

Article

Development of a New Sound Quality Parameter for Road Noise Perception Inside Vehicle Cabinet

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Abstract: Road noise significantly impacts how customers perceive vehicle noise, especially in electric vehicles, where it becomes more noticeable with the lack of the masking effect of the internal combustion engine. In this study, a novel sound quality (SQ) metric to capture the perception of road noise was established with the help of both objective measurements and subjective evaluations on six different vehicles under smooth and rough road conditions. A jury of 50 individuals participated in subjective evaluations in controlled settings, experiencing road noise on six vehicles under both smooth and rough conditions. The same vehicles were also objectively measured in these conditions. Using subjective responses and objective measurements, this study identified key sound quality parameters influencing perception. These parameters were used to develop a new regression model predicting customer perception of road noise, considering both aspects of comfort and satisfaction to follow as a key indicator for road noise, particularly in electric vehicles. While an R^2 of 0.312 was obtained with SPL, R^2 of 0.972 and 0.999 were obtained with the new comfort and satisfaction metrics, respectively. The effectiveness of the newly created SQ metrics was further validated across various vehicles.

Keywords: sound quality; road noise; acoustics; multi-variable regression



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1. Introduction

Acoustic events are generally described in terms of sound pressure level (SPL) with a unit of dB. However, the human ear not only focuses on the level but also on the frequency content of the sound waves. In fact, the variety in the spectrum results in completely different perceptions even under the same levels of sound pressure [1,2].

Studies on the perception of sound waves were gathered under the discipline of psycho-acoustics, and the spectral events were matched with sound quality metrics. These metrics are obtained by an extensive study on the perception of a huge number of people. Loudness, sharpness, roughness, fluctuation strength, and pitch constitute the fundamentals of sound quality [1].

Evaluating the sound quality (SQ) of vehicles, especially regarding road noise, necessitates a comprehensive assessment beyond just sound level. A multitude of metrics paint a vivid picture of the aural experience. Loudness, measured in A-weighted decibels (dBA), in sones, or in phons, reflects the perceived intensity. Sharpness, quantified by metrics like Loudness Spectrum Term (LST), gauges the high-frequency content influencing satisfaction. Roughness, assessed by the Roughness Perception Index (RPI), captures the unpleasantness caused by rapid sound pressure fluctuations [1–6].

The Articulation Index (AI) indicates how clearly speech can be understood over the noise, crucial for in-cabin environments. Fluctuation Strength (FS) reflects the variation in sound level over time, influencing how distracting the noise might be. Tonality Index (TI) measures the presence of prominent tonal components, often from engine noise [7]. The

tire–road noise, which can be a dominant sound source at some velocities depending on the engine type, can be better characterized using psychoacoustical parameters, such as loudness and sharpness, rather than sound pressure level [8]. By analyzing these metrics, alongside others, researchers and engineers gain a deeper understanding of how road noise impacts human perception and well-being. This knowledge empowers them to tailor noise reduction strategies that address the specific aspects deemed most unpleasant by individuals, ultimately refining the vehicle’s acoustic environment.

The historical advances in automotive NVH reduced noises of internal combustion engines and the powertrain systems to very low levels. Low noise levels do not necessarily mean good noise. The demand of customers for good sound are still increasing. Therefore, studies to improve the sound quality are essential for developing a car that sounds good [2]. Since the engine masking is reduced, the other systems are becoming more critical for their perception. In fact, the contribution of road noise on the vehicles has increased a lot in recent years, while the contribution of the engine noise is reducing [3,4].

Electrification is a dominant trend in the automotive industry, and it has benefits, like its silent soundscape, but it also has major NVH impacts due to lack of the masking effect of the engine. The NVH concern on electric or hybrid vehicles are concentrated in three major points: low-frequency road noise, high-frequency wind noise, and tonal components of motors and compressors. This situation results in a necessity to take countermeasures for emerging road noise perception [9,10].

In accordance with the demanding electrification trend, several aspects were studied for both interior and exterior noise impacts. Kim et al. investigated the sound quality of small motors, developing a sound quality metric related to the interior noise of vehicles [11]. Altinsoy examined the psychoacoustic properties of electrified vehicles, proposing a new sound quality metric that addresses their environmental impact during pass-by events [8]. Additionally, Park et al. studied engine noise to create a sound quality metric that captures the sportiness of interior sound perception in vehicles [2]. While these studies indicate that several aspects of in-cabin and emitted noise have been explored, our study focuses specifically on developing sound quality metrics for interior noise caused by rough road excitations.

The sounds arriving from the internal combustion engine and the associated power units have been a way of communication of the driver with the vehicle. With the electric vehicles, this communication becomes weakened [12]. This statement leads to a necessity to design a proper interior soundscape, primarily for the road noise, as it is the most dominant component in EV’s.

