Psychoakustik aus der Sicht der lärmbekämpfenden Psychologen. UVP-Report 3, 153-157.

Schick, A. (1993). Das Konzept der Lästigkeit in der Lärmforschung. Im Auftrag des Umweltbundesamtes. Forschungsbericht 105 01 999/01.

Schick, A. (1994a). Different interpretations of the meaning of annoyance. In: Proceedings of the Inter-noise ‘94, 785-790.

Schick, A. (1994b). History of evaluation of sound and noise in passenger cars. *Noise Abstracts and Reviews. 1*, 3-10.

Schick, A. (1994c). Zur Geschichte der Bewertung von Innengeräuschen in Personenwagen, *Zeitschrift für Lärmbekämpfung, 41*, 61-68.

Schick, A. (1995a). Geräusche im Fahrgastraum des PKW: Die Bedeutung der Sprache - erläutert am Beispiel der japanischen Klangfarbenforschung. In: Ahmed, S.R. (Hg.). Akustik und Aerodynamik des Kraftfahrzeuges. Grundlagen - Optimierungsmethoden - Meß- und Versuchstechnik. Renningen-Malsmheim: expert.

Schick, A. (1995b). Geräusche im Fahrgastraum des PKW: ein geschichtlicher Abriß. In: Ahmed, S.R. (Hg.). Akustik und Aerodynamik des Kraftfahrzeuges. Grundlagen - Optimierungsmethoden - Meß und Versuchstechnik. Renningen-Malsmheim: expert.

Schick, A. (1996a). Evaluation of sound and noise in passenger cars. History and survey of the Japanese applied timbre research. Thoughts on the role of psychology in the field of vehicle acoustics. Invited lecture of the Faculty of Mechanical Engineering University of Ljublijana, Slovenia.

Schick, A. (1996b). The role of subjects and its importance for differential noise psychology. In: Proceedings of the Inter-noise ‘96, 2121-2126.

Schick, A. (1997). Das Konzept der Belästigung in der Lärmforschung. Lengerich: Pabst Science.

Schick, A. (1998). Theories of meaning as bridges between psychology and engineering. In: Proceedings of the Euro-noise 1998, 529-534.

Schick, A. (2000). Semantics of hearing in car manufacturing. In: Proccedings of the Seventh International Congress on Sound and Vibration, 2519-2526.

Schmidt, R.F., Thews, G. & Lang, F. (2000). Physiologie des Menschen. Berlin: Springer.

Schreiber, C.A. & Kahneman, D. (2000). Determinants of the remembered utility of aversive sounds. *Journal of Experimental Psychology, 129*, 27-42.

Schroder, H.M., Driver, M.J. & Streufert, S. (1967). Human information processing. New York: Holt, Rinehart & Winston.

Schroder, H.M. & Suedfeld, P. (1971). Personality theory and information processing. New York: Ronald.

Schuemer, R. & Schuemer-Kohrs, A. (1984). Zum Einfluß außer-akustischer Faktoren ('Moderatoren') auf die Reaktionen auf Verkehrslärm. In: Schick, A. & Walcher, K.P. (Hg.). Beiträge zur Bedeutungslehre des Schalls, Ergebnisse des 3. Oldenburger Symposiums zur Psychologischen Akustik. Frankfurt am Main: Peter Lang.

Schulte-Fortkamp, B. (1994). Geräusche beurteilen im Labor. Entwicklung interdisziplinärer Forschungsmethoden und ihre forschungssoziologische Analyse. Düsseldorf: VDI.

Schulte-Fortkamp, B. (1995). Subjektive Bewertungen von Geräuscheinwirkungen. In: Fortschritte der Akustik - DAGA '95, 855-858.

Schulte-Fortkamp, B. (1996). Combined methods to investigate effects of noise exposure and subjective noise assessment. In: Proceedings of the Inter-noise '96, 2351-2356.

Schust, M. (1997). Biologische Wirkung von vorwiegend luftgeleitetem Infraschall. Schriftenreihe der Bundesanstalt für Arbeitsschutz und Arbeitsmedizin: Literaturdokumentation, Ld 7. Bremerhaven: Wirtschaftsverlag NW.

Schust, M., Seidel, H., Seidel, H. & Blüthner, R. (1997). Extraaurale Wirkung von Erdbaumaschinen-Lärm unterschiedlicher Tonhaltigkeit isoliert und in Kombination mit Ganzkörperschwingungen (Schlußbericht). Schriftenreihe der Bundesanstalt für Arbeitsschutz und Arbeitsmedizin: Forschung, Fb 775. Bremerhaven: Wirtschaftsverlag NW.

Schust, M., Seidel, H., Seidel, H. & Blüthner, R. (1998). Wirkung von Lärm unterschiedlicher Tonhaltigkeit nach DIN 45681 (E) in Kombination mit Schwingungen. Teil I: Subjektive Beurteilung. *Zeitschrift für Lärmbekämpfung, 45*, 150-156.

Seidel, H. (1997). Subjektive Beurteilung von Expositionen mit Geräuschen unterschiedlicher Charakteristik und arbeitsplatztypischen Ganzkörperschwingungen. Diplomarbeit im Fachbereich Arbeitspsychologie an der Humboldt Universität Berlin.

Seidel, H., Erdmann, U., Blüthner, R., Hinz, B., Bräuer, D., Arias, J.F. & Rothe, H.-J. (1990). Evaluation of simultaneous exposure to noise and whole body vibration by magnitude estimation and cross-modality matching - an experimental study with professional drivers. *Archives of Complex Environmental Studies, 2*, 17-24.

Seiler, T.B. (Hg., 1973). Kognitive Strukturiertheit: Theorien, Analysen, Befunde. Stuttgart: Kohlhammer.

Selye, H. (1956). The stress of life. New York: McGraw-Hill.

Selye, H. (1974). Stress without distress. Philadelphia: Lippincott.

Selye, H. (1976). Stress in health and disease. Boston: Butterworth.

Selye, H. (1981). The stress concept today. In: Kutash, I.L. & Schlesinger, L.B. (Eds.). Handbook of stress and anxiety. San Francisco: Jossey-Bass.

Selye, H. (1983). The stress concept: past, present, future. In: Cooper, C.L. (Ed.). Stress research. Issues for the Eighties. New York: Wiley.

Selye, H. (1991). Streß beherrscht unser Leben: das Standardwerk des Pioniers der Streßforschung. München: Heyne.

Serio, A. & Munafo, E. (1989). Hygiene and comfort in passenger transport: a side of quality. *Rail International, 1*, 125-131.

Shackel, B., Chidsey, K.D. & Shipsley, P. (1969). The assessment of chair comfort. *Ergonomics, 12*, 269-306.

Shepard, K.P. (1976). Effects of low-frequency tones and turbulent-boundary-layer noise on annoyance. NASA Technical Reports # 22.

Shepard, R.N. (1962a). The analysis of proximities: multidimensional scaling with an unknown distance function, part I. *Psychometrika, 27*, 125-140.

Shepard, R.N. (1962b). The analysis of proximities: multidimensional scaling with an unknown distance function, part II. *Psychometrika, 27*, 219-246.

Slater, K. (1985). Human comfort. Springfield, IL: Charles C. Thomas.

Smith, M.J.T. (1987). Subsonic aircraft noise. In: Nelson, P.M. (Ed.). Transportation noise reference book. London: Butterworths.

Smith, M.J.T. (1989). Aircraft noise. Cambridge Aerospace Series. Cambridge: University Press.

Solomon, L.N. (1958). Semantic approach to the perception of complex sounds. *Journal of the Acoustical Society of America, 30*, 421-425.

Solomon, L.N. (1959a). Search for physical correlates to psychological dimensions. *Journal of the Acoustical Society of America, 31*, 492-497.

Solomon, L.N. (1959b). Semantic reactions to systematically varied sounds. *Journal of the Acoustical Society of America, 31*, 986-990.

Spannheimer, H., Freymann, R. & Fastl, H. (2000). An active absorber to improve the sound quality in the passenger compartment of vehicles. In: Proceedings of the Inter-noise 2000, 439-444.

