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Contextual Aspects in Subjective Vehicle Sound Assessment

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Summary

In vehicle acoustics, the quantities *comfort*, *sportiness*, *type conformity* and *make conformity* are facets of overall sound quality. However, little attention is usually paid to contextual influences such as the vehicle's type or make, the driving condition one is engaged in or the driver type itself. These contextual aspects are expected to have a significant influence on sound quality assessment. In this paper, the results of an exploratory field study are used to determine the interactions between the aforementioned acoustic quantities on the one hand and contextual aspects on the other hand when assessing sound quality. Based on field test results of 85 subjects that participated in six car sound conditions, a regression model was determined that predicts overall sound quality from comfort, sportiness and type conformity. The predictive power of these three quantities varies depending on the considered car and driver type. Further analyses showed that for comfort and sportiness, much predictive power was obtained from specific driving conditions. Comfort is determined mainly in "static" driving conditions such as driving with constant speed, whereas sportiness manifests in a broader range of situations, with an emphasis on dynamic driving. Type conformity was observed as being closely related to comfort for non-sporty cars and to sportiness for sporty cars, respectively. These effects show that besides acoustic properties, context effects influence how acoustic properties are evaluated by subjects.

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1. Introduction

Blauert & Jekosch [1] distinguish three levels of acoustics for product sounds, which were transferred into the domain of vehicle sound by Letens [2]:

Physical acoustics, describing "sound events" in terms of, e.g., level, spectral or temporal properties of the sound wave.

Psychoacoustics, describing "auditory events" in terms of, e.g., loudness, sharpness or roughness. These are usually determined in listening experiments, where subjects are asked to make "unbiased" judgements, disregarding any further contextual aspects or informational content of the sounds [1].

Psychological acoustics, describing the evaluation of sounds by subjects in terms of, e.g., pleasantness, annoyance or sound quality. These are subject to contextual aspects, e.g., intersensory effects, situation and expectation [2], and involve psychological processes such as information reduction and the use of different frames of reference [1].

Due to the context dependency of sound quality (which falls in the category of "psychological acoustics"), it cannot be defined universally, but rather with respect to a particular context. Blauert & Jekosch point out that the evaluation of product sound quality must be viewed with regard to the (sound-emitting) product itself [1]. In the domain of vehicle acoustics, the sound-emitting product can be characterized by the *vehicle type* (i.e., segment) and *make*. Letens states that also the *driving condition*, as an aspect of the situational context, influences sound evaluation [2]. Jekosch emphasizes the role of sound as a sign, the "meaning" of which is associated by the *listener* factoring in his/her knowledge and experience [3]. In a series of experiments Västfjäll [4] showed that a positive or negative frame of mind or attitude towards the product influences the rating of sound quality. In addition, this short-term frame of mind interacted with the more stable personality trait of *noise sensitivity*. Noise sensitivity reflects "a judgemental, evaluative predisposition towards the perception of sounds" rather than "sensory components" [5], and thus a potential influence on vehicle sound evaluation is indicated. Hence, the *listener*'s personality can also be assumed to play a role in vehicle sound evaluation. Accordingly, Maiberger *et al.* found opinion and personality of the driver, aggregated to a discrete *driver typology*, to be a significant predictor of vehicle sound assessment

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[6]. Particularly the wishes regarding vehicle sounds differ considerably between the three identified driver types, labelled as *sound-oriented fun-driver*, *noise-sensitive aesthete* and *sound-uninterested pragmatist*. This threefold typology is based on the car- and sound-related factors "dynamic driving style & acoustical orientation", "noise sensitivity", "sound awareness", "status aspect", "reservations about cars" and "demand for comfort". In contrast to *sound-uninterested pragmatists*, who consider a car as "just a tool", *sound-oriented fun-drivers* and *noise-sensitive aesthetes* do care about vehicle sounds: the former because of their dynamic driving style, the latter because of their noise sensitivity. The typology could reliably be determined from data of a survey among more than 1,800 drivers of premium vehicles (see [6]). The status aspect, being part of the driver typology, is potentially a socially sensitive domain, and in these cases self-report measures are often distorted by "social desirable responding" (see [7]). Hence, an *implicit measurement technique*, in which the participant is not asked directly (see [8]), might be more suitable for assessing a person's attitude regarding the status aspect of a car. In many psychological studies, the *Big Five dimensions of personality* (Big Five) have shown to be a context-independent, reliable instrument for understanding individual differences [9, 10]. Due to their "noncontingent nature" [9], it can be assumed that the Big Five are also effective in vehicle sound evaluation. To sum up, the vehicle type, vehicle make, the driving condition and the listener's personality in combination might imply a certain expectation with regard to the corresponding sounds. Studies concerning vehicle sounds, however, rarely aim at giving an integrated view of the influence of contextual aspects on sound quality, yet acknowledging its existence.

Based on existing literature on vehicle sound evaluation, it can be concluded that vehicle sound quality depends on the perceptual quantities comfort, sportiness, type conformity and make conformity. For example, Letens [2] proposed the distinction between three factors for an integrated description of the overall "sound performance" of a car: 1) *valuation* ("Wertanmutung"), 2) *emotionality* and 3) *conformity* with respect to market positioning of the car as well as the make. He describes *valuation* as freedom from disturbing noise; *emotionality* is associated with sporty, dynamic driving characteristics, and an "aesthetic" sound; *conformity* is described as the extent to which the sound matches the car, and the extent to which a brand sound ("corporate sound") is realized, respectively. It can thus be concluded that sound quality considerations must include vehicle type and vehicle make in order to be able to determine conformity.

Köber *et al.* [11] state that "customers' requirements with regard to the sound impression of the exhaust system are mainly dependent on the market positioning of the vehicle", and thus influenced by the non-acoustic factor of market positioning. According to them, those requirements manifest themselves as the contrasting ideals of "comfort" and "sportiness", which implies that both quantities are not necessarily realizable at the same time.

Bisping [12] states that the perceptual factors "pleasantness" and "powerfulness" account for more than 60 % of the variance of car interior sound quality in standard driving conditions. Based on prior research he derives a map with the corresponding axes *weak–powerful* and *unpleasant–pleasant*, and shows based on the results of relative scaling experiments that cars of different types (i.e., small, middle, luxury, sport, truck) occupy different quadrants of the map. These locations can serve "as templates for target sound design or respectively as guidelines for optimization". In this way, the vehicle type is implicitly introduced as a context variable; moreover, conformity can be assumed to depend on pleasantness and powerfulness. In the diagram, Bisping finds "a general trend indicating that the pleasantness of the sounds decreases while their powerfulness increases", due to the "trade-off between the technical realization of both pleasantness and powerfulness", which again indicates a certain dependency between those two quantities.

Zeitler & Zeller [13] define vehicle sound quality as "the extent to which the sound character matches the overall vehicle character and brand values", bringing both vehicle type and vehicle make into play. They depict the requirements for the sound character of different vehicle types in a coordinate system, with axes composed of the *driving noise at constant speed* on the one axis and the *engine level difference between cruise and acceleration* as the other axis. These axes were found to be related to the perceptual dimensions of "comfort/loudness" and "sportiness", respectively[1]. In the diagram no vehicle type is found in the region that corresponds to high values for "comfort/loudness" *and* "sportiness", which seems to exclude the idea of both quantities being completely independent. Furthermore, as the vehicle types occupy different regions with respect to "comfort/loudness" and "sportiness" within the diagram, the earlier assumed dependency of conformity on comfort and sportiness is reinforced.

In summary, vehicle sound quality can be assumed to be dependent on the following quantities:

1. *comfort*,
2. *sportiness*,
3. *type conformity*, i.e., the match between comfort, sportiness and the vehicle type, and
4. *make conformity*, i.e., the match between comfort, sportiness and the vehicle make.