During the target-setting stage of a new vehicle, vehicle-level targets are established with the expectation that objective measurements will align with subjective performance criteria. However, conflicts sometimes arise between subjective targets and their corresponding objective parameters. In certain cases, although the target is objectively met, customer perception remains unsatisfactory. This issue stems from the improper use or limitations of sound quality metrics. Either the objective parameters fail to adequately represent the acoustic phenomenon, or the metrics used do not correlate strongly enough with subjective evaluations of noise perception.

The inconsistency between subjective evaluations and objective measurements presents a significant challenge in identifying and addressing sound quality issues throughout vehicle development. This divergence becomes particularly evident during the development of electric vehicles, where emerging noise sources like road and tire noise dominate. Current sound quality metrics often fail to capture these phenomena effectively, necessitating the development of a new metric that better reflects subjective perception. This study aims to create such a metric by combining objective measurements, subjective evaluations, and multiple linear regression analysis to develop an indicator that reliably predicts perceived road noise comfort and satisfaction.

2. Materials and Methods

To achieve accurate measurements of road noise, particularly on rough surfaces, controlled testing procedures are crucial. Coast-down maneuvers are the preferred method, as they minimize engine noise interference. This involves reaching a designated speed of 130 km/h and then allowing the vehicle to decelerate naturally with the engine off until a speed of 30 km/h is attained. This standardized maneuver is replicated across all test vehicles on the same rough road surface to ensure consistent comparisons.

Road noise measurement is a complex phenomenon influenced by several factors, primarily engine noise and wind noise, which becomes more prominent at higher speeds. To isolate and quantify the contribution of engine noise, coast-down tests were employed with the engine off for vehicles with internal combustion engines to remove any engine noise content.

For this study, six different cars with different brands at various segments were selected to have a vast range of noise levels and to ease quantification during the subjective tests.

Data acquisition throughout the measurements were performed using a PCB 378B02 microphone (PCB Piezotronics, Inc., Depew, NY, USA) positioned at the driver's left ear position, as seen in Figure 1. Siemens Simcenter SCADAS Mobile Data acquisition (Siemens, Leuven, Belgium) unit and Simcenter Testlab 2019.1 software were facilitated for the collection and analysis of the test data.



Figure 1. Position of microphones in drivers' seat.

The measurements were performed using PCB 378B02 ½" free-field ICP microphones, positioned near the driver's ear locations to capture the sound environment experienced by the occupants. These microphones are ideal for this application due to their high sensitivity and broad-frequency response, making them suitable for accurately capturing a wide range of frequencies associated with road noise.

A multi-channel array was not considered for this study because the objective was not to localize specific sound sources but to evaluate the overall sound pressure level (SPL) experienced in the cabin. Omnidirectional microphones were selected to ensure a uniform capture of sound from all directions, which aligns with the study's focus on overall sound quality rather than the spatial origin of the noise.

Regarding near-field considerations, since the microphones were placed near the driver's ear but not directly adjacent to any specific noise sources, near-field effects were expected to be minimal. However, the setup was designed to avoid placing microphones too close to strong individual sources like the dashboard or windows, which could amplify

near-field effects and skew the results. By positioning the microphones at a sufficient distance from dominant sound sources, we mitigated near-field influences and focused on capturing the representative acoustic environment within the cabin. The data acquisition was performed in the range of 20 Hz to 25.6 kHz with 1.56 Hz resolution.

To mitigate the influence of extraneous noise sources, the testing environment is carefully controlled. However, use of a semi-anechoic chamber was deliberately avoided to have real road excitation. Additionally, wind noise contribution was minimized by conducting all the tests under controlled conditions where wind speeds were below 3 km/h. The vehicles were thoroughly examined for any leakages, and it was ensured that the vehicles would not have any abnormal sealing or door settings. During the data collection, only the driver and the test engineer were allowed on the vehicles, so that the weight conditions kept unchanged between different vehicles. In this way, it was ensured that the gathered data accurately reflected true road noise characteristics.

2.1. Test Conditions

The coast-down data, collected during vehicle deceleration from 130 km/h to 30 km/h on a smooth road, spanned between 90 and 150 s. However, for seamless comparison of consecutive data recordings, 3 s samples were determined to be the most effective length for participants' assessment. Therefore, a simplified method with a much shorter duration was needed for subjective evaluations. High speeds were avoided in order to eliminate the contribution of wind noise; although, to have maximum road surface excitation, high speeds were preferred. In order to meet these conditions, the velocity range for coast-down maneuvers were determined from a 80 km/h to a 70 km/h range, which results in a duration of approximately 3 s.

2.2. Jury Member Selection Process

Subjective evaluations are most effective when conducted by a jury that reflects the target customer base. While experienced listeners may be adept at identifying specific sound qualities, highly specialized experts are not always necessary, especially in automotive studies where customer satisfaction is key.

Previous research on sound quality and jury evaluations suggests minimal influence from demographic factors like social class, age, and gender. Gender balance is typically maintained, and the jury size depends on the evaluation complexity and required training.

