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# Vehicle Ride Comfort: Subjective & Objective Evaluations with ANN Model

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***Abstract*** *Vehicle ride comfort is a key factor in customer satisfaction. Evaluation is conducted using two methods: subjective and objective. This research focuses on an approach for assessing ride comfort based on measured RMS values. The main objective is to develop a model that enables comfort assessment using experimentally obtained data. The paper presents the results of ride comfort testing conducted under controlled conditions, as well as the development of an ANN model for predicting comfort levels. Additionally, correlations between subjective and objective ride comfort assessments have been analyzed.*

***Keywords*** *vehicle, comfort, ANN model*

## 1. INTRODUCTION

Vehicle ride quality in relation to suspension is assessed using subjective and objective methods, with subjective evaluations being the most commonly used. However, they often fail to fully meet user expectations due to factors such as evaluation criteria, error definitions, fatigue, mood, and the perception levels of drivers during testing. As a result, the same driver may assess the same vehicle differently in different situations. Objective methods are more precise and repeatable but are not always sensitive enough to capture all the aspects of ride comfort that users feel.

Vehicle comfort and handling are assessed through tests and simulations, but the number of studies connecting subjective and objective evaluations is limited. There is a need for an objective evaluation system based on clearly defined comfort parameters, which would allow for a better understanding of the relationship between subjective and objective ride assessments.

The development of a reliable system for assessing ride comfort requires a combination of subjective and objective methods, with the establishment of a clear correlation model between these approaches being crucial. Subjective evaluations provide valuable insights into the real experience of drivers and passengers, while objective methods allow for precise measurement of parameters such as vibrations, accelerations, and suspension system response.

In this context, advanced data analysis techniques, including artificial intelligence and machine learning, can contribute to the development of sophisticated algorithms that predict subjective ratings based on objectively measured parameters. This would enable the automation of ride comfort assessments, reduce subjective errors, and increase the repeatability of tests.

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Furthermore, the application of numerical simulations and testing in controlled conditions can enhance the understanding of a vehicle's dynamic behavior on various types of roads. By integrating these approaches, it is possible to create a more precise system for evaluating ride comfort that would meet both engineering standards and the expectations of end-users.

## 2. LITERATURE REVIEW

There are numerous studies in the literature that focus on vehicle ride comfort. In general, ride comfort can be analyzed in two ways:

- Objective evaluation: Data acquisition (acceleration measurements, RMS values, ride comfort index calculation based on the ISO 2631 standard).
- Subjective evaluation: Survey studies (semantic differential method, SAE rating system, etc.).

To objectively assess ride comfort, acceleration signals are recorded under different driving conditions and maneuvers, and the comfort index is then calculated according to relevant standards. These methods are defined by international norms, while some vehicle manufacturers also develop their own evaluation criteria. The standards currently used for ride comfort index calculations include:

- ISO 2631 – 1 (1997) – "Mechanical vibration and shock – Evaluation of human exposure to whole-body vibration. Part 1: General requirements."
- British Standard 6841 (1987) – "Measurement and evaluation of human exposure to whole-body vibration."
- Vehicle manufacturers' norms and guidelines.

Below is a brief review of studies related to ride comfort. Study [3] explores how comfort is perceived in automated driving, emphasizing that advancements in vehicle technology are shifting the driver's role from active control to a more passive one. This transition introduces new factors that may influence the level of comfort during driving. The authors conducted a comprehensive analysis of existing literature, identifying 51 studies related to comfort in automated driving. Most of these studies focus on the physical aspects of comfort, particularly regarding the vehicle's behavior on the road. The authors suggest that while physical comfort is important, it is crucial to adopt a broader perspective that includes various factors influencing comfort beyond just vehicle dynamics. To systematically organize these factors, the authors present an integrative framework that includes 27 factors affecting comfort and their interrelationships. This framework categorizes the factors into six different groups:

- Driving environment
- Physical characteristics of the vehicle
- Automation system
- User activities
- Individual characteristics
- Understanding of the automated system.

These groups are further classified into three main categories: environment, vehicle, and user aspects, which help in systematically understanding comfort. The framework highlights several patterns, such as the distinction between factors that enhance physical well-being (e.g., motion forces) and those that may cause discomfort (e.g., automation errors). Additionally, some factors are stable and known before the journey (e.g., individual characteristics), while others may change during the trip (e.g., driving environment). The study suggests that feelings of comfort or discomfort may lead users to adjust relevant factors, such as the level of automation, or modify their behavior, such as engaging in secondary activities while driving.