Splittgerber, B., Kreuzer, M. & Jansen, G. (1991). Lärm an erschütterungsbelasteten Arbeitsplätzen. *Zeitschrift für Lärmbekämpfung, 38*, 43-50.

Splittgerber, H. & Hillen, R. (1991). Wahrnehmungsschwelle für Ganzkörperschwingungen in sitzender Körperhaltung. LIS-Berichte der Landesanstalt für Immissionsschutz Nordrhein-Westfalen, Essen.

Stephens, D.G. (1992). Developments in ride quality criteria. In: Sanders, M.S. & McCormick, E.J. (Eds.). Human factors in engineering and design. New York: McGraw-Hill.

Stephens, D.G. & Leatherwood, J.D. (1979). Physical and subjective studies of aircraft interior noise and vibration. NASA Technical Reports, TM-80084.

Stephens, D.G., Leatherwood, J.D. & Clevenson, S.A. (1990). The development of interior noise and vibration criteria. *Archives of Complex Environmental Studies, 2*, 9-16.

Stephens, R.W.B. (1972). Natural sources of low frequency sound. In: Proceedings of the Fall Meeting of the British Acoustical Society paper, 71-105.

Stevens, S.S. (1955). The measurement of loudness. *Journal of the Acoustical Society of America, 27*, 815-829.

Stevens, S.S. (1957). On the psychophysical law. *Psychological Review, 64*, 153-182.

Stevens, S.S. (1972). Perceived level of noise by Mark VII and decibels. *Journal of the Acoustical Society of America, 51*, 575-593.

Stevens, S.S., Guirao, M. & Slawson, A.W. (1965). Loudness, a product of volume times density. *Journal of Experimental Psychology, 69*, 503-510.

Steyer, R., Schwenkmezger, P., Notz, P. & Eid, M. (1994). Testtheoretische Analysen des Mehrdimensionalen Befindlichkeitsfragebogens (MDBF). *Diagnostica, 40*, 320-328.

Strelau, J. (1970). Nervous system type and extraversion – introversion. *Polish Psychological Bulletin, 1*, 17-24.

Strelau, J. (1974). Temperament as an expression of energy level and temporal features of behavior. *Polish Psychological Bulletin, 5*, 119-127.

Strelau, J. (1982). Biologically determined dimensions of personality or temperament? *Personality and Individual Differences, 13*, 355-360.

Strelau, J. (1983). Temperament, personality, activity. London: Academic.

Strelau, J. (1987). The concept of temperament in personality research. *European Journal of Personality, 1*, 107-117.

Strelau, J. (1989). The regulative theory of temperament as a result of East-West influences. In: Kohnstamm, G.A., Bates, J.E. & Rothbart, M.K. (Eds.). Temperament in childhood. New York: Wiley.

Strelau, J. (1991). Renaissance in research on temperament: where to? In: Strelau, J. & Angleitner, A. (Eds.). Explorations in temperament. International perspectives on theory and measurement. London: Plenum.

Strelau, J. (1993). The location of the regulative theory of temperament (RTT) among other temperament theories. In: Hettema, J. & Deary, I.J. (Eds.). Foundations of personality. Dordrecht: Kluver.

Strelau, J. (1995). The regulative theory of temperament: current status. *Personality and Individual Differences, 20*, 131-142.

Strelau, J. (1999). Temperament: a psychological perspective. New York: Plenum.

Stumpf, C. (1883, 1890). Tonpsychologie. Leipzig: Hirzel.

Suzuki, H. (1998a). Effects of the range and frequency of vibrations on the momentary riding comfort evaluation of a railway vehicle. *Japanese Psychological Research, 40*, 156-165.

Suzuki, H. (1998b). Research trends on riding comfort evaluation in Japan. In: Proceedings of the Institution of Mechanical Engineers, Part F, Journal of Rail and Rapid Transit, 212, 61-72.

Suzuki, H. (1998c). Momentary discomfort caused by vibration of railway vehicle. *Industrial Health, 36*, 98-106.

Swedish Defence Materiel Administration (Ed., 1985). Infrasound. A summary of interesting articles. Stockholm: Swedish Defence Materiel Administration.

Takao, H. & Hashimoto, T. (1994). Die subjektive Bewertung der Innengeräusche im fahrenden Auto - Auswahl der Adjektivpaare zur Klangbewertung mit dem Semantischen Differential. *Zeitschrift für Lärmbekämpfung, 41*, 72-77.

Taylor, S. (1984). A path model of aircraft annoyance. *Journal of Sound and Vibration, 96,* 243-260.

Tempest, W. (1973). Loudness and annoyance due to low frequency sound. *Acustica, 29,* 205-209.

Tempest, W. (Ed., 1976a). Infrasound and low frequency vibration. London: Academic.

Tempest, W. (1976b). Infrasound in transportation. In: Tempest, W. (Ed.). Infrasound and low frequency vibration. London: Academic.

Tempest, W. (1979). Loudness and annoyance due to low frequency sound. *Acustica, 29,* 205-209.

Tempest, W. & Bryan, M.E. (1972). Low frequency sound measurements in vehicles. *Applied Acoustics, 5*, 133-139.

Treier, C. (1997). Zur Wirkung von Ganzkörperschwingungen auf den stehenden Menschen und Konsequenzen für die Forschungs- und Beurteilungspraxis aus arbeitswissenschaftlicher Perspektive. Bochum: Universitätsverlag Dr. N. Brockmeyer.

Umweltbundesamt (1997). Geräuschbewertung des Transrapid. Ist der Transrapid wie die Bahn zu beurteilen? Berlin: Umweltbundesamt-Texte.

Västfjäll, D. (2001). Affective reactions to interior aircraft sound quality. Licentiate Thesis at the Department of Applied Acoustics, Chalmers University of Technology, Göteborg, Sweden.

Vallet, M. (1987). The effects of non acoustic factors on annoyance due to traffic noise. In: Koelega, H. (Ed.). Environmental annoyance: characterization, measurement and control. Proceedings of the International Symposium on Environmental Annoyance at the Conference Centre Winschoten. Amsterdam: Elsevier Science.

Wanner, H.U., Wehrli, B., Nemecek, J. & Turrian, V. (1977). Die Belastung der Anwohner verkehrsreicher Straßen durch Lärm und Luftverunreingungen. *Soziale Präventivmedizin, 22*, 108-115.

Webster's new dictionary of synonyms (1984). A dictionary of discriminated synonyms with antonyms and analogous and contrasted words. Springfield: Merriam-Webster Inc.

Webster's ninth collegiate dictionary (1991). Springfield: Merriam-Webster Inc.

Wedin, L. & Goude, G. (1972). Dimension analysis of the perception of instrumental timbre. *Scandinavian Journal of Psychology, 13*, 228-240.

Weinstein, N.D. (1978). Individual differences in reaction to noise: a longitudinal study in a college dormitory. *Journal of Applied Psychology, 63*, 458-466.

Weinstein, N.D. (1980). Individual differences in critical tendencies and noise annoyance. *Journal of Sound and Vibration, 68*, 241-248.

Whittle, L.D., Collins, S.J. & Robinson, D.W. (1972). The audibility of low frequency sounds. *Journal of Sound and Vibration, 21*, 431-448.

Widmann, U. (1997). A psychoacoustic annoyance concept for application in sound quality. In: Proceedings of the Noise Conference '97, 491-496.

Widmann, U. (1998). Aurally adequate evaluation of sounds. In: Proceedings of the Euro-noise '98, 29-46.

Widmann, U. & Goossens, S. (1993). Zur Lästigkeit tieffrequenter Schalle: Einflüsse von Lautheit und Zeitstruktur. *Acustica, 77*, 290-292.

Wiener Umwelterhebung (1984). In: MA 22/Umweltschutz der Gemeinde Wien (Hg.). Wiener Umwelterhebung. Wien.

Wilby, J.F. (1989). Noise transmission into propeller-driven airplanes. *Shock and Vibration Digest, 21*, 3-10.