For this study, we assembled a diverse jury of 50 individuals. We carefully considered factors like age, gender, profession, automotive experience, and others, aiming to create a representative sample of our target audience.

The age, gender, profession, and automotive experience distributions of the jury members are shown in Figures 2–5.

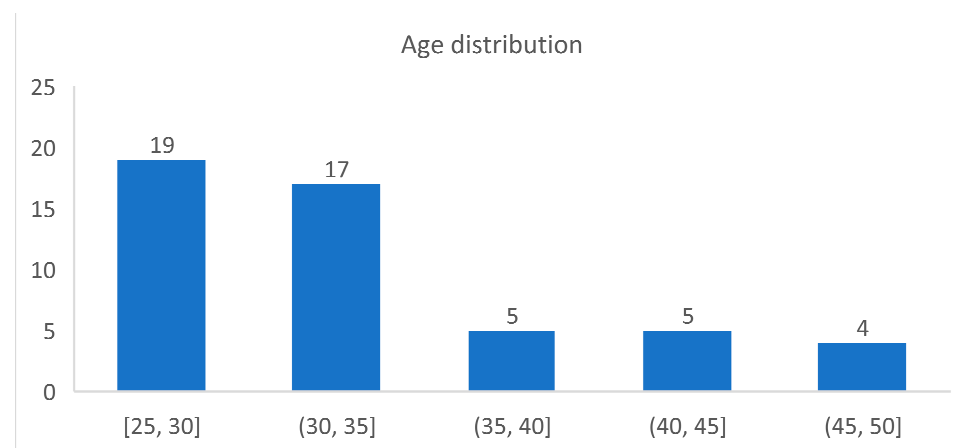


Figure 2. Age distribution of the jury members.

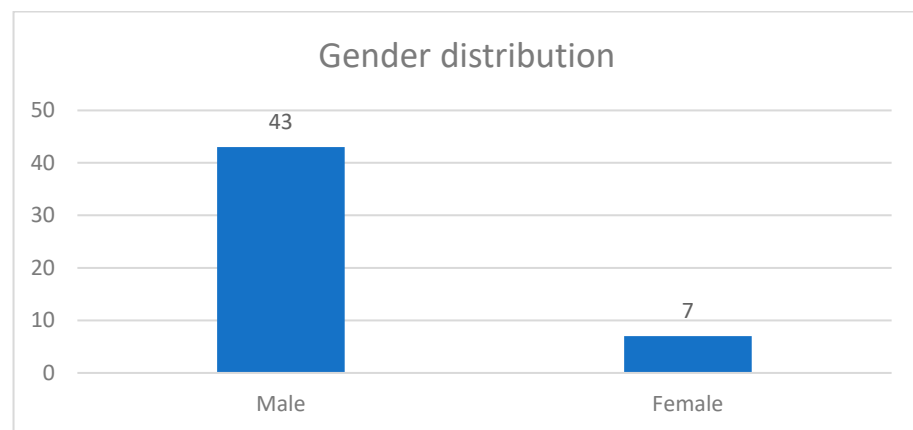


Figure 3. Gender distribution of the jury members.

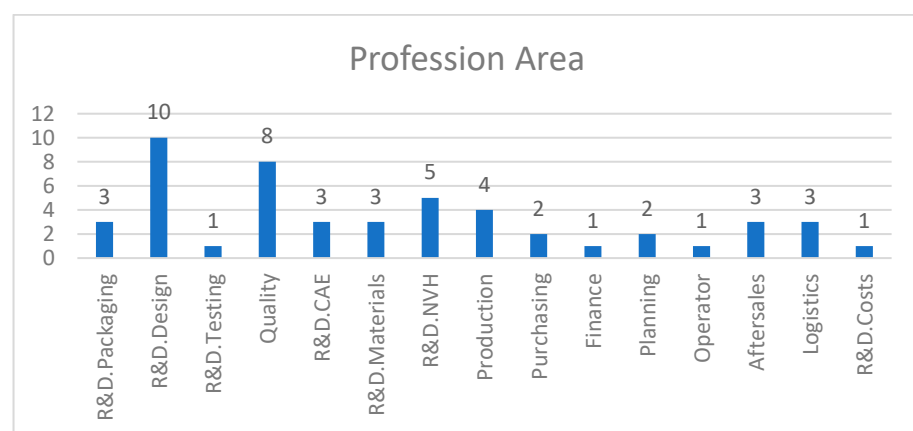


Figure 4. Profession distribution of the jury members.