In summary, this study aims to create a structured resource for future research on comfort in automated driving, emphasizing the importance of understanding the various factors involved.

In study [1], researchers focused on understanding how different driving durations affect passenger comfort and seat pressure distribution. They used the SAE (Society of Automotive Engineers) rating table to assess comfort levels among subjects. Floor mats were utilized to analyze how pressure is distributed across the seat during driving. The study employed statistical methods, including repeated measures one-way ANOVA and Tukey's Honestly Significant Difference (HSD) test, to analyze subjective and objective data. Results indicated that longer drives significantly impact various pressure variables, such as contact force in the upper and lower back. The research revealed strong correlations between pressure variables and overall comfort, particularly in the lower back area. Principal Component Analysis (PCA) was used to propose practical measures for improving comfort during prolonged driving. A nonlinear model was developed to capture comprehensive comfort ratings, achieving an $R^2$ value of 0.605, indicating a reasonable fit. The findings provide insights into subjective comfort patterns and objective pressure distribution during driving, which can inform automotive seat design. This research contributes valuable knowledge to the automotive seat comfort industry, helping manufacturers improve seat designs for extended comfort.

Study [4] addresses "ride comfort" in passenger vehicles, which refers to how comfortable passengers and drivers feel during travel. It highlights the importance of reducing vibrations, noise, and acceleration, as these factors can negatively impact comfort and health. The study discusses how prolonged exposure to vibrations can lead to fatigue, reduced performance, and even affect traffic safety. Therefore, improving ride comfort is a key requirement for modern vehicles. The research encompasses various studies conducted to measure and analyze factors influencing ride comfort. It also examines methods for evaluating these factors and proposes improvements. The study identifies several dynamic factors affecting ride comfort, including mechanical vibrations, noise levels, and the microclimate inside the vehicle. It emphasizes that comfort is a subjective experience that varies from person to person. The study explains the effects of vibrations on the human body, noting that different frequencies can cause discomfort or even motion sickness. It details how vibrations are transmitted through the vehicle and how they affect passengers. Motion sickness is a significant issue, especially when there is a mismatch between visual and vestibular perceptions. The study describes the conditions under which motion sickness can occur and identifies contributing factors such as air quality and vibration levels. Various methods for measuring ride comfort are discussed, including the use of accelerometers and mathematical models. The study emphasizes the importance of comparing results with international standards to ensure accuracy.

Finally, the study presents recommendations for improving ride comfort, such as enhancing vehicle suspension systems, using reclined seatbacks, and optimizing tire design. These improvements aim to reduce vibrations and enhance the overall travel experience for passengers.

The research in study [5] addresses the lack of an integrative model for understanding comfort in autonomous driving, despite the extensive existing literature on the topic. A literature review was conducted to identify key automation-related factors that influence driver comfort. The authors categorize these factors into six groups: driving environment, vehicle and automation, user activity, personality, and system understanding. The proposed model is structured into a comprehensive framework that includes factors related to the environment, vehicle, and user. This framework aims to facilitate the formulation of research questions related to comfort in automation. By integrating various factors affecting comfort, the model provides a holistic perspective on the elements influencing driver comfort in autonomous vehicles. The study emphasizes the importance of understanding the interrelationships between these factors to enhance the overall driving experience. This integrative approach is expected to guide future research and development in the field of autonomous driving. The authors argue that a better understanding of comfort can lead to improved design and functionality of autonomous vehicles. Certain studies recognize that traditional assessments of driving comfort have largely relied on subjective sensory evaluations by drivers, which can be abstract and difficult to quantify [2]. This research focuses on quantifying driver comfort by analyzing the effects of different damper characteristics in vehicles, specifically comparing comfort mode and sport mode.

To address this, researchers applied a scientific approach by collecting data on driver behavior and vehicle dynamic characteristics using advanced technologies such as motion capture systems and CAN and IMU sensors. A three-dimensional mathematical muscle model was developed to simulate driver movements, enabling the calculation of energy expenditure in joints and muscles during driving. In comfort mode, vehicle dampers are softer, resulting in reduced vibration transmission to the driver, thereby decreasing driver strain. Conversely, in sport mode, the dampers are stiffer, providing better handling stability but increasing the transmission of road vibrations to the driver, thereby increasing strain. The research findings indicate that the driver's neck joint is particularly affected by these changes in damper characteristics, making it a critical area for evaluating driving comfort. By quantifying the load on the driver's neck, the study provides an objective measure for assessing driving comfort, which can be useful for improving vehicle design. This study contributes to a better understanding of how vehicle dynamic characteristics impact driver comfort and offers a framework for future research in automotive design. Overall, the study bridges the gap between subjective driving comfort experiences and objective measurements, paving the way for an improved vehicle design that prioritizes driver comfort.