Wilby, J.F. (1992). Noise transmission into propeller-driven airplanes II. *Shock and Vibration Digest, 24*, 3-13.

Williams, D. (1985). Noise in transportation. In: Tempest, W. (Ed.). The noise handbook. London: Academic.

Williams, D. & Tempest, W. (1975). Noise in heavy goods vehicles. *Journal of Sound and Vibration, 43*, 97-107.

Winer, B.J. (1971). Statistical principles in experimental design. New York: McGraw Hill.

Winneke, G. & Neuf, M. (1992). Psychological response to sensory stimulation by environmental stressors: trait or state? *Applied Psychology, 41*, 257-267.

Winneke, G., Neuf, M. & Steinheider, B. (1996). Separating the impact of exposure and personality in annoyance response to environmental stressors, particularly odours. *Environmental International, 22*, 73-81.

Winsberg, S. & De Soete, G. (1993). A latent approach to fitting the Euclidean model, CLASCAL. *Psychometrika, 58*, 315-330.

Winsberg, S. & De Soete, G. (1997). Multidimensional scaling with constrained dimensions: CONSCAL. *British Journal of Mathematical and Statistical Psychology, 50*, 55-72.

Witkin, H.A. (1964). Origins of cognitive style. In: Sheerer, C. (Ed.). Cognition: theory, research, promise. New York: Harper and Row.

Witkin, H.A. (1975). Personality through perception: an experimental and clinical study. Westport: Greenwood.

Witkin, H.A. & Goodenough, D. (1981). Cognitive styles: essence and origins: field dependence and field independence. New York: International University Press.

Wohlwill, J.F. (1974). Human response to levels of environmental stimulation. *Human Ecology, 2*, 127-147.

Yamada, S., Sueki, M., Okamura, A., Hagiwara, S. & Watanabe, T. (1990). Combined effects on man by low frequency noise and vibration. In: Proceedings of the Inter-noise '90, 1311-1314

Yamada, S., Watanabe, T., Kosaka, T., Uchiyama, Y., Kasada, K. & Tamura, S. (1984). Psychological and physiological effects of low frequency noise. In: Proceedings of the Inter-noise '84, 921-924.

Yamada, S., Watanabe, T., Negishi, H. & Watanabe, H. (1986). Psychological effects of low-frequency noise. *Journal of Low Frequency Noise and Vibration, 5*, 14-25.

Yamazaki, K. & Tokita, Y. (1984). Effects of infra and low frequency sound on sleep stages. In: Proceedings of the Inter-noise '84, 929-932.

Yeowart, N.S. (1976). Thresholds of hearing and loudness for very low frequencies. In: Tempest, W. (Ed.). Infrasound and low frequency vibration. London: Academic.

Yeowart, N.S., Bryan, M.E. & Tempest, W. (1969). Low-frequency noise thresholds. *Journal of Sound and Vibration, 9*, 447-453.

Yerkes, R.M. & Dodson, J.D. (1908). The relation of strength of stimuli to rapidity of habit formation. *Journal of Comparative and Neurological Psychology, 18*, 459-482.

Zajonc, R.B. (1968). Cognitive theories in social psychology. In: Lindzey, G. & Aronson, E. (Eds.). The handbook of social psychology, Vol. 1, Reading. Mass.: Addison-Wesley.

Zeichart, K. (1998). Kombinatorische Wirkungen von Bahnlärm und Bahnerschütterungen. *Zeitschrift für Lärmbekämpfung, 45*, 7-16.

Zeichart, K., Sinz, A., Schuemer-Kohrs, A. & Schuemer, R. (1994a). Erschütterungen durch Eisenbahnverkehr und ihre Wirkungen auf Anwohner. Teil 1: Zum Zusammenwirken von Erschütterungs- und Geräuschbelastung. *Zeitschrift für Lärmbekämpfung, 41*, 43-51.

Zeichart, K., Sinz, A., Schuemer-Kohrs, A. & Schuemer, R. (1994b). Erschütterungen durch Eisenbahnverkehr und ihre Wirkungen auf Anwohner. Teil 2: Überlegungen zu Immissionsrichtwerten für Erschütterungen durch Schienenverkehr. *Zeitschrift für Lärmbekämpfung, 41*, 104-111.

Zhang, L., Helander, M.G. & Drury, C.G. (1996). Identifying factors of comfort and discomfort in sitting. *Human Factors, 38*, 377-389.

Zimmer, K. & Ellermeier, W. (1997). Construction and evaluation of a noise sensitivity questionnaire. In: Schick, A. & Klatte, M. (Eds.). Contributions to psychological acoustics. Results of the seventh Oldenburg symposium on psychological acoustics. Oldenburg: bis.

Zwicker, E. (1958). Über psychologische und methodische Grundlagen der Lautheit. *Acustica, 8*, 237-258.

Zwicker, E. (1960). Ein Verfahren zur Berechnung der Lautstärke. *Acustica, 10*, 304-308.

Zwicker, E. (1999). Psychoakustik. Berlin: Springer.

Zwicker, E. & Fastl, H. (1999). Psychoacoustics. Facts and models. Berlin: Springer.

Zwicker, E. & Scharf, B. (1965). A model of loudness summation. *Psychological Review, 72,* 3-26.

APPENDIX

APPENDIX I

Instruction for the first laboratory pretest

In diesem Versuch sollen Sie die Geräusche und Vibrationen von Hubschraubern und Flugzeugen beurteilen. Zu diesem Zweck werden Ihnen über Lautsprecher sechs Aufnahmen von Hubschraubern und drei Aufnahmen von Flugzeugen dargeboten. Diese Aufnahmen dauern jeweils ca. 25 Sekunden.
Bei der Darbietung der Hubschrauberaufnahmen werden Sie zusätzlich einen Kopfhörer tragen.
Damit Sie jeden Hubschrauber- bzw. Flugzeugtyp kennenlernen, wird Ihnen zunächst jede Aufnahme einmal vorgespielt. Dabei brauchen Sie nur zuhören.
Im Anschluß daran sollen sie nach jeder Darbietung die Geräusche und Vibrationen nach ihrem Komfort beurteilen. Danach schreiben Sie bitte alles auf, was Ihnen zu jeder Darbietung durch den Kopf geht.
Abschließend haben Sie die Gelegenheit, Ihre Beschreibungen zu ergänzen oder zu verändern, indem Sie gemeinsam mit der Versuchsleiterin Ihre Beschreibungen durchgehen und gegebenenfalls nochmals die Aufnahmen anhören.

Haben Sie noch Fragen zu dem Versuch?

Bitte füllen Sie als erstes die Angaben zur Person aus.

Setzen Sie bitte danach den Kopfhörer auf.

APPENDIX II-1

Instruction for the suitability rating of adjectives

Sehr geehrte Damen, sehr geehrte Herren,

Wir möchten Sie um Ihre Mitarbeit bei der Entwicklung eines semantischen Differentials zur Beurteilung der Situation in Hubschraubern und Flugzeugen bitten. Zu diesem Zweck finden Sie im folgenden eine Liste mit Eigenschaftswörtern, die der Beurteilung dienen könnten.
Ihre Aufgabe ist es, anhand einer fünfstufigen Kategorialskala einzuschätzen, wie <u>geeignet</u> Ihnen diese Wörter zur Beurteilung der Situation in Hubschraubern und Flugzeugen erscheinen.

Die Zahlen hinter den Wörter bedeuten dabei:

5 – sehr geeignet
4 – geeignet
3 – möglich
2 – ungeeignet
1 – sehr ungeeignet

Bitte kreuzen Sie bei <u>jedem</u> Wort nur eine Antwort an und lassen Sie keines der Wörter aus.

Beurteilen Sie bitte spontan, ohne lange nachzudenken!

Bitte füllen Sie als erstes die Angaben zur Ihrer Person aus.

Vielen Dank für Ihre Mitarbeit!