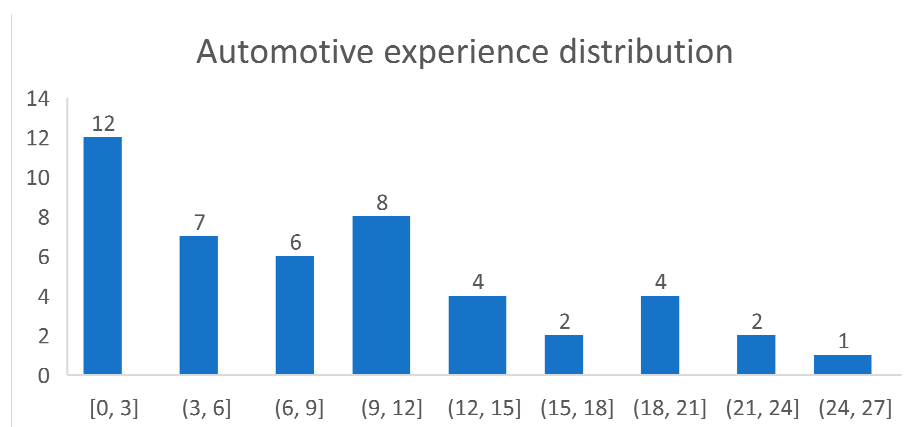


Figure 5. Automotive-experience distribution of the jury members.

2.3. Subjective Evaluations

For the subjective evaluations, the jury members were asked to evaluate 3 s road noise samples in a listening room using acoustic headphones in order to avoid any disturbance during their evaluations. The evaluations in the listening room were performed using two methods: Paired Comparison (PC) Test and SAE Subjective Evaluation Rating Scale (RS) [1]. In the PC test, participants compared sets of two sound samples for their satisfaction and comfort perception. A total of 18 pairs were evaluated, with 3 pairs repeated to assess consistency.

Two key parameters ensured reliable results: repeatability and consistency. Repeatability represents how often participants gave the same answer to a repeated question. The percentage of consistent responses for repeated pairs indicated a high level of repeatability. Consistency represents whether participants' choices followed a logical pattern. For example, if someone preferred sound A to B, and B to C, it was expected that they would also prefer A to C. Inconsistent responses were identified and noted, as juror responses need to exhibit a consistent pattern.

Consistency (ζ) was calculated as the ratio of inconsistent sound triplets (three-way comparisons where the preference order did not follow logic) to all possible sound triplets within a single PC test.

$$\zeta = 1 - (c/c_{\max}), \quad (1)$$

where c is the number of inconsistent triples, and $c_{\max}$ is the total number of sound sample triples.

Repeatability, ensuring participants gave consistent responses to repeated questions, reached a minimum score of 89%, exceeding the established threshold of 75%. This indicates that all participants successfully passed this test.

However, consistency, which measured whether participants' choices followed a logical pattern, presented a challenge. Four jury members' scores fell below the 60% threshold, meaning their evaluations were excluded from the analysis.

For the rating-scale evaluations, jurors rated the sound samples on a scale of 1 to 10 based on comfort and satisfaction levels. The SAE scale was utilized for the evaluations. [13].

2.4. Sound Quality Parameters

The sound quality (SQ) parameters in Table 1 were investigated during the studies.

Table 1. Basket of SQ parameters in the study.

No	Abbreviation	SQ Metric	Unit
1	OL	Overall level	[dBA]
2	TVL	Time-varying loudness	[sone]
3	L	Loudness	[sone]
4	S	Sharpness DIN45692	[acum]
5	AI	Articulation index	[%AI]
6	OAI	Open articulation index	[%AI]
7	FS	Fluctuation strength	[vacil]
8	R	Roughness	[asper]
9	NC	Noise criterion	[#]
10	BNC	Balanced noise criterion	[#]
11	NR	Noise rating	[#]
12	PR	Prominence ratio	[/ ²]
13	SI	Speech interference	[Pa]
14	SNR	Tone to noise ratio	[/ ²]
15	T	Tonality	[t.u]

2.5. Multi-Variable Regression Analyses

The regression analyses were conducted to arrive at the following model:

$$y^m = A_0 + A_1x_1^m + A_2x_2^m + \cdots + A_nx_n^m, \quad (2)$$

The regression analysis focused on how changes in independent variables (x_i^m) for a set of n SQ metrics would affect the predicted jury score (y^m). A_i represents the coefficients

if only the value of x_i^m changes, while all other variables are kept constant to have the impact of a single variable on the predicted score.

3. Results

3.1. Sound Pressure Level and SQ Metrics

The overall level and articulation index curves of the vehicles in basket during a coast-down maneuver on a smooth surface track are shown in Figure 6.