From what was presented above, it is not clear how exactly these four quantities act and interact to form the overall sound quality. However, certain dependencies became evident: first, comfort and sportiness must not be assumed to be perfectly orthogonal [11, 12, 13]; second, a certain dependency of the conformities on comfort and sportiness is indicated [12, 13]; third, for sound quality evaluation also contextual aspects must be taken into account [1, 2, 3, 4, 5, 6]. Type conformity and make conformity

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[1] These were determined in factor analysis, together with "harshness" and "timbre", and "are assumed to reflect the perceptual space underlying the [sound] evaluations" [13].

already incorporate the context as they are intrinsically linked to the non-acoustic factors vehicle type and vehicle make, respectively, but also the driving condition and the driver type should be considered for a valid understanding of vehicle sound assessment.

The aim of this paper is to investigate the connection between the acoustic quantities in the real-life context, and how the non-acoustics factors relate to these acoustic quantities in sound quality evaluation. To this end, a predictive model for the participants' ratings will be developed as an exploratory approach. The model will be built from data gained in the very realistic context of a field study, where subjects drive the rated car themselves. In this field study, the four acoustic quantities will be rated, and contextual data will be collected with questionnaires. The modeling will be done with statistical methods, namely ANCOVA models. The leading questions in this process are whether the quantities found in literature, i.e. comfort, sportiness, type conformity and make conformity, indeed do influence sound quality, and if so, whether they exert an effect "on their own" (as a *main effect*) or just in combination with other quantities (as an *interaction*), especially with the abovementioned contextual, non-acoustic aspects. If such interactions with contextual aspects are found, this would emphasize and specify the context-sensitivity of the vehicle sound assessment process. As ANCOVA models can only yield "two-layered" models (i.e., one predictor layer and one outcome layer), subsequent models of the predictors will be developed in the same manner, in order to get deeper insight into the dependencies between the participants' ratings. These subsequent models of the main predictors of sound quality will be called *submodels*. Finally, all presented models are tested using cross-validation.

2. Data acquisition

In this section, the acquisition of the subjective, contextualized data will be described.

2.1. Procedure

The study was designed as a field test because this allows for contextualized data acquisition, offering a high ecological validity. For the exploratory approach followed in this paper, this design seemed adequate. The field test was conducted at two locations: Sindelfingen, Germany (*Location A*), with 3 cars of the same make but different types, namely a compact car, a mid-size car (sedan) and a roadster; and Oldenburg, Germany (*Location B*), with a single mid-size car (sedan) of the same make as in Location A, but three different engine sound conditions, namely "original", "booming/howling" and "rough/sporty". The sound in Location B was modified via electric sound synthesis and reproduction over the car's audio system (cf. Section 2.3), aiming at explicitly altering the type conformity of the car's sound.

The procedure, which was inspired by [14, 15], was the same in both locations, and is depicted in Figure 1. The subjects were instructed to assess the driving sound of the respective car in a test ride by driving themselves. The term "driving sound" was introduced to the subjects as the sounds coming from the engine, the tires, the wind and the chassis. For the time of the trip, the subjects were asked to "think aloud", i.e., to tell the investigator everything that comes to their mind concerning the driving sound during the assessment process, e.g., giving a description of the sound, or naming positive, neutral as well as negative aspects of the sound. This was intended for focusing the participants on the topic matter of the study, while not priming them with regard to the quantities comfort, sportiness, type conformity and make conformity. The subjects then drove on a predetermined route, which contained city traffic, country road and highway. The investigator, posed as the co-driver, guided along the route, took notes about the subjects' comments and reminded them to think aloud if necessary.

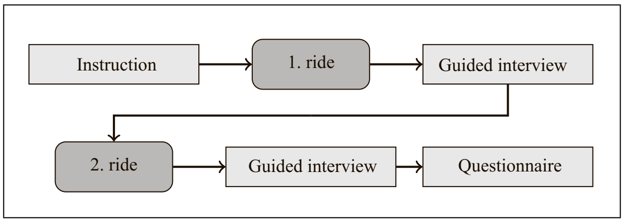

Figure 1. Schematic of the experimental procedure.

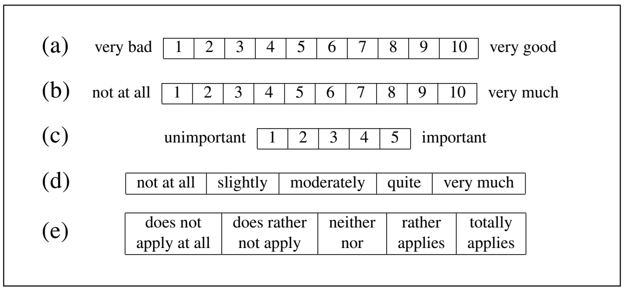

Figure 2. Rating scales used in the study.

After the first half of the route, which usually took around half an hour, there was a pause on a parking area for a guided interview. The interview started with a question for the overall sound quality ("Which rating do you give for the driving sound of this car?", using Scale (a) from Figure 2) as well as aspects of the driving sound that were most striking to the subjects (as an open question). After that, the focus was set on the (acoustic) quantities comfort, sportiness, type conformity and make conformity of the driving sound, and the subjects had to rate the extent to which each of these quantities was met ("How comfortable/sporty is the overall driving sound of this car to you?", "How well does the driving sound fit the vehicle type/make?", using Scale (b)). Furthermore, the subjects rated the importance of comfort and sportiness, respectively, for the respective vehicle type as well as for the vehicle make ("How important is it to you for the driving sound of this vehicle type/make to be comfortable/sporty?", using Scale (c)). After answering an open question for important driving conditions ("In general, when you do a test ride, in which driving conditions do you attach importance to the driving sound?"), the subjects were asked to indicate the importance of nine preselected driving conditions (see Section 2.4) for the overall impression of comfort and sportiness ("How important is this situation to you for the judgement of how comfortable/sporty the driving sound is?", using Scale (c)).

The second half of the route was identical to the first half. The subjects were again asked to think aloud when driving, and to give a rating of the comfort and sportiness, respectively, for the nine preselected driving conditions once they occurred ("How comfortable/sporty do you find the driving sound?", using Scale (b)); in Location B, these ratings were acquired directly after the ride.

After the ride, some concluding questions were asked concerning the importance of comfort, sportiness, type conformity and make conformity for the overall sound quality of the driving sound ("How important for your overall rating was how comfortable/sporty the driving sound is?", "How important for your overall rating was whether the driving sound fits the vehicle type/make?", using Scale (c)). After that the participants completed a combined questionnaire, with items to determine their *driver type* [6], their noise sensitivity (by means of the *questionnaire on the individual attitude towards the acoustical environment* [16]) and the *Big Five dimensions of personality* [10]. For the items concerning the driver type and noise sensitivity, Scale (d) was used, while for items concerning the Big Five, Scale (e) was used, following [6, 16, 10]. For determining the driver type, the six scales "dynamic driving style & acoustical orientation", "noise sensitivity", "sound awareness", "status aspect", "reservations about cars" and "demand for comfort" were calculated according to [6]; from the resulting profile each participant was assigned to one of the driver types *sound-oriented fun-driver*, *noise-sensitive aesthete* or *sound-uninterested pragmatist*, according to their prototypical profiles in [6]. For the analyses, the four scales of noise sensitivity and the five scales of the Big Five were further calculated according to [16] and [10], respectively. Finally, the subjects did a computer-based *go/no-go association task* (GNAT) [17] that dealt with the implicit attitude towards status symbols, where "implicit" means that the attitude is measured without directly asking participants. The resulting GNAT score is derived from the participants' response time and assignment of selected words to categories, and indicates the implicit preference for status symbols.

The conversation during the whole ride was recorded with a microphone inside the car cabin, as well as the engine speed, driving velocity, acceleration and accelerator pedal position. However, these data are not the focus of this paper but might be used for future analyses.

2.2. Sample

In Location A, 61 participants between 22 and 69 years (Ø = 49, σ = 14) took part, 21 of which were female. 20 participants were invited for the compact car, 21 for the mid-size car and 20 for the roadster. The acquisition was done via a panel consisting of vehicle drivers, who are willing to take part in various car-related studies. The panel members drive vehicles of premium makes, i.e., makes with a high perceived quality and value, and the participants were required to be experienced with a car of the corresponding segment.

Table I. Distribution of participants over the three driver types *sound-oriented fun-driver* (Type 1), *noise-sensitive aesthete* (Type 2) and *sound-uninterested pragmatist* (Type 3).