## 3. COMFORT RATING

The quality of vibro-acoustic performance (NVH) is one of the key factors in assessing the overall quality of a vehicle. During driving, automobiles and other ground vehicles are exposed to various vibrations that can reach frequencies of up to 20 kHz. The primary causes of these vibrations include road surface irregularities, aerodynamic forces, and certain vehicle components. Vibrations can negatively impact passenger comfort as well as other driving aspects. For example, variations in the vertical load on tires can affect vehicle stability and road grip. Additionally, vibrations can contribute to accelerated component wear, reduced vehicle durability, and increased road surface damage. The main objective is to minimize the transmission of vibrations and noise to passengers without compromising other driving characteristics. Improving NVH performance involves reducing the levels of vibrations and noise perceived by passengers. This can be achieved by optimizing the sources of vibrations and noise or enhancing isolation through a carefully designed vehicle system.
Vibrations can be classified based on their frequency range, and this division depends on how the human body perceives them. Vibrations with frequencies above 100 Hz are primarily registered as sound through hearing. Those below 25 Hz are perceived as physical vibrations through various sensory receptors in the body. Vibrations in the range of 25 to 100 Hz can be experienced both as mechanical vibrations and as sound. Figure 1 illustrates the vibrations that occur in a driver inside a vehicle.

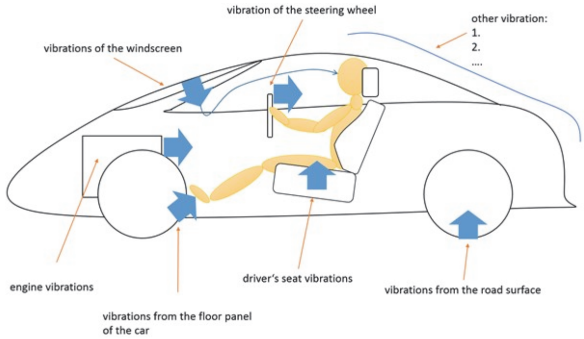


**Fig. 1.** Vibrations affecting the driver [7]

Objective evaluation criteria are used to assess ride comfort and the vehicle's response to various road and powertrain influences. The analysis of driving comfort is conducted by measuring acceleration using sensors placed on the driver's seat. This method enables the evaluation of ride comfort performance.
Numerous studies in scientific literature focus on objective comfort measurement. The ISO 2631 standard (ISO, 1997) defines the methodology and procedures for the objective evaluation of ride comfort, and this study also applies that standard.
The most well-known standards for measuring and evaluating whole-body vibrations are BS 6841:1987, ISO 2631-1:1997, and ISO 2631-1:2014. In multi-axis vibrations, sensitivity to vibrations below 1 Hz is specifically defined, as these vibrations can cause nausea.
The ISO 2631-1:2014 standard outlines methods for measuring periodic, random, and transient vibrations affecting the whole body. It also establishes acceptable exposure limits and defines frequency ranges that impact:

- Health, comfort, and perception (0.5 Hz - 80 Hz)
- Motion sickness ("seasickness" or "travel sickness") (0.1 Hz - 0.5 Hz).

There are several methods for evaluating comfort as defined by the SRPS ISO 2631–1:2014 standard [10]:

- Root mean square (RMS) acceleration value, $a.r.m.s.$
- Weighted acceleration value, $aw$
- Daily vibration exposure, A (8)
- Vibration dose value (VDV).

The effective value of the acceleration ($a_{r.m.s.}$) is calculated as follows:

$$a_{r.m.s.} = \sqrt{\frac{{a_1}^2 + {a_2}^2 + {a_3}^2 + \cdots + {a_n}^2}{n}}$$

The values $a_1$, $a_2$ to $a_n$ represent the measured acceleration values, where n is the number of samples within the observed time interval. Each value in equation (1) represents the acceleration modulus for all three axes of the accelerometer (x, y, and z), which is calculated using equation (2):

$$a = \sqrt{x^2 + y^2 + z^2}$$

The ISO 2631-1:1997 [9] standard provides acceptable values for human discomfort based on daily vibration exposure, but it does not define specific limits. Table 1 shows the aforementioned discomfort values.