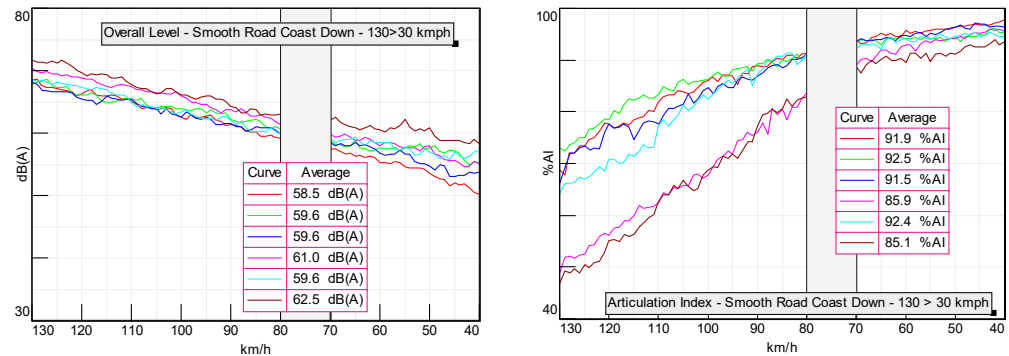


Figure 6. Overall level and articulation index of the vehicles in basket.

It was demonstrated that the road noise performance of the vehicles varies noticeably both in overall level and articulation index. An average range of 4.0 dB and 7.4% AI was obtained in the selected band from 80 to 70 km/h with the selection of the vehicles in the study.

To introduce greater variation in participant responses and enhance test stimulation, additional coast-down tests were conducted on rough road surfaces with the engine off. The outcomes of these rough road tests are presented in Figure 7.

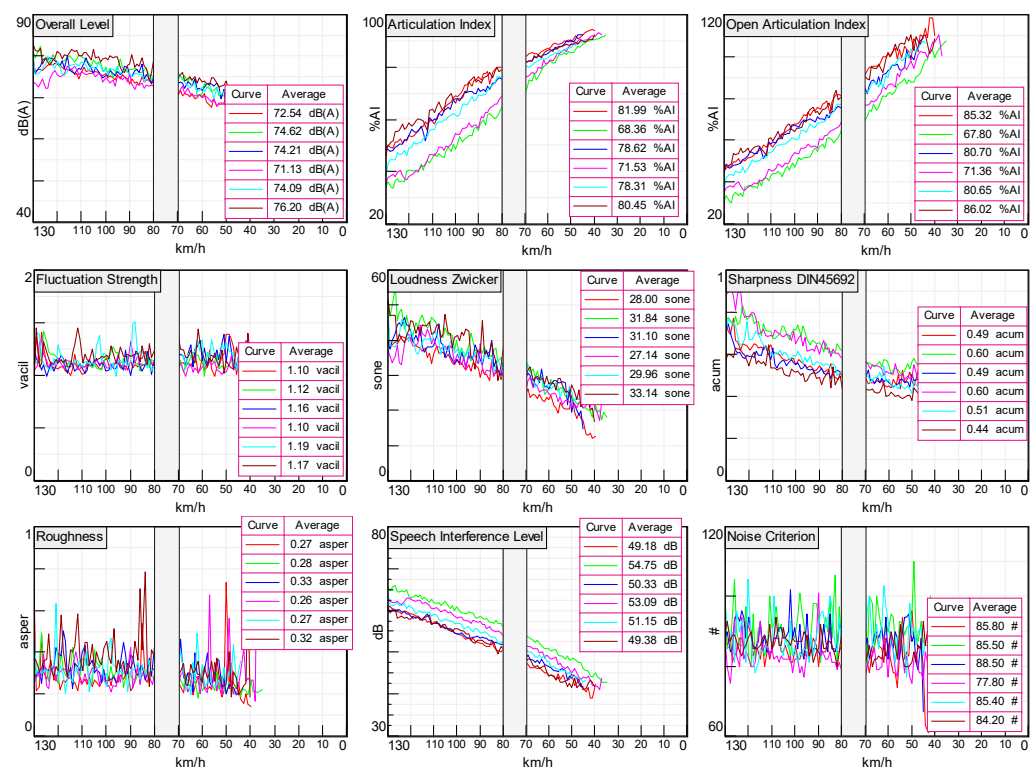


Figure 7. SPL and various SQ metrics during coast-down tests.

The variations in these metrics are summarized in Table 2.

Table 2. SQ metrics for 80 to 70 km/h coast-down maneuver ¹.

	SPL	AI	OAI	FS	L	S	R	SIL	NC
	dB(A)	%	%	Vacil	Sone	Acum	Asper	dB	#
Car1	72.5	82.0	85.3	1.101	28.0	0.49	0.27	49.2	85.8
Car2	74.6	68.4	67.8	1.116	31.8	0.59	0.28	54.8	85.5
Car3	74.2	78.6	80.7	1.158	31.1	0.49	0.33	50.3	88.5
Car4	71.1	71.5	71.4	1.098	27.1	0.60	0.26	53.1	77.8
Car5	74.1	78.3	80.6	1.192	30.0	0.51	0.27	51.1	85.4
Car6	76.2	80.4	86.0	1.170	33.1	0.44	0.32	49.4	84.2
Avg	73.8	76.5	78.6	1.139	30.2	0.52	0.29	51.3	84.5
Range	5.1	13.6	18.2	0.095	6.0	0.16	0.07	5.6	10.7
Std dev	1.6	4.9	6.8	0.04	2.1	0.06	0.03	2.0	3.3

¹ The best and worst values for SPL and for each SQ metric are indicated by green and red background colors, respectively.