	Type 1	Type 2	Type 3	Total
Location A	23	20	18	61
Location B	2	11	11	24
Total	25	31	29	85

In Location B, 24 university members between 20 and 54 years (Ø = 37, σ = 9) took part, 10 of which were female. As opposed to Location A, every participant did a ride in each of the three sound conditions, but with a separation interval of one to two weeks between successive rides. The participants were not told about the sound modification, but were instructed to pay as much attention with respect to the driving sound as in the ride(s) before, as something *could* have changed. The order of the three sound conditions was randomized for all participants.

No statistical evidence was found to support a learning effect of the participants in Location B, i.e., the order of assessment of the three sound conditions was not a significant predictor for the participants' ratings, which is why the respective results were further considered as (the more conservative type of) between-subject data. Furthermore, no effect of location (A and B) on the dependent variables was found, which is why all data were treated as one sample.

As stated before, the driver type [6] of every participant was determined. The distribution of participants over driver types is shown in Table I. It can be seen that there is a lack of *sound-oriented fun-drivers* in Location B as compared to the other two driver types. This might originate from the different backgrounds of the subsamples in the two locations, i.e., premium vehicle drivers vs. university members. It seems that university members are less likely to be *sound-oriented fun-drivers*, which means that they are less interested in dynamic driving and more critical against cars and noise than the premium vehicle drivers.

2.3. Sound conditions

In Location B, the same car was used in three different sound conditions. Along with the *original condition*, i.e., original sound of the car, two modifications were made by generating sinusoidal components corresponding to certain engine orders (EO) (i.e., harmonics of the engine's rotational frequency) over the car's audio system, with levels depending on engine speed and load. The *Campbell diagrams*, i.e., the depictions of the frequency distribution

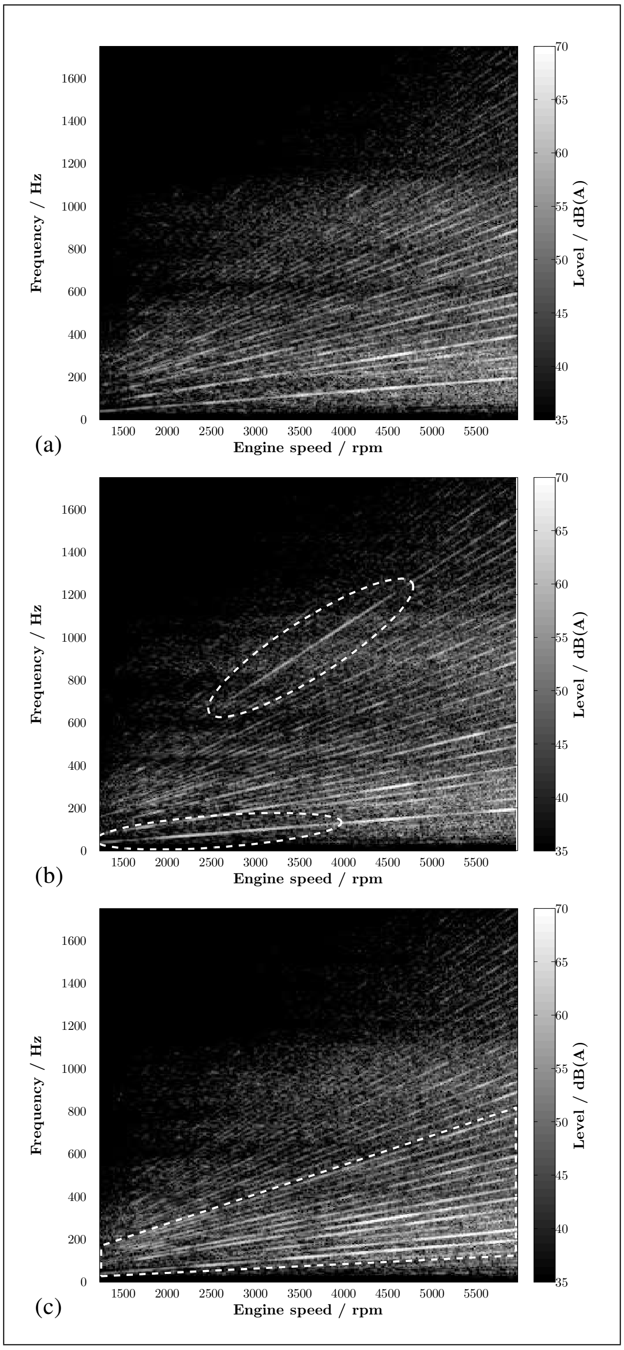

Figure 3. Campbell diagrams of the three sound conditions used in Location B, measured with WOT in third gear. The modified regions are marked with white dashed lines. (a) Original condition, (b) Booming/howling condition, (c) Rough/sporty condition.

with respect to engine speed, of the three sound conditions are shown in Figure 3, as measured with wide-open-throttle (WOT) in third gear. For the *booming/howling condition*, the second EO is emphasized up to around 3500 rpm (for the booming part), and the 16th EO is emphasized between 2500 and 4500 rpm (for the howling part) (see Figure 3b). For the *rough/sporty condition*, the EOs 1.5 to 8 (in steps of 0.5 EO) are emphasized, which gives the sound a rough and thus sporty character (see Figure 3c).

2.4. Selection of driving conditions

In the course of the experiment, the subjects were provided with a printed list of nine driving conditions and were asked to give ratings regarding various aspects. The selection of driving conditions on this list was composed prior to the experiment, based on the driving conditions that are frequently considered in studies dealing with the process of vehicle sound assessment (such as [12, 18, 19, 20, 21, 22, 23]), with the optimization of the subjectively rated sound character of a car (such as [24, 25]) or with the development of metrics for vehicle sound quality (such as [13, 26, 27]). The list gained from these studies was further adjusted and complemented, and finally consisted of nine driving conditions:

1. engine start;
2. engine idle;
3. driving off from standstill;
4. overtaking;
5. accelerating;
6. coast down;
7. constant speed of 50 km/h (inner-city);
8. constant speed of 80 km/h (rural road);
9. constant speed of 140 km/h (highway).

3. Analysis of driving conditions

In contrast to the driver type and the car, the context variable “driving condition” is continuously changing during the ride, and could thus be called the “short-term context”. Due to this property, also the differentiation between the driving conditions is more intricate. In the course of the experiment several questions were asked concerning comfort, sportiness and importance of the nine preselected driving conditions. In this section the corresponding findings will be grouped together to make them easier to handle in the linear model that will be fitted in Section 4.

It is expected that not all driving conditions contribute equally to the sound assessment. Some might occur more frequently than others, and some might have a greater effect than others on certain aspects of the vehicle sound. In order to separate the more important driving conditions from the less important, several approaches were chosen: an open question directly asking for the most important driving conditions, a rating of the importance of nine preselected driving conditions, and a factor analysis of the ratings of comfort and sportiness of the nine preselected driving conditions.

3.1. Open question

In an open question, the participants were asked directly for the driving conditions to which they attach importance with regard to the driving sound during a test ride. The answers were sorted into nine categories corresponding to the driving conditions introduced in Section 2.4. The relative frequencies are depicted in Figure 4. It is observed that “constant speed (highway)” is named most often (43 % of the participants), followed by “accelerating” (22 %) and “constant speed (inner-city)” (15 %).

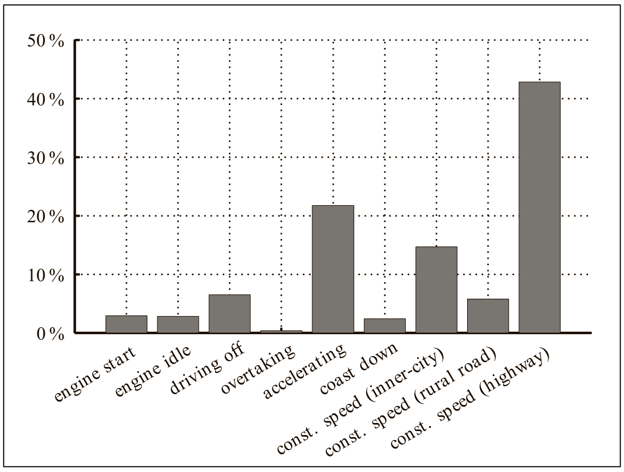

Figure 4. Relative frequencies of driving conditions named by the participants as being important for sound assessment.