APPENDIX II-2

Instruction for the association of appropriate opposites

Sehr geehrte Damen, sehr geehrte Herren,

Wir möchten Sie erneut darum bitten, sich bei der Entwicklung eines semantischen Differentials zur Beurteilung der Situation in Hubschraubern und Flugzeugen zu beteiligen. Zu diesem Zweck haben wir Ihnen das letzte Mal eine Liste mit Eigenschaftswörtern vorgelegt, die Sie anhand einer fünfstufigen Kategorialskala bezüglich ihrer Geeignetheit beurteilt haben.
Die nun folgenden Eigenschaftswörter wurden von Ihnen als geeignet eingestuft.
Heute sollen Sie bitte zu jedem Eigenschaftswort das Wort aufschreiben, das Ihrer Ansicht nach das <u>Gegenteil</u> dieser Eigenschaft am besten beschreibt.

Bitte nehmen Sie für jedes Eigenschaftswort das Gegenteil, das Ihnen <u>spontan</u> in den Sinn kommt.
Schreiben Sie bitte pro Wort nur <u>ein</u> Gegenteil auf.

Uns interessiert ausschließlich Ihre persönliche Meinung. Dabei gibt es keine „falschen“ oder „richtigen“ Antworten.

Bitte füllen Sie als erstes die Angaben zur Ihrer Person aus.

Vielen Dank für Ihre Mitarbeit!

APPENDIX III-1

Instruction for the second laboratory pretest (semantic differential)

In dieser Untersuchung sollen Sie die Flugsituation in einem Hubschrauber nach verschiedenen Merkmalen beurteilen.
Dazu dienen die Antwortbögen, die Sie gleich ausgehändigt bekommen.

Ihre Aufgabe ist es, auf den verschiedenen Skalen eine Beurteilung vorzunehmen.
Wenn Ihnen also beispielsweise die Flugsituation recht kurz vorkommt, dann sollten Sie das etwa so kennzeichnen:

kurz O O ~~O~~ O O O O lang

Solche Beurteilungen nehmen Sie bitte auf allen Skalen vor.

Auch wenn Ihnen die Beurteilung nicht immer leicht fallen sollte, kreuzen Sie bitte in jedem Fall auf jeder Beurteilungsskala einen Kreis an.

Bitte beurteilen Sie spontan, ohne lange nachzudenken!

Uns interessiert ausschließlich Ihre persönliche Bewertung.
Natürlich gibt es dabei keine *„richtigen“* oder *„falschen“* Antworten.

Zu Ihrer Orientierung wird die Darbietung durch einen kurzen Piepton angekündigt. Bitte fangen Sie erst nach der Darbietung der Flugsituation mit der Beurteilung an.

Haben Sie noch Fragen zum Versuch?

Bitte füllen Sie als erstes die Angaben zu Ihrer Person aus.

Instruction for the second laboratory pretest (suitability rating)

Sie haben gerade die Flugsituation in einem Hubschrauber anhand verschiedener Merkmale beurteilt.
Wir möchten Sie jetzt um Ihre Mitarbeit bei der Entwicklung eines semantischen Differentials zur Beurteilung von Flugsituationen bitten. Zu diesem Zweck sollen Sie bitte mit Hilfe einer fünfstufigen Kategorialskala einschätzen, wie geeignet Ihnen diese Merkmale zur Beurteilung von Flugsituationen erscheinen.

Die Zahlen hinter den Merkmalen bedeuten dabei:

5 – sehr geeignet
4 – geeignet
3 – möglich
2 – ungeeignet
1 – sehr ungeeignet

Bitte kreuzen Sie bei jedem Merkmal nur eine Antwort an und lassen Sie keines der Merkmale aus.

Beurteilen Sie bitte spontan, ohne lange nachzudenken!

Damit Ihnen die Beurteilung leichter fällt, wird Ihnen jetzt noch einmal die gleiche Flugsituation im Hubschrauber dargeboten.

Bitte fangen Sie erst nach der Darbietung mit der Beurteilung an.

Vielen Dank für Ihre Mitarbeit!

APPENDIX IV

The „Eigenschaftswörterliste" (EWL):

Normal capitals: adjectives constituting the mood aspects „well-being" and „fear" according to Janke and Debus (1978)

Bold capitals: adjectives constituting the orthogonal mood dimensions „well-being" and „ill-being" according to study 1

WELL-BEING	FEAR (ILL-BEING)
joyful	anxious
excellent	intrepid
marvelous	filled with fear
comfortable	vulnerable
content	jumpy
light-hearted	hesitant
animated	fearful
glad	**driven**
happy	fluttery
humorous	excited
satisfied	fidgety
cheerful	**unbalanced**
jaunty	**unsteady**
in good spirits	jittery
sunny	restless
merry	absent-minded
self-confident	unpredictable
unconcerned	**disorganised**
unhindered	nervous
uninhibited	manic
optimistic	**irritable**
unworried	awkward
self-satisfied	
carefree	

APPENDIX V-1

Instruction for study 1 (semantic differential)

Wir werden Ihnen gleich die Geräusche und Vibrationen von 14 Flugsituationen darbieten.
Die Darbietungen dauern jeweils etwa 2 Minuten.

Ihre Aufgabe besteht darin, jede Flugsituation mit 15 Adjektivpaaren zu beurteilen.

Ein Beispiel: Wenn Sie beispielsweise die Flugsituation als recht schön beurteilen, dann sollten Sie das so kennzeichnen:

schön O O ~~O~~ O O O O häßlich

Solche Beurteilungen nehmen Sie bitte für alle 15 Adjektivpaare vor.

Bitte beurteilen Sie immer spontan!

Beurteilen Sie bitte nicht den Anfang und das Ende der jeweiligen Darbietung.

Haben Sie noch Fragen zum Versuch?

Instruction for study 1 (practice)

Damit Sie mit den Darbietungen vertraut werden, werden Ihnen zunächst die Geräusche und Vibrationen von sieben Flugsituationen einmal kurz dargeboten. Bitte beurteilen Sie jede Flugsituation anhand des Adjektivpaares "schön / häßlich".

No. 1

schön	O	O	O	O	O	O	O	häßlich

No. 2

schön	O	O	O	O	O	O	O	häßlich

No. 3

schön	O	O	O	O	O	O	O	häßlich

No. 4

schön	O	O	O	O	O	O	O	häßlich

No. 5

schön	O	O	O	O	O	O	O	häßlich

No. 6

schön	O	O	O	O	O	O	O	häßlich

No.7

schön	O	O	O	O	O	O	O	häßlich

APPENDIX V-3

Instruction for study 1 (mood scales)

Sie bekommen gleich eine Liste von Wörtern, mit denen man beschreiben kann, wie man sich augenblicklich fühlt.
Gehen Sie bitte alle Wörter der Liste nacheinander durch, und entscheiden Sie sofort bei jedem Wort, <u>inwieweit</u> es auf Ihr <u>augenblickliches</u> Befinden zutrifft.

Die Zahlen hinter den Wörtern bedeuten dabei:
6 – trifft genau zu
5 – trifft fast ganz zu
4 – trifft ziemlich genau zu
3 – trifft etwas mehr zu
2 – trifft ein wenig zu
1 – trifft gar nicht zu

Wenn es also beispielsweise <u>ziemlich genau</u> zutrifft, daß Ihr augenblickliches Befinden <u>gut</u> ist, dann sollten Sie das etwa so kennzeichnen:

	trifft gar nicht zu	**trifft ein wenig zu**	**trifft etwas mehr zu**	**trifft ziem-lich ge-nau zu**	**trifft fast ganz zu**	**trifft genau zu**
gut	1	2	3	**4**	5	6

Bitte beurteilen Sie jetzt Ihr augenblickliches Befinden.

APPENDIX VI

Qualitative questionnaire of study 1

1. Haben Sie noch Anmerkungen zum Versuch?

____

____

____

____

2. Was hat Ihnen an dem Versuch gar nicht gefallen?

____

____

____

____

3. Wie realistisch würden Sie die Darbietungen auf einer Skala von 1 ("nicht realistisch") bis 6 ("sehr realistisch") einstufen?