It is clearly seen that car1 is better than the average in all metrics except NC, and it is in the best two in all others. It is also noticed that Car4 is the best in four metrics besides SPL, but it is the worst in sharpness at the same time. A similar situation is observed also for Car6. It is the best in open AI and sharpness but the worst in SPL and loudness. All these metrics provide a way of describing perception from different aspects. So, the need is to create a specific SQ metric for road noise perception using highly correlated SQ metrics.

3.2. Subjective Evaluations Results

The average of the subjective evaluations of the jury for each vehicle is summarized in Table 3. The original scores provided by the participants are presented in Table A1 in Appendix A.

Table 3. Average of subjective evaluations of the jury.

	Comfort	Satisfaction
Car1	6.71	6.65
Car2	5.74	6.02
Car3	6.54	6.36
Car4	5.56	5.99
Car5	5.34	5.54
Car6	6.33	6.37

It was seen that car5 was perceived as having the less comfortable (5.34) and more annoying (5.54) sound. On the other hand, car1 was perceived as having the most comfortable (6.71) and most satisfactory (6.65) sound perception.

3.3. Regression Analysis

Table 4 shows Pearson correlation of several SQ metrics with subjective evaluations performed on this set of 6 vehicles.

Table 4. Pearson correlation of several SQ metrics with subjective evaluations for satisfaction index.

	SPL	AI	OAI	FS	L	TVL	R	SIL	NC
	dB(A)	%	%	Vacil	Sone	Sone	Asper	dB	#
Rxy	−0.559	0.880	0.913	−0.066	−0.836	−0.859	−0.262	−0.885	−0.781
R ²	0.312	0.774	0.834	0.004	0.699	0.738	0.069	0.783	0.610
p-value	0.249	0.021	0.011	0.900	0.038	0.028	0.616	0.019	0.067

Multi-variable regression analyses were performed using SQ metrics that provide correlation with a 95% confidence limit ($p < 0.05$). According to this criteria, AI, OAI, R, TVL, L, S, and SI metrics were considered in the regression analyses for both comfort and satisfaction criteria as shown in Table 5.

Table 5. Ranking of correlated variables.

	X ₁	X ₂	X ₃	X ₄	X ₅	R ²	p-Value
Comfort	AI	OAI	SIL			0.972	0.042
Satisfaction	OAI	AI	SIL	L	TVL	0.999	0.034

Although the final model contains all the metrics in Table 4, it can be considered that X₁, X₂, and X₃ are the most dominant metrics.

The regression analysis was performed in Matlab R2019a, using different sound quality metrics, and, finally, a new model based on these parameters was obtained. The results of the new comfort and satisfaction metrics for road noise are shown in Table 6.

Table 6. Subjective evaluations vs. new SQ metrics.

	Subjective Evaluations		SQ Metrics	
	Comfort	Satisfaction	Comfort	Satisfaction
Car1	6.71	6.65	7.09	6.89
Car2	5.74	6.02	5.51	5.81
Car3	6.54	6.36	6.24	6.05
Car4	5.56	5.99	5.27	6.28
Car5	5.34	5.54	5.19	5.33
Car6	6.33	6.37	6.75	6.39
Avg	6.04	6.16	6.01	6.13
Range	1.37	1.11	1.90	1.56
Std dev	0.52	0.36	0.74	0.49

4. Discussion

The results of the derived sound quality (SQ) metrics indicate that car5 produces the least comfortable and most annoying sound, while car1 provides the most comfortable and least annoying sound perception, as illustrated in Figure 8. The Figure uses different colors to represent various cars, with subjective evaluations shown as full circles and SQ metric results represented by full diamonds.

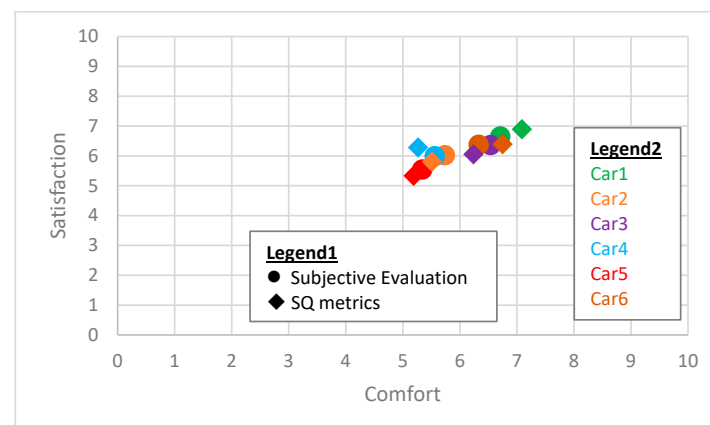


Figure 8. SQ metrics for road noise perception.