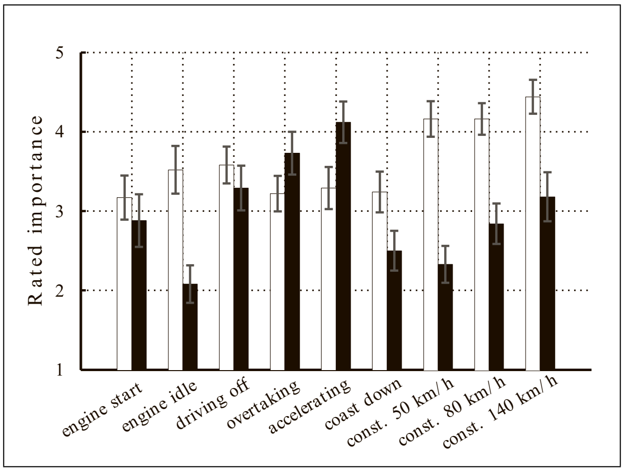

Figure 5. Means and 95 %-CIs of the rated importance of the driving conditions for the overall acoustic comfort (white) and for the overall acoustic sportiness (black), respectively.

3.2. Rated importance

During the guided interview, a table was handed to the participants that contained the nine abovementioned driving conditions. The task of the participants was to indicate the importance of each driving condition for the rating of the overall acoustic comfort on the one hand, and for the rating of the overall acoustic sportiness on the other hand. For this purpose, a five-point scale ranging from "unimportant" to "important" was given to the participants. The means and 95 %-confidence intervals (CIs) across participants are depicted in Figure 5. For the overall acoustic comfort, driving with constant speed is rated more "important". This is well in line with the answers to the open question presented in Section 3.1. In contrast, for overall acoustic sportiness the dynamic driving conditions accelerating and overtaking are rated most important. The importance of accelerating matches the results from the open question (Section 3.1); however, the high importance of overtaking was not observed. A possible explanation is that overtaking, as a combination of driving with constant speed and accelerating, is not regarded as a separate driving condition by the participants unless they are specifically asked to rate this maneuver.

A MANOVA with the rated importance of the driving condition for comfort and for sportiness as the dependent variables and the driving condition as fixed factor reveals a significant effect of the driving condition ($\Lambda = .699$, $F(16, 2368) = 29.06$, $p < .05$, $\eta_p^2 = .16$) for both comfort ($F(8, 1185) = 27.32$, $p < .05$, $\eta_p^2 = .16$) and sportiness ($F(8, 1185) = 33.46$, $p < .05$, $\eta_p^2 = .18$). BONFERRONI *post hoc tests* (cf. [28]) confirm that the three constant driving conditions are significantly more important for comfort than the rest of the conditions, while overtaking and accelerating are significantly more important for sportiness than the other driving conditions.

3.3. Factor analysis of ratings

After the guided interview the participants were asked to rate the extent to which they perceived comfort and sportiness in each of the driving conditions, using a ten-point scale ranging from "not at all" to "very much". These ratings of comfort and sportiness in the driving conditions are expected to be important for the modeling in Section 4, because in contrast to the overall ratings they allow for differentiated consideration of the driving conditions. However, this means a lot of additional variables, which is why the driving conditions are grouped together beforehand depending on the correlation between their ratings, by a *factor analysis* (FA) (see [28]). As each resulting factor defines an independent construct, a *scale value* will be calculated for each factor by averaging the ratings of those driving conditions that have high factor loadings on the corresponding factor. These scale values will be further used in the model calculations.

FA of the comfort ratings for all driving conditions revealed two factors. Although the *elbow criterion* from the *scree plot* was somewhat ambiguous, the *Kaiser-Guttmann criterion* pointed at this solution. Further, the rotated factor solution showed nice and clear-cut loadings for the majority of the driving conditions on the two factors, i.e., these variables have a high loading on one factor but a low loading on the other factor (see Table II, column "comfort"). More importantly, the factors could intuitively be named as 1) *dynamic comfort* and 2) *static comfort*. At this point dynamic comfort consisted of driving off, overtaking and acceleration, and static comfort consisted of constant speed of 50 km/h, 80 km/h and 140 km/h. Engine start, engine idle and coast down showed ambiguous loadings and were therefore excluded. The reliability was further analyzed using CRONBACH's α (see [28]) to see whether any of the driving conditions had to be excluded to guarantee that the yielded comfort scales are reliable. It showed that with driving off the value of $\alpha = .877$ for dynamic comfort was lower than when excluding this scale, yielding $\alpha = .908$. Similarly, exclusion of constant speed of 140 km/h yielded a higher value of $\alpha = .913$ for static comfort as when including it, which resulted in $\alpha = .888$. Hence, both driving conditions were excluded from the respective scales.

Table II. Factor loadings of the two factor analyses: column "comfort" shows the rotated component matrix for the comfort ratings, column "sportiness" shows the component matrix for the sportiness ratings. Values below .4 are printed in grey; bold values indicate the reliable driving conditions, which were used for calculating the scale values for each factor.

Factor no.	Comfort 1	Comfort 2	Sportiness 1
engine start	.664	.413	**.882**
engine idle	.538	.632	**.841**
driving off	.860	.303	**.881**
overtaking	**.835**	.299	**.824**
accelerating	**.904**	.153	**.764**
coast down	.520	.486	**.894**
const. 50 km/h	.216	**.935**	**.914**
const. 80 km/h	.225	**.922**	**.910**
const. 140 km/h	.386	.775	**.930**

FA of the sportiness ratings for all driving conditions revealed only one factor (see Table II, column "sportiness"). Both the elbow criterion from the scree plot as well as the Kaiser-Guttmann criterion pointed in this direction. The reliability analysis revealed no real outliers and therefore all driving conditions were included in the new scale, yielding a value of $\alpha = .957$.

To sum up, overall comfort splits into two parts, namely the static comfort and the dynamic comfort, which means that two distinct kinds of comfort are perceived by the participants. Overall sportiness, however, manifests in the ratings of all driving conditions in equal measure, which is contrary to the higher rated importance of the dynamic driving conditions for sportiness as observed in Section 3.2. There might be a difference between the importance rated by the participants and the "latent" importance as revealed by FA.

For the further model calculations in Section 4 the following variables, reflecting the factors, were calculated: **dynamic comfort** as the average of comfort ratings during overtaking and accelerating, **static comfort** as the average of comfort ratings during constant speed of 50 km/h as well as 80 km/h, and **mean sportiness** as the average of sportiness ratings in *all* driving conditions.

4. Model for vehicle sound assessment

In this section, a regression model for vehicle sound assessment will be presented. Since it was an exploratory study, the idea was to make as little prior assumptions about dependencies as possible, in order not to mask any relations present in the data. Only in cases of statistical ambiguity, e.g., when different model configurations were equally likely, theoretical considerations as posed in the introduction were used as decisive criteria. The modeling procedure started with the most general rating, the overall sound quality, and assumed it to be a dependent variable. All the remaining data were in principle considered as predictor variables for the rated sound quality, based on a linear regression model. The aim was then to find an "economic" model, i.e., a model that provides a reasonable trade-off between a low number of variables and a high predictive power. Such a model is assumed to give hints about the participants' vehicle sound assessment process.

The same modeling procedure was then undertaken in order to find regression models to predict each of the main predictors of sound quality (which will be called *submodels*); in this way, a deeper insight into the vehicle sound assessment process is possible.