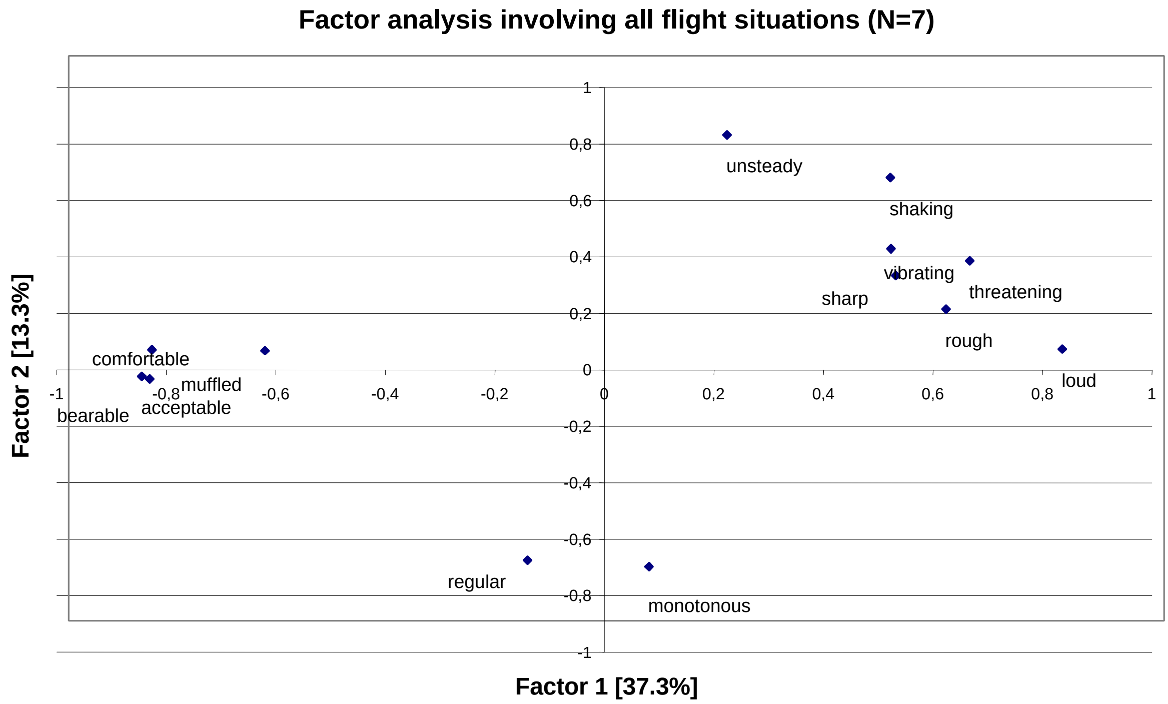
1 2 3 4 5 6

4. Würden Sie an einem solchem Versuch noch einmal teilnehmen?

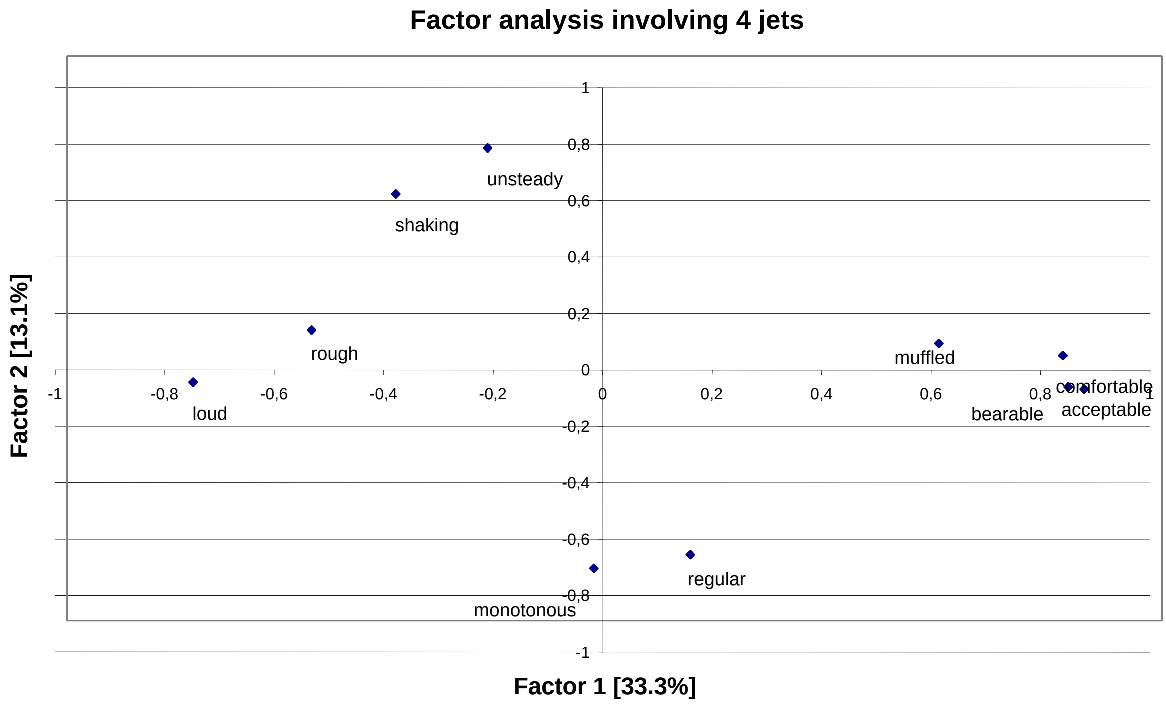
O Ja O Nein

Vielen Dank für Ihre Teilnahme!