The results indicate that car1 performs best in both aspects of the new road noise SQ metrics, excelling particularly in AI, OAI, and SIL. Although SPL ranks second, this suggests that SPL can still be considered a useful indicator of sound perception. However, the superior performance of the SQ metrics demonstrates their added value in more accurately reflecting human perception.

On the other hand, car5 ranks the lowest according to the new road noise SQ metrics. This distinction would not have been clear using SPL alone, as its value of 74.1 dBA is close to the average of 73.8 dBA, making it indistinguishable from other cars. The SQ metrics provide much more relevant information regarding subjective evaluations and, thus, the perception of road noise in vehicles.

This highlights a key finding: While SPL remains a standard tool for providing basic acoustic measurements, its correlation with road noise perception is relatively weak. Instead, spectral variations play a far more significant role in how noise is perceived. This study demonstrates that subjective evaluations are closely aligned with OAI, AI, and SIL, which emerge as the most influential factors in perceived road noise.

This relationship is better captured by a new sound quality (SQ) model that combines these key SQ metrics to reflect subjective experiences more accurately. This model will be pivotal in the target-setting phase of future vehicle development, offering deeper insights into customer expectations regarding road noise. By applying this model, it will be possible to design vehicles that more effectively meet these expectations, ultimately enhancing acoustic comfort and overall customer satisfaction.

5. Conclusions

In this study, road noise perception was investigated by measuring road noise on six different vehicles under smooth and rough road conditions. Following the objective measurements, a jury of 50 individuals participated in subjective evaluations under controlled settings. By comparing these subjective responses with the objective data, we aimed to identify correlations between what people hear and what is measured. This study was continued with the development of a regression model that predicts how customers perceive road noise, considering both aspects of comfort and satisfaction. Finally, new sound quality metrics were revealed with the help of the regression analyses. These metrics were validated across various vehicles, confirming their effectiveness in assessing road noise. With these new SQ metrics, the road noise perception of a vehicle can be evaluated physically. A further step could be to achieve the same results with a combination of loads on the wheel hubs from the road excitations and virtual transfer paths between the hubs and drivers' ear positions. Such a work would provide a more useful tool in the vehicle target-setting and deployment process, ensuring that the resulting sound levels align with the desired perception of comfort and quality.

Author Contributions: Conceptualization, A.O.; validation, A.O.; formal analysis, M.Y.; investigation, A.O.; writing—original draft preparation, A.O.; writing—review and editing, A.O.; supervision, A.O. and A.Y.; project administration, A.O. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement: Ethical review and approval were waived for this study as it involved the administration of anonymous questionnaires that did not collect sensitive personal information. The study adhered to the ethical guidelines of Bursa Uludag University. Participants' age, sex, profession, and years of experience were recorded for demographic analysis but were not linked to individual responses.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author.

Conflicts of Interest: Authors Aytekin Özkan and Mehdi Yıldız were employed by the company TOFAS Turkish Automobile Factory. The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Appendix A

The raw data of jury evaluation is shown in Table A1.

Table A1. Raw data of the jury scores.