4.1. Modeling procedure

A *multiple linear regression model* was taken as the basis, which aims at predicting sound quality (SQ) as a weighted sum of the predictor variables P_i:

$$\begin{aligned} SQ &= w_0 + w_1 \cdot P_1 + w_2 \cdot P_2 + \ldots + w_n \cdot P_n + \epsilon \\ &= w_0 + \sum_{i=1}^{n} w_i \cdot P_i + \epsilon, \end{aligned} \tag{1}$$

each weighted with a regression coefficient w_i. The constant term w_0 is also called the *intercept*. The error term ϵ accounts for the variance in SQ that is not explained by any of the predictors P_i. In addition, two-way *interaction* terms of the form $P_i \cdot P_j$ can be introduced that account for effects that depend on the simultaneous outcome of two variables:

$$SQ = w_0 + \sum_{i=1}^{n} w_i \cdot P_i + \sum_{i \neq j} w_{ij} \cdot P_i \cdot P_j + \epsilon. \tag{2}$$

From their mathematical formulation as products it becomes evident that interaction terms contribute all the more to SQ as the (absolute) values of P_i *and* P_j get higher. In a similar manner, higher order interactions (three-way, four-way etc.) are possible. As opposed to interaction terms, the "standard" terms $w_i \cdot P_i$ are called *main effects*.

As it does not seem reasonable and insightful to just use all the collected variables to explain sound quality, a procedure was first applied to identify the most important predictors as will be explained below. With these predictor variables several models complying with Equation (2) were built successively and compared with regard to their predictive power. The final model providing the best fit will be described in Sections 4.2 to 4.5. Prior to that, the modeling procedure will be described in more detail.

Potential predictor variables The following variables were considered as potential predictor variables for the rated sound quality: rated comfort; rated sportiness; rated type conformity; rated make conformity; the rated importances of comfort, of sportiness, of type conformity and of make conformity, respectively, for sound quality; the rated importances of comfort and of sportiness, respectively, for type conformity and for make conformity, respectively; dynamic comfort; static comfort; mean sportiness; the driven car; the location (A or B); gender; age;

the driver type [6]; the four scales of noise sensitivity [16], i.e., critical attitude towards noise, music activation, noise sensitivity and distraction by noise, appreciation of silence and natural sounds; the Big Five dimensions of personality [10], i.e., extraversion, neuroticism, openness to experience, conscientiousness, agreeableness; the GNAT score.

Reduction of predictors The basic idea for reducing the number of predictors is to compare the predictive power of each variable P_i to a certain reference. This reference is chosen as the coarsest model, the "intercept only"-model, that predicts sound quality just as the collective average $\overline{SQ}$ of sound quality ratings. For the comparison, one predictor variable P_i is added to the model, and the predictive power of the resulting model is compared to the "intercept only"-model in terms of its *-2 log-likelihood*[2], which is a measure of the goodness of fit of a model [28]. If the model including P_i has a significantly lower -2 log-likelihood, it is regarded as a better model and the corresponding variable P_i is kept for further analyses; otherwise P_i is excluded. This is repeated with every potential predictor P_i, comparing its predictive power to the "intercept only"-model. As a result, many variables can be excluded from the sound quality model and its submodels specifically, keeping only the valuable predictors. The corresponding results will be presented in Sections 4.2 to 4.5.

Relationship between predictors All predictor variables P_i that have not been excluded yet are used as pure main effects in an ANCOVA model corresponding to Equation (1), i.e., disregarding any possible interactions. The result of this first model indicates whether each variable's contribution in explaining SQ is still significant in the presence of the other (maybe better) predictors. For this purpose variables are compared by their *probability value* p, which represents the probability for the corresponding regression coefficient w_i to actually be zero, given its observed value. Hence, variables with high p-values are not significant and can in principal be excluded [30, p. 82]. Although such an insignificant main effect is a hint that a variable is not useful for the model, the possibility remains that the variable is involved in an interaction that is of predictive value in the model (corresponding to Equation (2), or even higher order interactions). As this main effects model only provides a first inspection of the combination of the variables left after the initial reduction of predictors, more complex model configurations including interactions are tested thereafter. Since it would be very laborious to test all possible interactions and because such an approach would also cause a lot of results becoming significant by chance, not all interactions were tested systematically. As every change in the composition of predictor terms will produce potentially different p-values, the iterative modeling procedure was guided by the following principles. The main focus was set on those variables that do have a main effect, and nonsignificant variables were kept as interaction partners when their influence on vehicle sound assessment has already been demonstrated in literature (such as comfort, sportiness, conformity, vehicle type and make, driver type, see Section 1). In order to get an economic but comprehensive model, variables were excluded if they were only considered to be meaningful as a main effect but did not get significant. When there were pairs of redundant variables (in the sense that they only got significant if one or the other was considered in the model), the one with the lower predictive power was also excluded. The predictive power of a variable or interaction was assessed by η^2_{partial}, which is a measure for the variance of SQ explained by this variable.

In this way a variety of models was built, and these models were compared by their *adjusted* R^2 (denoted by R^2_{adj}) [31, p. 376], which, as compared to the unadjusted *coefficient of determination* R^2, "penalizes" a model for a higher number of predictor variables. As this step-by-step approach produces a lot of data which would go beyond the scope of this paper, only the resulting model with the highest R^2_{adj} will be presented, denoted as the *best-fit* model[3].

To assess the validity of the resulting model on unseen data, a *10-fold cross validation* (CV) was performed. The whole data set was split into ten parts of approximately equal size, and the model parameters were derived from nine out of these ten parts (containing 90 % of the data). The resulting parameters were tested by calculating predictions for the remaining part (10 % of the data) and evaluating the value of R^2. This was done successively with each of the ten parts being used as the test set, constituting 10-fold CV. The whole process was then repeated 100 times, resulting in a total of 1000 model derivations and tests. The average value of R^2 will be reported.

4.2. Model for sound quality

The initial reduction of predictor variables revealed that the following variables can potentially predict the rated overall sound quality: comfort; type conformity; make conformity; driven car; openness (Big Five); static comfort; sportiness; driver type.

In the next step, these variables were used as pure main effects. It was observed that make conformity, the driven car, openness, static comfort, sportiness and the driver type are not significant. Since the driver type and the driven car, as categorical variables, were very interesting for potential interaction, they were kept in the analysis. Sportiness was regarded to be underrepresented in the study because only one car could be considered a sports car and therefore was also kept in the analysis as an interesting interaction partner.

As stated in the introduction, the conformities have an "intermediate" role as they depend on comfort and sportiness to some extent; therefore, the leading question for the

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[2] To be specific, the *Mixed Linear Model* (MLM) in SPSS [29] was used to analyze the data at this point.

[3] As the data arise from a mixed design, all presented best-fit models were also checked with the MLM, confirming the reported significant regression coefficients.

development of the model was if and how the hypothetic predictors comfort, sportiness and the conformities predict sound quality, and especially whether conformity (in this case only type conformity) is tied to comfort and sportiness in interaction terms or if it exerts a main effect on sound quality. For both cases, many models were possible but those who employed conformity as a separate main effect had a higher R^2_{adj}. Table III lists the predictors that form the best-fit model. While comfort and sportiness interact with the driven car and the driver type, type conformity unfolds its greatest predictive power when it is used as a pure main effect. A depiction of the dependencies between the constituents of the presented model for sound quality is given in Figure 6.

In the following, the regression coefficients w_i associated with the best-fit model will be discussed. It is noteworthy that the w_i of comfort and sportiness, which occur as interaction terms with the categorical variables driver type and car, vary depending on the specific combination of driver type and car. As the exploratory data underlying these estimates are unbalanced, some of the regression coefficients w_i are based on very few data points, which is why their absolute value has limited informational value. Hence, only the sign of the significant w_i will be considered (as a more conservative approach). For all cars except the roadster (A), higher comfort leads to higher sound quality. For *sound-oriented fun-drivers* and *noise-sensitive aesthetes*[4] in the roadster (A), higher sportiness leads to higher sound quality; for *noise-sensitive aesthetes* in the compact car (A), the mid-size car (A) and the original condition (B), higher sportiness leads to lower sound quality; for *noise-sensitive aesthetes* in the rough/sporty condition (B), higher sportiness leads to higher sound quality. The higher the type conformity, the higher the sound quality.