**Table 1.** Discomfort values under whole-body vibration exposure (according to ISO 2631-1:1997 and SRPS ISO 2631-1:2014)

| Acceleration ($m/s^2$) | Comfort Level |
|---|---|
| <0.315 | Not uncomfortable |
| 0.315-0.63 | A little uncomfortable |
| 0.5-1 | Fairly uncomfortable |
| 0.8-1.6 | Uncomfortable |
| 1.25-2.5 | Very uncomfortable |

## 4. MATERIALS AND METHODS

The study conducted laboratory tests on the hydrodynamic pulsator HP 2007. The 01dB-Metravib PRO-132 data acquisition system was also used. Using the dBFA software package, simultaneous measurement, recording, monitoring, and subsequent processing of acceleration signals were performed. For recording vibration responses, AC102-1A accelerometers were used. Figure 2 shows the measurement diagram.

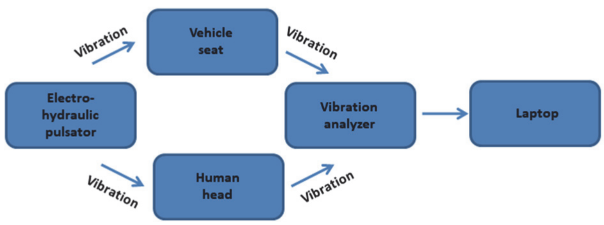


**Fig. 2.** Experimental measurement scheme

The experiment involved 10 healthy subjects (5 males and 5 females). The average values for the five healthy male subjects were: 33 years of age, 180.6 cm in height, 84.8 cm in seat height, 84.8 kg in weight, and a BMI of 25.94. Additionally, the experiment included five healthy female subjects with an average age of 31.6 years, a height of 168.2 cm, a seat height of 80.6 cm, a weight of 59.2 kg, and a BMI of 20.78. Both male and female subjects were exposed to random vertical vibrations with a stimulus value of 0.45 $m/s^2$ r.m.s. in the frequency range of 0.1 Hz - 20 Hz. The seat tilt angle was 90°.

After experimentally measuring the weighted acceleration values in the subjects, a neural network was used to create a model. Neural networks are a relatively new method in data analysis and have wide applications in technical and social sciences, as well as many other fields. In this study, an artificial neural network was applied to assess the oscillatory comfort during driving. The network structure consists of 50 neurons in the first hidden layer and one neuron in the output layer. The data used to train the network were collected through experiments on the subjects. For each participant, parameters such as BMI, height, weight, seat height, age, gender, years of experience, and the measured r.m.s. values were considered.

Figure 3 shows the structure of the artificial neural network used in this research.

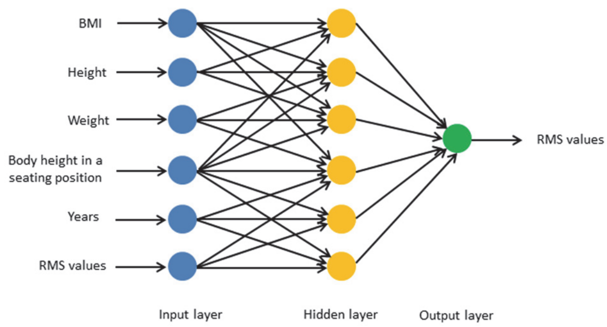


**Fig. 3.** Neural network schema

During the training phase, the mean absolute error is used as the loss function. The loss minimization process is achieved using the Adam optimization algorithm.

## 5. RESULTS

### 5.1 Experimental results

This study conducted an analysis of oscillatory comfort using the ISO 2631 standard, relying on the total effective value of weighted acceleration. Table 2 presents the r.m.s. values of weighted acceleration and the assessment of oscillatory comfort under the influence of vertical motion for five male subjects. Based on the ISO 2631 standard, it can be observed that subjects numbered 1, 2, and 5 were exposed to mild discomfort, while subjects numbered 3 and 4 experienced comforts. Based on subjective perception, slight differences in the discomfort assessment were noted. Subject 1 reported significant discomfort, while the other subjects agreed with the ratings defined by the standard.

**Table 2.** R.m.s. weighted acceleration values and oscillatory comfort ratings under the influence of vertical excitation for five male subjects

| ID | R.m.s. | Comfort level | |
|---|---|---|---|
| | | ISO 2631 | Subjective feeling |
| **1** | 0.398 | A little uncomfortable | Fairly uncomfortable |
| **2** | 0.386 | A little uncomfortable | A little uncomfortable |
| **3** | 0.213 | Not uncomfortable | Not uncomfortable |
| **4** | 0.22 | Not uncomfortable | Not uncomfortable |
| **5** | 0.318 | A little uncomfortable | A little uncomfortable |

Table 3 shows the comfort results for 5 female subjects.