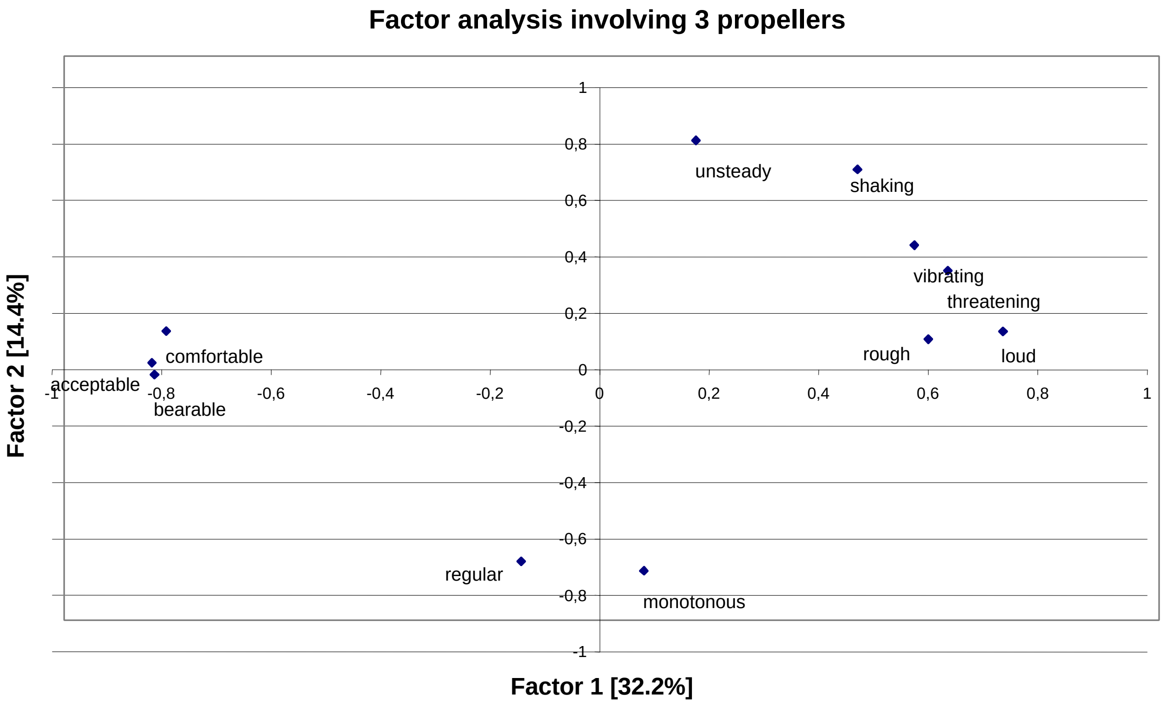
APPENDIX VII-1

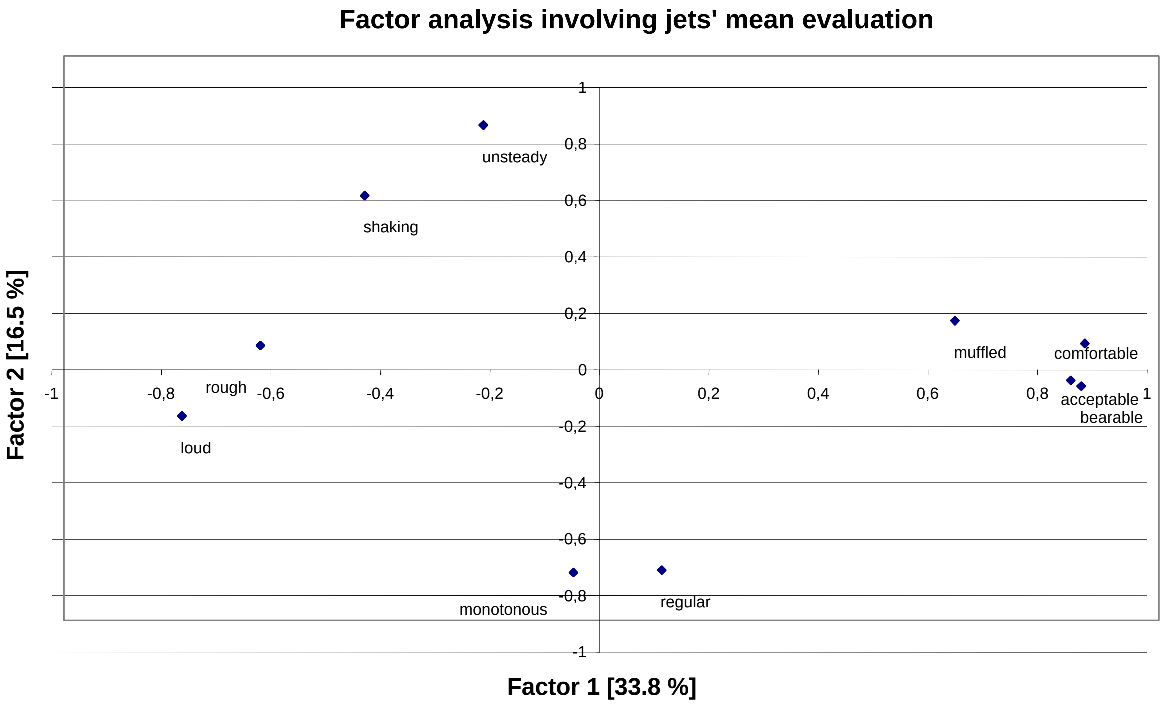


APPENDIX VII-2



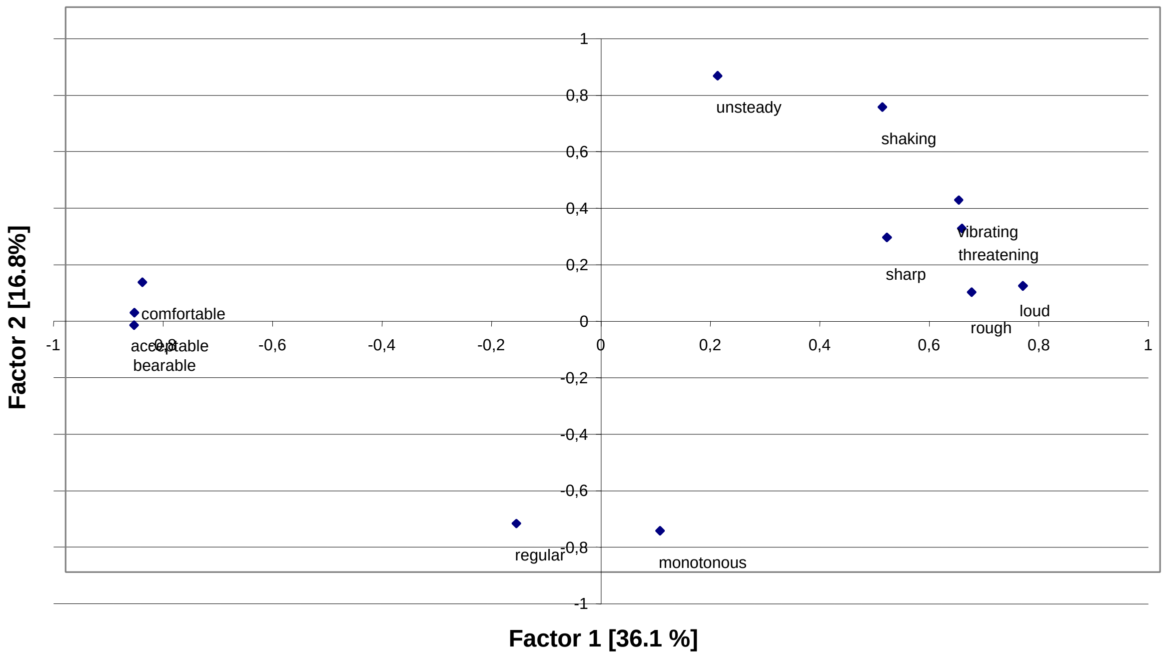
APPENDIX VII-3



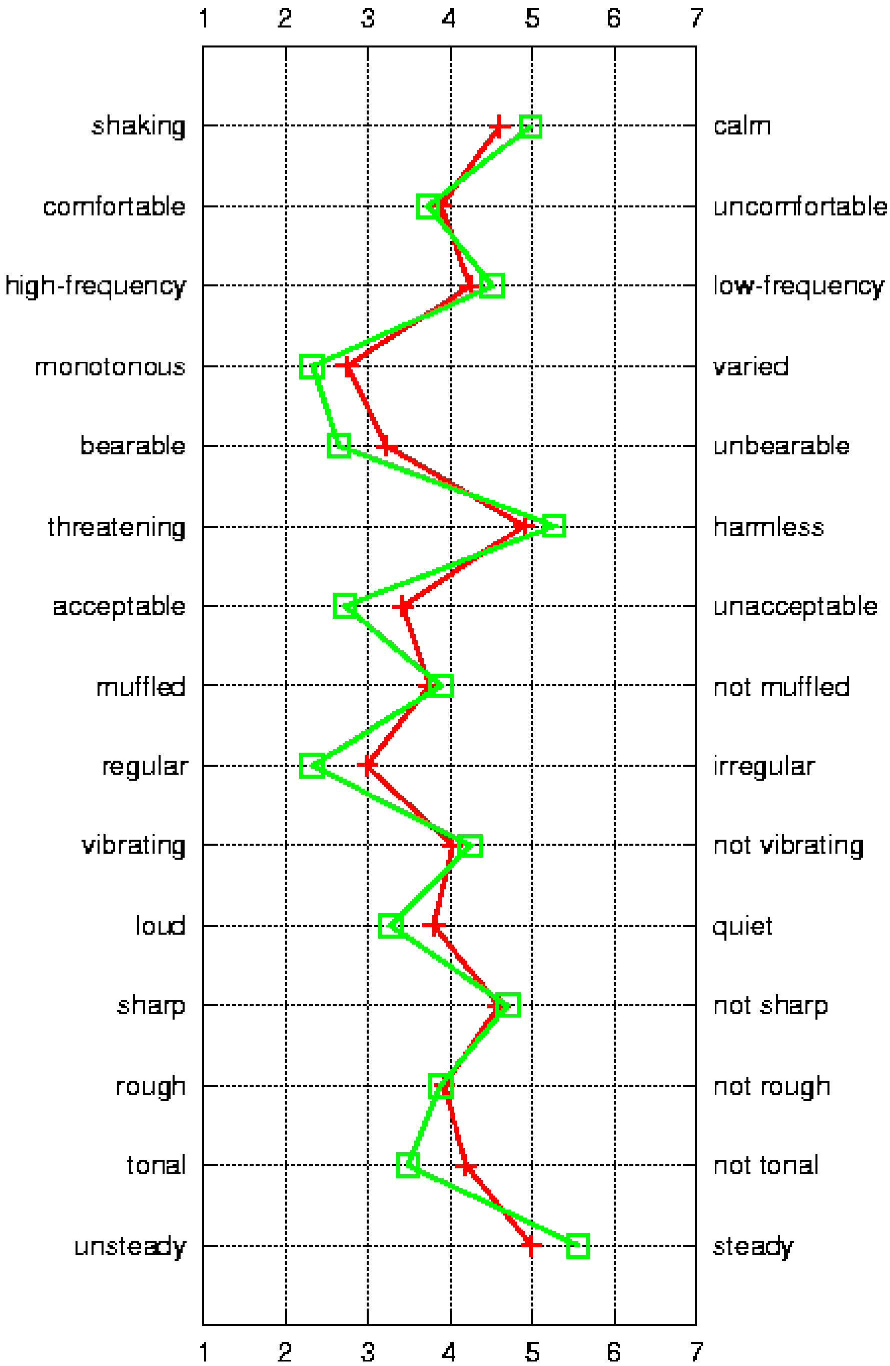

Factor analysis involving jets' mean evaluation
Factor 2 [16.5 %]
Factor 1 [33.8 %]
unsteady
shaking
rough
loud
muffled
comfortable
acceptable
bearable
monotonous
regular
1
0,8
0,6
0,4
0,2
0
-0,2
-0,4
-0,6
-0,8
-1
-1
-0,8
-0,6
-0,4
-0,2
0
0,2
0,4
0,6
0,8
1

APPENDIX VII-5

Factor analysis involving propellers' mean evaluation



APPENDIX VIII



Comfort dimension: mean semantic profiles of the aircraft type jet for GC1 (N=62; +) and GC2 (N=28; □)

Sensitivity index d' of physical variations of vibration level (in dB re 10^{-6} m/s^2):

d'	+ 1.5 dB	+ 3.0 dB	- 1.5 dB	- 3.0 dB
Jet	1.054	2.697	1.317	2.451
Propeller	.856	2.304	1.011	2.258

Sensitivity index d' of physical variations of sound pressure level (in dB re 2×10^{-5} N/m^2):

d'	+ 1.0 dB	+ 2.0 dB	+ 4.0 dB	- 1.0 dB	- 2.0 dB	- 4.0 dB
Jet	.484	.940	2.318	.382	.819	2.183
Propeller	.920	1.52	2.877	.588	1.286	2.556

APPENDIX X-1

Instruction for study 2 (semantic differential)

Sie bekommen gleich die Geräusche und Vibrationen von 9 Flugsituationen dargeboten.

Die Darbietungen dauern jeweils 1 Minute.
Jede Darbietung wird durch einen kurzen Piepston angekündigt.

Ihre Aufgabe besteht darin, jede Flugsituation mit 15 Adjektivpaaren zu beurteilen.

Ein Beispiel:
Wenn Sie etwa die Flugsituation als recht schön beurteilen, dann sollten Sie das so kennzeichnen:

schön	O	O	~~O~~	O	O	O	O	häßlich

Solche Beurteilungen nehmen Sie bitte für jede Flugsituation auf allen 15 Adjektivpaaren vor.

Bitte beginnen Sie erst mit der Beurteilung, wenn das Licht aufleuchtet.

Beurteilen Sie bitte immer spontan!

Haben Sie noch Fragen zum Versuch?

Instruction for study 2 (practice 1)

Damit Sie mit den Darbietungen vertraut werden, werden Ihnen die Geräusche und Vibrationen der neun Flugsituationen zunächst einmal kurz dargeboten. Bitte beurteilen Sie jede Flugsituation anhand des Adjektivpaares "schön / häß-lich".

No. 1

schön O O O O O O O häßlich

No. 2

schön O O O O O O O häßlich

No. 3

schön O O O O O O O häßlich

No. 4

schön O O O O O O O häßlich

No. 5