	Comfort						Satisfaction (Not Annoying)					
	C1	C2	C3	C4	C5	C6	C1	C2	C3	C4	C5	C6
J1	7.30	5.50	5.95	7.30	9.10	8.20	6.40	6.85	5.95	8.20	7.75	7.30
J2	4.72	5.50	3.80	7.80	9.03	6.65	4.17	5.50	3.06	7.46	8.98	6.41
J3	4.63	4.63	4.33	5.05	6.34	4.77	4.63	4.31	4.26	6.60	7.39	5.63
J4	5.33	1.97	3.82	7.73	8.91	6.65	3.64	5.81	4.61	7.94	9.01	6.95
J5	4.08	5.07	3.34	7.41	8.10	6.55	5.19	4.05	4.35	7.46	8.68	7.62
J6	5.50	5.50	6.04	6.67	7.13	5.50	5.50	6.09	2.34	8.89	8.73	4.63
J7	5.86	3.57	4.24	5.05	7.32	6.60	3.45	7.46	5.95	6.69	5.05	4.22
J8	6.88	6.44	6.25	6.90	7.50	6.25	6.44	5.19	5.95	6.07	5.72	5.58
J9	4.15	4.60	4.60	6.85	7.30	6.40	5.95	4.60	5.95	8.65	8.20	7.30
J10	6.14	6.07	6.07	8.43	7.80	5.50	5.50	5.50	5.50	5.50	5.50	5.50
J11	5.50	5.05	5.26	5.66	6.92	6.11	5.53	5.12	4.45	6.25	7.13	6.78
J12	6.85	5.50	6.40	3.70	4.60	2.80	3.25	4.15	2.80	9.10	8.20	9.55
J13	7.30	5.50	5.95	7.30	9.10	8.20	6.40	6.85	5.95	8.20	7.75	7.30
J14	4.68	2.78	1.00	8.94	10.00	7.43	5.67	2.99	1.00	8.20	10.00	6.92
J15	2.35	2.35	1.90	4.15	8.20	2.35	4.15	1.90	1.45	8.20	9.55	1.00
J16	4.72	5.50	3.80	7.80	9.03	6.65	4.17	5.50	3.06	7.46	8.98	6.41
J17	7.30	5.50	5.95	7.30	9.10	8.20	6.40	6.85	5.95	8.20	7.75	7.30
J18	4.60	3.70	4.15	5.50	6.85	6.40	4.60	3.70	4.15	5.95	7.30	5.50
J19	5.60	5.26	4.91	6.62	7.89	7.36	5.14	4.66	4.03	6.04	7.66	6.74
J20	4.72	5.50	3.80	7.80	9.03	6.65	4.17	5.50	3.06	7.46	8.98	6.41
J21	3.29	3.45	1.72	7.50	8.52	5.30	8.15	7.83	8.94	3.73	2.48	3.11
J22	1.90	3.25	2.35	5.05	7.75	6.85	4.60	1.90	5.05	9.55	8.20	9.55
J23	7.30	6.40	5.95	8.20	8.65	7.30	5.95	5.95	5.50	7.30	8.65	7.75
J24	6.41	5.23	4.91	7.36	6.67	7.83	5.50	5.12	3.50	6.90	6.90	5.74
J25	5.95	6.85	6.40	6.85	5.50	7.75	5.50	7.30	5.05	9.10	8.20	7.75
J26	7.34	5.05	4.33	8.52	9.12	9.44	5.50	5.50	3.75	7.87	6.74	6.07
J27	5.50	5.50	5.05	7.75	7.30	6.85	4.60	4.60	4.60	6.85	6.40	6.85
J28	5.50	5.50	2.80	8.82	10.00	8.50	1.00	7.43	2.13	4.17	5.58	2.78
J29	4.10	4.38	4.22	4.66	9.05	4.84	1.60	5.50	2.90	6.09	5.50	5.50
J30	6.09	5.07	4.31	6.85	7.85	5.50	5.50	5.56	6.30	7.48	8.36	6.65
J31	5.05	4.15	4.15	5.05	8.20	3.70	3.70	8.20	4.60	3.70	7.30	2.80
J32	5.50	5.00	5.72	5.50	6.74	4.96	5.35	6.85	5.95	6.02	6.34	5.74
J33	5.50	5.70	4.15	4.84	7.94	7.15	4.68	4.17	6.81	6.51	7.29	5.50
J34	6.30	6.62	5.50	6.60	7.34	4.59	5.50	5.50	4.82	6.30	7.18	6.99
J35	4.98	5.50	3.96	7.62	8.50	6.85	4.84	3.98	5.84	7.43	8.82	6.51
J36	5.95	5.05	5.05	6.85	7.75	8.65	4.60	3.25	3.70	6.40	7.75	5.50
J37	3.71	4.47	2.55	6.69	10.00	8.33	5.50	2.37	3.85	8.04	8.89	6.81
J38	6.69	6.53	5.97	6.81	7.15	6.51	6.69	6.39	5.79	7.59	7.62	6.88
J39	2.80	6.40	3.70	5.50	8.20	4.15	3.70	4.60	3.70	6.40	7.30	5.05
J40	5.63	5.16	5.14	5.14	6.18	5.58	6.00	5.50	5.47	5.12	8.29	5.12
J41	4.15	5.50	4.15	7.30	8.20	7.30	7.75	6.40	5.95	5.95	7.75	7.75
J42	5.60	5.26	4.91	6.62	7.89	7.36	5.14	4.66	4.03	6.04	7.66	6.74
J43	5.05	5.50	5.05	7.30	7.75	6.40	3.70	5.50	4.15	5.05	5.95	4.60
J44	5.50	6.40	5.95	6.85	8.65	8.20	5.05	4.60	5.95	7.30	6.40	7.75
J45	4.15	4.60	4.60	6.85	7.30	6.40	5.95	4.60	5.95	8.65	8.20	7.30
J46	5.50	4.60	5.05	5.50	6.40	5.50	5.05	4.60	4.60	5.05	6.40	4.60
J47	4.52	5.50	3.80	7.80	8.03	6.65	4.63	4.33	4.19	6.88	7.46	6.60

Table A1. Cont.

	Comfort						Satisfaction (Not Annoying)					
	C1	C2	C3	C4	C5	C6	C1	C2	C3	C4	C5	C6
J48	5.50	5.95	2.97	7.69	3.82	7.50	5.50	7.20	6.18	6.55	4.91	5.50
J49	3.25	5.05	4.15	6.40	7.30	5.50	4.15	3.70	4.60	5.95	7.30	5.50
J50	6.40	5.50	5.50	5.95	6.85	5.95	5.95	5.95	5.95	6.40	6.85	6.40

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