**Table 3.** R.m.s. weighted acceleration values and oscillatory comfort ratings under the influence of vertical excitation for five female subjects

| ID | R.m.s. | Comfort level | |
|---|---|---|---|
| | | ISO 2631 | Subjective feeling |
| **1** | 0.432 | A little uncomfortable | Fairly uncomfortable |
| **2** | 0.333 | A little uncomfortable | A little uncomfortable |
| **3** | 0.412 | A little uncomfortable | Fairly uncomfortable |
| **4** | 0.391 | A little uncomfortable | A little uncomfortable |
| **5** | 0.324 | A little uncomfortable | A little uncomfortable |

From Table 3, it can be observed that, according to the ISO standard, all female subjects were exposed to mild discomfort, while slight differences were noted based on subjective perception. Subjects numbered 1 and 3 reported increased discomfort, while the other subjects agreed with the ratings defined by the standard. By analyzing Tables 2 and 3, differences between male and female subjects can be observed, indicating that the testing conditions were more favorable for the male population compared to the female population.

## 5.2 Artificial neural network results

By utilizing an artificial neural network and ISO standard 2631, it was possible to train the neural model [6]. The ANN model underwent 100 training epochs. The accuracy coefficient during training, validation, and testing was 90.5% for male subjects. The mean squared error in predicting RMS values for male subjects was 0.062. For female subjects, the training, validation, and testing coefficient was 89.5 %, while the mean squared error for predicted RMS values was 0.076. It is well known that anatomical differences exist between genders, with the female population having a higher percentage of visceral fat compared to the male population. Due to these differences in anthropometric characteristics, separate analyses were conducted for male and female subjects. Tables 4 and 5 present the predicted RMS values for the male participant numbered 1 and the female participant numbered 1 under vertical vibration exposure.

**Table 4.** Predicted r.m.s. values for the male subject under serial number 1

| ID | Original | Predicted |
|---|---|---|
| **r.m.s.** | 0.398 | 0.360 |
| **Comfort level** | A little uncomfortable | A little uncomfortable |

**Table 5.** Predicted r.m.s. values for the female subject under serial number 1

| ID | Original | Predicted |
|---|---|---|
| **r.m.s.** | 0.432 | 0.392 |
| **Comfort level** | A little uncomfortable | A little uncomfortable |

These results highlight the significant advantages of using neural networks in vehicle comfort analysis. When large amounts of experimental data are available, a trained neural network can serve as a reliable foundation for further research, reducing the need for costly and time-consuming experiments. Additionally, this approach enables faster data processing and more accurate predictions in real-world conditions. With further development and optimization of the model, it is possible to enhance the accuracy of assessments and expand its application to various vehicle types and driving conditions.

## 6. CONCLUSIONS

This study investigated vehicle ride comfort through both subjective and objective methods, emphasizing the importance of integrating these approaches. While subjective assessments provide valuable insights into passenger experience, they are prone to variability due to personal perception and external conditions. Objective methods, on the other hand, offer precise and repeatable measurements but may fail to capture all aspects of comfort.

By utilizing artificial neural networks and ISO 2631 standards, this research successfully modeled oscillatory comfort with a high degree of accuracy. The ANN model demonstrated strong predictive capabilities, achieving high correlation coefficients during training, validation, and testing. The results indicate that male and female subjects exhibited different comfort levels under the same test conditions, highlighting the need for gender-specific analyses due to anthropometric differences.

Experimental findings showed that some participants reported mild discomfort, aligning with the ISO 2631 standard assessments, while others exhibited variations in their subjective responses. This suggests that a hybrid approach combining subjective feedback with objective measurements can enhance the accuracy of comfort evaluations.

The application of artificial intelligence in this field proves to be highly beneficial, as it enables the automation of comfort assessments, reducing the reliance on expensive and time-consuming physical experiments. With further optimization, neural network models can be refined to predict ride comfort more accurately across diverse vehicle types and driving conditions [8].

Future research should focus on expanding the dataset and incorporating additional parameters, such as road surface conditions and dynamic vehicle responses. This would allow for the development of a more comprehensive comfort evaluation system, ultimately improving ride quality and passenger satisfaction.


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