schön O O O O O O O häßlich

No. 6

schön O O O O O O O häßlich

No.7

schön O O O O O O O häßlich

No.8

schön O O O O O O O häßlich

No.9

schön O O O O O O O häßlich

Instruction for study 2 (practice 2)

Sie bekommen gleich die Geräusche und Vibrationen von 9 weiteren Flugsituationen dargeboten. Ihre Aufgabe besteht wieder darin, jede Flugsituation mit 15 Adjektivpaaren zu beurteilen.
Um Sie mit den Darbietungen vertraut zu machen, werden Ihnen die Geräusche und Vibrationen der neun Flugsituationen zunächst einmal kurz dargeboten. Bitte beurteilen Sie jede Flugsituation anhand des Adjektivpaares "schön / häßlich".

No. 1

schön O O O O O O O häßlich

No. 2

schön O O O O O O O häßlich

No. 3

schön O O O O O O O häßlich

No. 4

schön O O O O O O O häßlich

No. 5

schön O O O O O O O häßlich

No. 6

schön O O O O O O O häßlich

No.7

schön O O O O O O O häßlich

No.8

schön O O O O O O O häßlich

No.9

schön O O O O O O O häßlich

APPENDIX X-4

Instruction for study 2 (mood scales)

Es folgt gleich eine Liste von Wörtern, mit denen man beschreiben kann, wie man sich augenblicklich fühlt.
Gehen Sie bitte alle Wörter der Liste nacheinander durch, und entscheiden Sie sofort bei jedem Wort, inwieweit es auf Ihr augenblickliches Befinden zutrifft.

Die Zahlen hinter den Wörtern bedeuten dabei:
6 – trifft genau zu
5 – trifft fast ganz zu
4 – trifft ziemlich genau zu
3 – trifft etwas mehr zu
2 – trifft ein wenig zu
1 – trifft gar nicht zu

Kreuzen Sie bei jedem Wort immer diejenige Zahl an, die am besten angibt, wie gut es Ihrem augenblicklichen Befinden entspricht.

Ein Beispiel:
Wenn es ziemlich genau zutrifft, daß Ihr augenblickliches Befinden gut ist, dann sollten Sie das so kennzeichnen:

	trifft gar nicht zu	**trifft ein wenig zu**	**trifft etwas mehr zu**	**trifft ziem-lich ge-nau zu**	**trifft fast ganz zu**	**trifft genau zu**
gut	1	2	3	**4**	5	6

Bitte beurteilen Sie jetzt Ihr augenblickliches Befinden.

Qualitative questionnaire of study 2

Teil A

1. Haben Sie noch Anmerkungen zum Versuch?

____
____
____
____

2. Was hat Ihnen am Versuch <u>gar nicht</u> gefallen?

____
____
____
____

3. Wie <u>realistisch</u> würden Sie die Darbietungen auf einer Skala von 1 ("nicht realistisch") bis 6 ("sehr realistisch") einstufen?