A general distinction is found between the non-sporty cars on the one hand (i.e., the compact car and the sedans in all sound conditions) and the sporty car on the other hand (i.e., the roadster); the sound quality of the former is mainly influenced by comfort, and the sound quality of the latter is mainly influenced by sportiness. In addition, especially for the influence of sportiness, the driver types come into play. In particular the *noise-sensitive aesthetes* make distinctions with regard to the car; for the compact car (A), the mid-size car (A) and the original condition (B), sportiness affects their sound quality judgement negatively, as it might be considered inappropriate and noisy. In contrast, for the roadster (A) and the rough/sporty condition (B), where in fact a sportier sound is present, it positively affects their sound quality ratings. It seems that the *noise-sensitive aesthete* is able to perceive sportiness, but does not demand it in general, because of his noise sensitivity; when a sporty sound is present, however, he can appreciate it. In contrast, the *sound-uninterested pragmatist* does not care at all about sportiness, and may even be unable to perceive it, which is well in line with the disinterest of this driver type in vehicle sounds, indicated already by the choice of name. Type conformity has a significant positive main effect on sound quality, but its η^2_{partial} is the lowest among the model's constituents. As it was itself expected to be influenced by comfort and sportiness, it remains unclear how it effectively affects sound quality. This "entanglement" will be further considered in the submodel for type conformity (see Section 4.5).

Table III. Contributions to the best-fit model for the rated sound quality; $R^2 = .825$, $R^2_{\text{adj}} = .742$.

Source	p-value	η^2_{partial}
Intercept	.000	.187
car * driver type * comfort	.001	.382
type conformity	.000	.219
car * driver type * sportiness	.001	.397

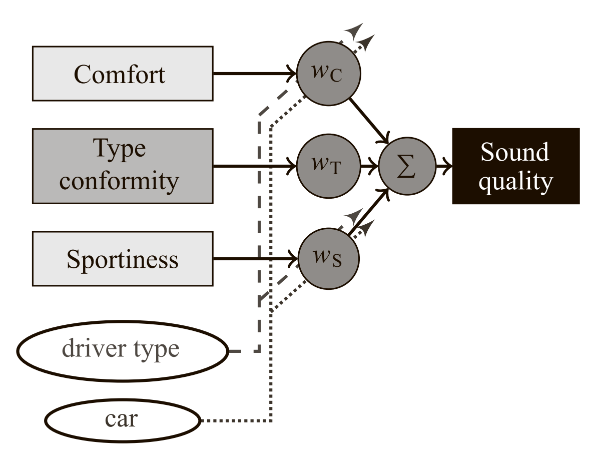

Figure 6. Model for sound quality, derived from the experimental data. Weights w_i vary depending on driver type and car.

In cross-validation, the model for sound quality yields an average $R^2 = 64.8\,\% \pm 0.6\,\%$ on the test data. It should be noted that for almost half of the CV models the regression matrix is rank deficient, meaning that there are too few cases in some cells for a robust estimation of the regression coefficients. However, the 95 %-CIs of the estimated coefficients overlap with the 95 %-CIs arising from considering all participants (in more than 99.1 % of the CV models).

After having determined the best-fit model for sound quality emerging from the data, submodels for the three main predictor variables comfort, sportiness and type conformity (gained in a similar manner) will be presented in the following sections.

4.3. Submodel for comfort

In the previous section, comfort, sportiness and type conformity were found to form the basis of sound quality. The next step is now to apply the same approach for modeling comfort instead of sound quality, obtaining a "submodel" to the sound quality model. The same variables as before

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[4] For *noise-sensitive aesthetes* this regression coefficient only slightly misses significance ($p = .054$).

(cf. Section 4.1) are considered as potential predictors for comfort.

The initial reduction of predictor variables revealed that the following variables can potentially predict the rated overall comfort: driven car; extraversion (from Big Five); type conformity; make conformity; dynamic comfort; static comfort; importance of comfort for sound quality.

In the next step, these variables were used as pure main effects. It was observed that the driven car, extraversion, make conformity, dynamic comfort and importance of comfort for sound quality are not significant. However, all of these variables were still considered as being potentially relevant for comfort; after testing the model configurations that seemed reasonable from what was stated in the introduction, it became clear that dynamic comfort, importance of comfort for sound quality and make conformity could indeed be excluded as they did not increase the model's predictive power. From the remaining variables, the model with the best R^2_{adj} is shown in Table IV. The model consists of three two-way predictors each including the driven car, and is visualized in Figure 7.

The significant regression coefficients w_i imply that for all sedans (i.e., the mid-size car (A) and all conditions in Location B), higher type conformity leads to higher comfort. For the compact car (A), the roadster (A), the booming/howling condition (B) and the rough/sporty condition (B), higher static comfort leads to higher comfort. For the roadster (A), higher values of extraversion lead to higher comfort.

Again type conformity comes into play and affirms the finding from the model for sound quality, namely that type conformity of non-sporty cars is connected to comfort; the reversed influence observed in this model (i.e., type conformity influences comfort) results from the choice of dependent and independent variables. This connection conforms to the depictions in [12, 13], where luxury cars are positioned at the regions corresponding to high pleasantness or comfort. It seems that the sedans with conform sound (i.e., mid-size car (A) and original condition (B)) do not need the static comfort to be rated as comfortable, whereas the other cars (i.e., the compact car (A), the sporty roadster (A) and the non-conform booming/howling condition (B) and rough/sporty condition (B)) do need the static comfort. It is possible that the participants already have their predetermined comfort judgement in mind, and stick to it as long as the experienced acoustic comfort does not differ too much from it. The influence of extraversion, which is one of the Big Five personality traits, for the roadster might be a form of justification if the driver cares about his fellows: his car is not just sporty and fun-oriented, but also comfortable, which might socially be more accepted (for "socially desirable responding", see e.g. [7]). Another possible explanation is that extroverted drivers are especially attracted by sports cars, and thus give in general better ratings for those as a kind of "halo effect" (cf. [32]).

Table IV. Contributions to the best-fit model for the rated acoustic comfort; $R^2 = .716$, $R^2_{\text{adj}} = .660$.

Source	p-value	η^2_{partial}
Intercept	.384	.008
car * type conformity	.000	.334
car * static comfort	.000	.256
car * extraversion	.032	.138

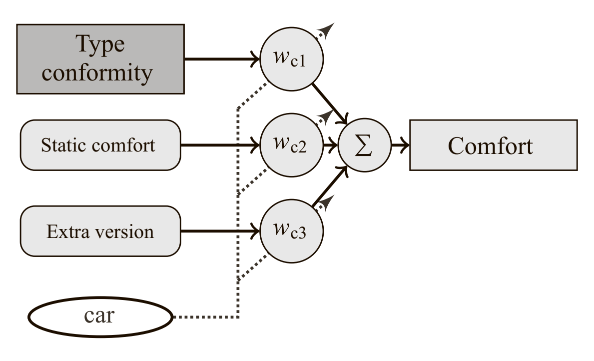

Figure 7. Submodel for comfort, derived from the experimental data. Weights w_i vary depending on the car.

The static driving conditions (in the form of the variable "static comfort") have shown to be important for the rated comfort. This affirms the findings of Section 3 where the high importance of static driving conditions was found, in particular for comfort. The participants' conscious as well as subconscious ratings seem to match up.

In cross-validation, the submodel for comfort yields an average $R^2 = 56.0\,\% \pm 0.7\,\%$ on the test data.

4.4. Submodel for sportiness

The initial reduction of predictor variables revealed that the following variables can potentially predict the overall rated sportiness: the driven car; the driver type; importance of sportiness for sound quality; importance of make conformity for sound quality; type conformity; importance of sportiness for type conformity; importance of sportiness for make conformity; GNAT score; mean sportiness.

In the next step, these variables were used as pure main effects. It was observed that type conformity, the importance of make conformity for sound quality, the importance of sportiness for sound quality, the importance of sportiness for make conformity and the GNAT score are not significant. The latter three of these were excluded from further analyses because they did not contribute significantly to any of the model configurations that seemed reasonable from what was said in Section 1. Table V shows the model that emerged as the best-fit model. The model consists of a three-way predictor and two two-way predictors. The variables driven car, type conformity and mean sportiness are more related to the actual car sound, whereas importance of sportiness for type conformity, importance of make conformity for sound quality and the

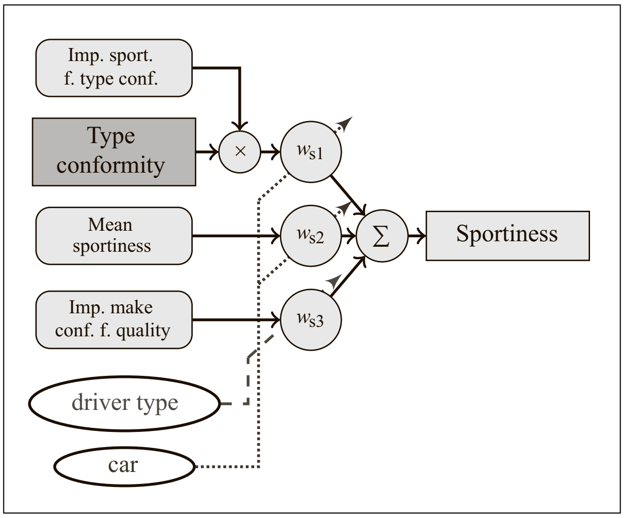

Figure 8. Submodel for sportiness, derived from the experimental data. Weights w_i vary depending on driver type or car.

driver type are more related to the subject. The model is visualized in Figure 8.

The significant regression coefficients w_i imply that for the roadster (A) and the mid-size car (A), the simultaneous occurrence of high rated importance of sportiness for type conformity and high type conformity leads to higher sportiness. For the compact car (A) and all conditions in Location B, higher mean sportiness leads to higher sportiness. For the *sound-uninterested pragmatist*, higher rated importance of make conformity for sound quality leads to higher sportiness.

The influence of type conformity on sportiness is moderated by the importance of sportiness in the roadster (A) and the mid-size car (A). That means that for those participants who find sportiness important, type conformity is directly correlated to sportiness, which seems a reasonable outcome. However, the indicated direction of the effect is again attributed to the chosen roles for the variables (independent vs. dependent), as in the comfort submodel in the previous section. The influence of the mean sportiness can be interpreted similarly to the influence of static comfort in the comfort model (see Section 4.3): participants might have a predetermined sportiness rating in mind, which they dismiss only if the experienced acoustic sportiness differs considerably. As the affected cars are not influenced by aspects of type conformity in the model, the dependency on the mean sportiness might be due to the lack of a prospect of the sportiness of these cars. Those *sound-uninterested pragmatists* who attach more importance to a make conform vehicle sound tend to give higher sportiness ratings. As there was only one single make tested in this study, which belongs to the premium segment, it is supposed that again a halo effect is observed: the cars get rated higher due to the assumed “premiumness” of the make by the *sound-uninterested pragmatists* who, as discussed in Section 4.2, might be unable to perceive sportiness.

In cross-validation, the submodel for sportiness yields an average $R^2 = 75.0\,\% \pm 0.5\,\%$ on the test data.

Table V. Contributions to the best-fit model for the rated acoustic sportiness; $R^2 = .829$, $R^2_{\mathrm{adj}} = .797$.

Source	p-value	$\eta^2_{\mathrm{partial}}$
Intercept	.709	.002
car * importance of sportiness for type conformity * type conformity	.000	.456
car * mean sportiness	.000	.414
driver type * importance of make conformity or sound quality	.000	.290

Table VI. Contributions to the best-fit model for the rated type conformity; $R^2 = .853$, $R^2_{\mathrm{adj}} = .825$.

Source	p-value	$\eta^2_{\mathrm{partial}}$
Intercept	.720	.001
car * make conformity	.000	.493
car * comfort	.000	.339
car * sportiness	.011	.159

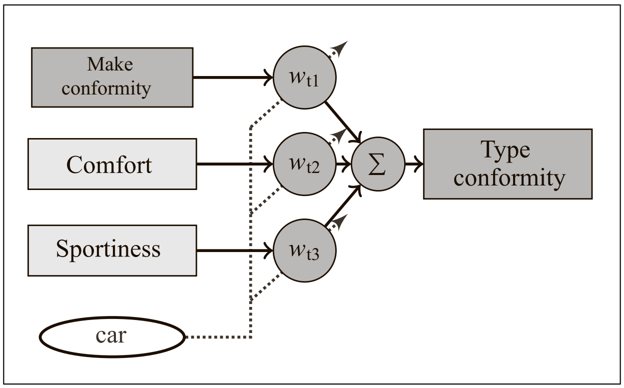

Figure 9. Submodel for type conformity, derived from the experimental data. Weights w_i vary depending on the car.

4.5. Submodel for type conformity

The initial reduction of predictor variables revealed that the following variables can potentially predict the overall rated type conformity: openness (Big Five); sportiness; comfort; make conformity; static comfort; driven car.

In the next step, these variables were used as pure main effects. It was observed that sportiness, static comfort and openness are not significant. The latter two were excluded from further analyses, as static comfort was regarded as redundant because rated comfort was already in the model. Openness, which is one of the Big Five personality traits, was only assumed to be meaningful as a main effect. The best-fit model can be seen in Table VI. It consists of three two-way predictors, each of which includes the driven car, and is visualized in Figure 9.

The significant regression coefficients w_i imply that for all cars except the original condition (B), higher make conformity leads to higher type conformity. For the mid-size car (A) and the original condition (B), higher comfort leads to higher type conformity. For the compact car (A), higher sportiness leads to higher type conformity.

Make conformity has the strongest influence on type conformity. However, no variability was provided with regard to the cars' makes as they all were of the same make. The significant correlation between the ratings of the two conformities might result from an "integral conformity" that the participants effectively rated. Thus, also an alternative model without make conformity as a predictor is considered. The alternative model just consists of the interaction between the driven car and the rated comfort and the interaction between the driven car and the rated sportiness (see Table VII).

In this alternative model, the significant regression coefficients w_i imply that for all cars except the roadster (A), higher comfort leads to higher type conformity. For the compact car (A) and the roadster (B), higher sportiness leads to higher type conformity.

This submodel confirms the findings of the previous models: type conformity of non-sporty cars is dominated by comfort, type conformity of sporty cars is dominated by sportiness. The exception is the compact car (A), where sportiness has a positive effect on type conformity, too. It is possible that in the context of a compact car, the participants interpret loudness or unpleasantness as sportiness, or maybe it is pointless to assess the sportiness of such a (rather pragmatic) car, which is why the rating might follow the overall impression of type conformity.

This submodel recaps the earlier observed correlation between comfort and sportiness on the one hand and type conformity on the other hand (Sections 4.3 and 4.4). However, the supposable *causal* relationship is reflected in the present submodel, namely comfort and sportiness determining type conformity (and not vice versa). It is noteworthy that apart from the driven car there are no further predictors in the alternative model for type conformity, especially not the driver type.

In cross-validation, the alternative submodel for type conformity yields an average $R^2 = 65.1\,\% \pm 0.6\,\%$ on the test data.

As make conformity was not encompassed in the sound quality model (see Section 4.2) and was highly correlated with type conformity for the data at hand, no separate model for make conformity was fitted.

4.6. Final model for sound quality

The final model for overall sound quality assessment can be visually assembled from the submodels discussed in Sections 4.2 to 4.5, and it is depicted in Figure 10. It summarizes the dependencies found in the previous sections.

First and foremost, it confirms that sound quality depends on comfort, sportiness and conformity. While type conformity seems to be a general requirement for sound quality, the influence of comfort and sportiness depends on the driven car as well as the driver type. This influence boils down to the following: if a non-sporty car is considered, comfort is required; for a sporty car, sportiness is required; for *noise-sensitive aesthetes*, sportiness can decrease sound quality if it is not adequate for the car; for *sound-uninterested pragmatists* sportiness does not play a role at all. Although the drivers have a different notion of how a car should sound, they agree on whether a given sound matches a certain vehicle type, as the driver type is not directly involved in type conformity.

Table VII. Contributions to the alternative model for the rated type conformity; $R^2 = .710$, $R^2_{\text{adj}} = .675$.