1 2 3 4 5 6

4. Würden Sie an einem solchen Versuch noch einmal teilnehmen?

O Ja O Nein

APPENDIX XI-2

Qualitative questionnaire of study 2

Teil B

1. Was verstehen Sie ganz allgemein unter dem Begriff "Komfort"?

____

____

____

____

____

2. Welche Merkmale muss eine Flugsituation aufweisen, damit sie für Sie komfortabel ist?

____

____

____

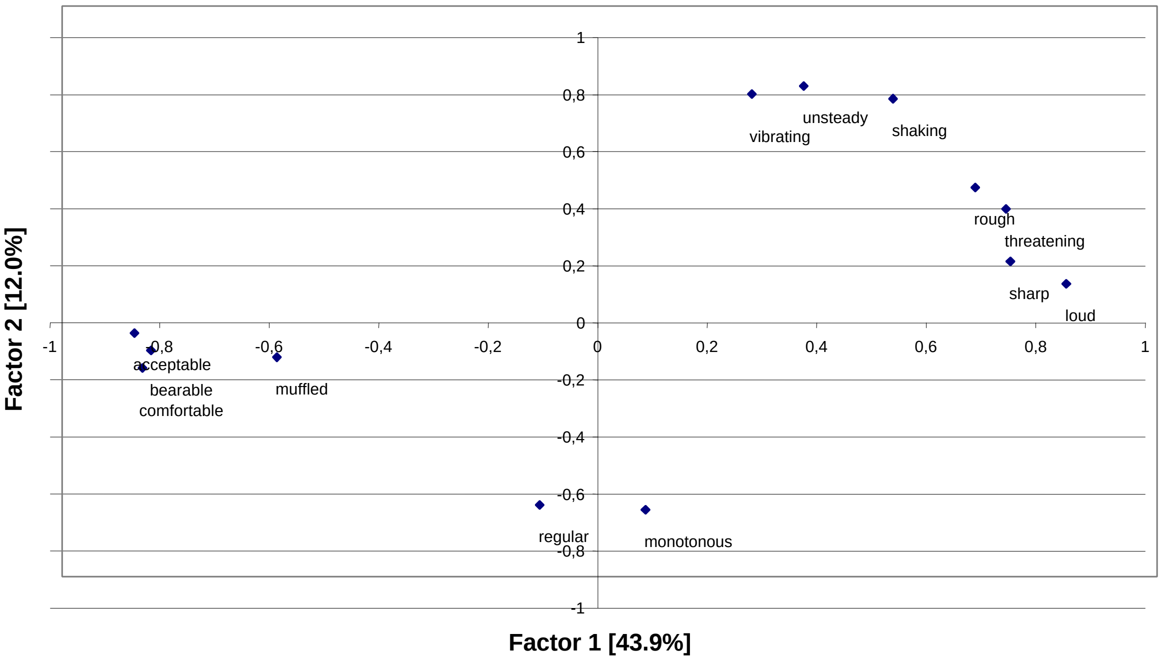
____

____

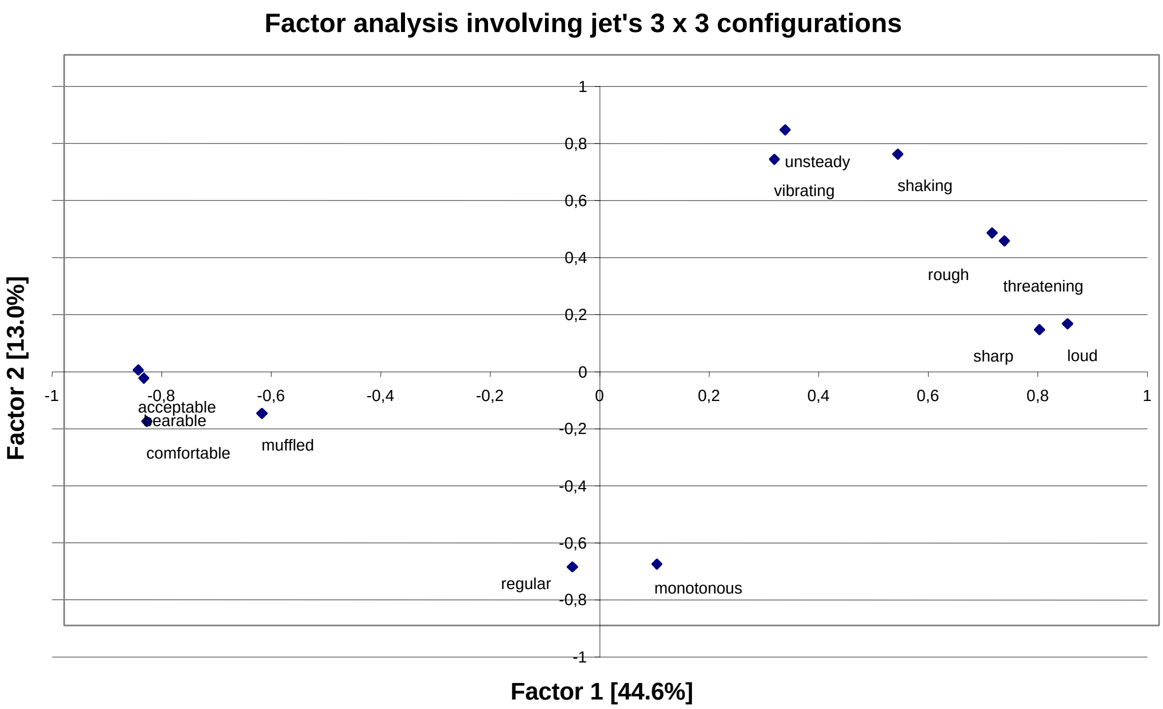
Vielen Dank für Ihre Teilnahme!

APPENDIX XII-1

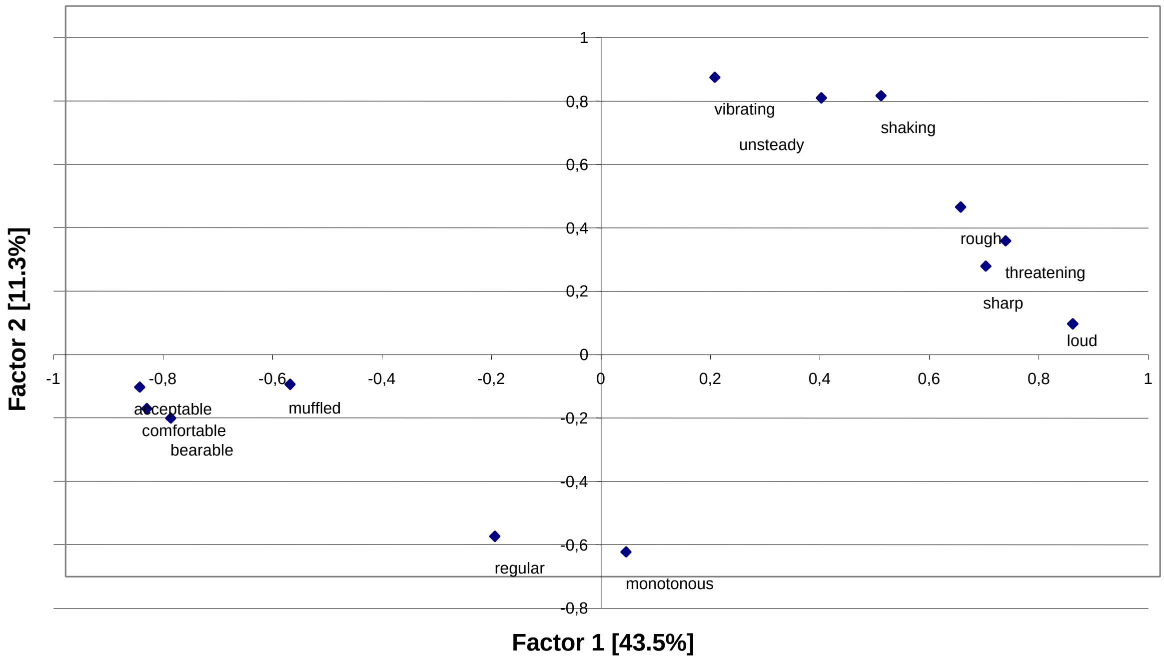
Factor analysis involving propeller's and jet's 3 x 3 configurations



APPENDIX XII-2



Factor analysis involving propeller's 3 x 3 configurations



LEBENSLAUF

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Hiermit versichere ich, daß ich diese Arbeit selbständig verfaßt und keine anderen als die angegebenen Hilfsmittel und Quellen benutzt habe.

Oldenburg, im Juli 2001

Julia Quehl

Hiermit versichere ich, daß ich die Zulassung zur Promotion nicht gleichzeitig an einer anderen Hochschule beantragt und mich nicht bereits erfolglos einem Promotionsverfahren unterzogen habe.

Oldenburg, im Juli 2001

Julia Quehl