Source	p-value	η^2_{partial}
Intercept	.889	.000
car * comfort	.000	.656
car * sportiness	.000	.455

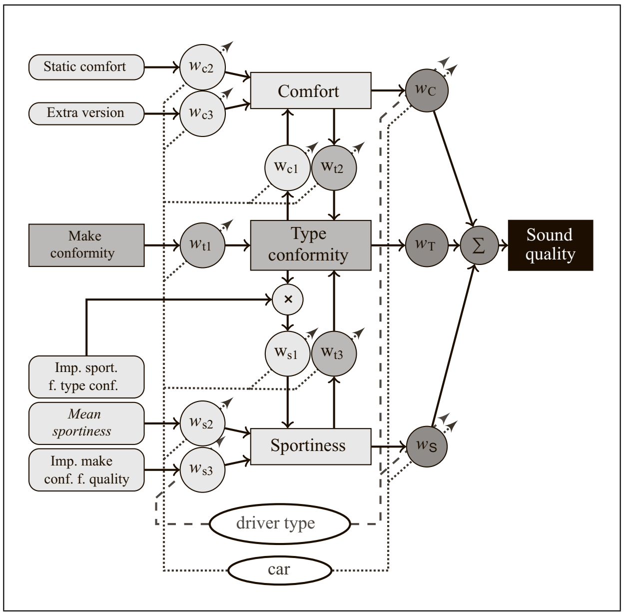

Figure 10. Final model for overall sound quality, assembled from the previous submodels. Weights w_i vary depending on driver type and/or car.

The car itself has a huge impact on the whole assessment process, as can be seen from its moderating influence on almost all of the weights w_i. Only w_T and w_{s3} are independent of the car, indicating the paramount role of type conformity for sound quality, and the *sound-uninterested pragmatists*' strategy of assessing sportiness from make attributes, respectively.

Overall comfort and sportiness can be traced back to the driving conditions: static driving conditions, such as driving with constant speed, are particularly important for comfort, while sportiness manifests in all considered driving conditions. For comfort ratings in the sporty car, also the personality trait extraversion plays a role.

A striking observation is the "dependency-loop" between comfort and sportiness on the one hand and type conformity on the other hand, i.e., type conformity depends on comfort and sportiness and vice versa. This is considered to be an artifact from the modeling approach and the visual assembly in Figure 10: due to the succes-

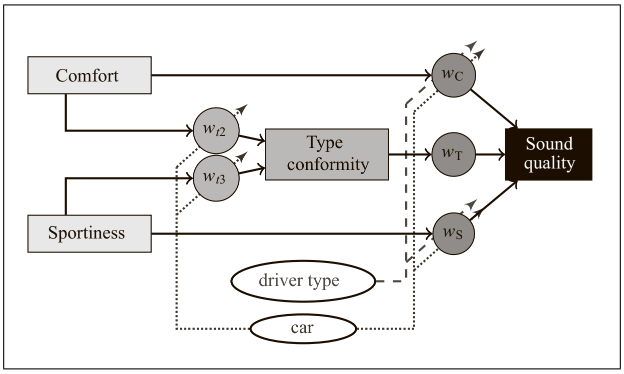

Figure 11. Schematic model for the mediation analysis.

sive but independent construction of the submodels, the aforementioned quantities take turns being predictors or dependent variables, respectively, which implies a certain direction of causality. However, *correlation* rather than causality can be determined in linear regression models. Sportiness, comfort and type conformity are indeed valuable predictors for each other, as there seems to exist a tight relation between these, but from what was said in the introduction it seems more likely that comfort and sportiness cause the outcome of type conformity rather than vice versa. That is to say, in Figure 10 the paths via w_{t2} and w_{t3} rather than w_{c1} and w_{s1} are to be used in future model calculations.

To further test this "intermediate" role of type conformity, a *mediation analysis* was performed on the respective part of the model (see Figure 11). Comfort and sportiness were taken as the two independent variables, sound quality was taken as the dependent variable, and type conformity was put in between as a mediator. As in Figure 10, both comfort and sportiness have an influence on type conformity (moderated by the car) and on sound quality (moderated by the interaction between car and driver type), while type conformity has an (unmoderated) effect on sound quality. In mediation analysis, it is tested whether the *indirect effect* via type conformity, characterized by the product of the regression coefficients $w_{t2} \cdot w_T$ or $w_{t3} \cdot w_T$, respectively, is significantly different from zero [33]. This was realized using *bootstrapping* with $k = 10^6$ random samples. It was observed that the indirect effect $w_{t2} \cdot w_T$ originating from comfort was significant (and positive) for all cars except the roadster (A) ($p = .122$), while the indirect effect $w_{t3} \cdot w_T$ of sportiness was only significant (and positive) for the compact car (A) ($p = .015$) and the roadster (A) ($p = .001$). The direct effects w_C of comfort and w_S sportiness on sound quality are also significant, indicating partial mediation. The only exception is the direct influence of comfort on sound quality for the *sound-uninterested pragmatist* in the mid-size car (A), where full mediation is indicated by an insignificant regression coefficient. This corroborates the earlier interpretation: type conformity can be interpreted as being a mediator between comfort and sportiness on the one hand and sound quality on the other hand.

Since multicollinearity, i.e., linear dependencies between the predictor variables, can substantially lower the model estimation accuracy, the *variance inflation factor* (VIF) was calculated for all predictors. A VIF greater than 10 indicates serious multicollinearity between the predictors, which leads to inaccuracy of the estimated weights w_i [28]. In the set of all predictors used in the final model, the highest VIFs are those of type conformity (4.97) and make conformity (4.87). The high correlation between these two was already observed and discussed in Section 4.5, and without make conformity the VIFs are all smaller than 3.99, which is the value for sportiness.

5. Discussion

As discussed in the beginning, vehicle sound quality depends on (acoustic) comfort, sportiness, type conformity and make conformity. The aim of this article was to specify the relations between these quantities, as well as the influence of contextual aspects on vehicle sound assessment from data of an exploratory study. In the developed model, the driven car and the driver are included as moderating factors, and different combinations of driving conditions account for the averaged comfort and sportiness terms. Since unnecessary predictors were excluded during the modeling procedure, it can be concluded that the model's predictive power indeed benefits from the consideration of these contextual aspects. In the final model, especially comfort and sportiness determine sound quality, in a way that depends on the driven car and driver type: sporty cars are basically determined by sportiness, the other vehicle types are basically determined by comfort. It showed that *sound-uninterested pragmatists* are not sensitive to sportiness, while *sound-oriented fun-drivers* and *noise-sensitive aesthetes* are; however, *noise-sensitive aesthetes* in most cases do not require sportiness, or find it even annoying, as opposed to *sound-oriented fun-drivers*, who enjoy sporty sounding cars. As expected, type conformity plays an important role but is entangled with comfort and sportiness. Although hypothesized from literature, make conformity itself was not found to be a significant predictor for sound quality in this study. However, just cars of a single make were used, and thus no variance was provided in this dimension. It rather seems that the participants rated an "overall conformity" for the particular car, as seen by the strong interrelatedness of make conformity and type conformity. As customer expectations are particularly high for premium makes, the absence of make conformity in the sound quality model is considered to be a modeling artifact. Hence, it will be interesting to see if this finding will be confirmed with data that contain cars of different makes.

Furthermore, comfort showed to be mainly dominated by "static driving conditions", such as constant driving at different speeds, and to some extent by the personality trait of extraversion. Thus, when optimizing the sound of a non-sporty car, acoustic engineers can first focus on static driving conditions before making the dynamic situations more comfortable. Sportiness seems to depend on all driving conditions, but is especially required by the participants in dynamic situations such as accelerating and overtaking. As there was only one real sports car among the tested vehicles, it just might not have been possible to resolve the individual role of the driving conditions in the sportiness model. Type conformity depends on comfort and sportiness, but their influence differs depending on the vehicle type: sporty cars need sportiness to be type conform, while other cars need comfort to be type conform. It seems to be of great importance to understand the nature of type conformity (and possibly make conformity) in future research as it showed to be related to *all* other quantities, and thus plays a central role in the whole vehicle sound assessment process.

The presented model was obtained from highly contextualized data of an exploratory study, which allows for a high ecological validity. As a field study, however, many of the parameters were not controllable as it would be the case in a pure listening experiment. A future challenge will be to investigate the differences between judgements made in a car context and such made in a listening experiment, and especially to compare the results in the light of the model described above.

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