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Influence of vehicle color on loudness judgments (L)

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This experiment investigates the effect of images of differently colored sports cars on the loudness of a simultaneously perceived car sound. Still images of a sports car, colored in red, light green, blue, and dark green, were displayed to subjects during a magnitude estimation task. The sound of an accelerating sports car was used as a stimulus. Statistical analysis suggests that the color of the visual stimulus may have a small influence on loudness judgments. The observed loudness differences are generally equivalent to a change in sound level of about 1 dB, with maximum individual differences of up to 3 dB.
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I. INTRODUCTION

Loudness plays an important role in sound-quality engineering and sound design. While loudness perception depends primarily on physical properties of the sound field, loudness judgments may also be influenced by nonacoustical factors (Blauert and Jekosch, 1997). For example, Namba *et al.* (1997) examined interior vehicle sounds and found that subjects tended to avoid extreme categorical ratings of loudness when a video of the scenery surrounding the driving car was presented. Thus loud sounds were rated softer, while soft sounds were rated louder. Dynamic visual information was also found to affect semantic differential ratings in a study reported by Suzuki *et al.* (2000). Different environmental sounds had to be rated with and without corresponding video sequences. The "volume" factor, which included adjectives such as powerful, loud, and noisy, had smaller loadings when there was additional visual stimulation. The influence of apparent size on the loudness of trucks was studied by Höger and Greifenstein (1988). In an eleven-point categorical scaling task, the sound accompanied by the video sequence of a small truck frequently was judged as being softer than the same sound combined with the video of a big truck.

Patsouras *et al.* (2002) and Rader *et al.* (2004) reported that the color of passenger trains may influence magnitude estimates of loudness. Still images which were electronically edited to show a bright red train caused subjects to give higher ratings when asked for the loudness of the sound of a passing train, while light-green trains elicited lower loudness judgments compared to purely auditory presentation. A summary of these and other studies concerning influences of visual stimulation on loudness estimation is given in Fastl (2004).

These phenomena of audio-visual interactions may also be of interest in the field of automotive design, especially regarding the typical bright red color of premium sports cars. It is expected that red cars cause an overestimation of loudness compared to cars of other colors.

II. EXPERIMENT

A. Stimuli

The picture of a British sports car (Aston Martin V8) was chosen as visual stimulus. Its dark-green (DG) color was digitally modified, so that in addition to the original color the images of a red (R), blue (B), and light-green (G) vehicle were available for the experiment (see Fig. 1). The images were shown on a 19 in. CRT computer monitor, with a viewing distance of 0.7 m. The monitor was positioned outside a soundproof booth and was visible through a window. The subjects were seated inside the booth and were instructed to keep their eyes focused on the image throughout the experiment.

The sound of an accelerating sports car with a duration of 4 s was used as auditory stimulus. It was presented diotically through calibrated electrodynamic headphones (Beyer

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FIG. 1. (Color online) The four images used as visual stimuli. The original color of the car, a dark green, is depicted on the lower right-hand side.

DT 48), using a free field equalizer as described by Fastl and Zwicker (2007). To minimize memory effects during loudness judgments four different sound levels were chosen [L_{AFmax}=90, 86, 82, and 78 dB(A)].

B. Listeners

Sixteen subjects (four female, twelve male), aged 22 to 62 years (median 26 years), participated in the experiment. All had normal hearing, as verified by pure-tone audiometric measurements.

C. Procedure

Each subject participated in two sessions. Written instructions (in German) were given which informed the subjects that they were about to rate the perceived loudness of sounds accompanying the images of sports cars. They were told to do so by giving arbitrary positive numbers that correspond to perceived loudness ratios. In each session, all possible combinations of auditory and visual stimuli were presented four times in random order. At the beginning, a short training sequence was inserted consisting of four randomly chosen stimulus combinations. The subjects then judged the loudness of the sounds via free magnitude estimation, entering their answers on a computer keyboard. This resulted in 64 loudness ratings per subject per session.

D. Results

The data for each subject were normalized relative to the median of the ratings given for the dark-green image at 90 dB(A). The median rating of each stimulus combination across the four repetitions was then calculated and used in the following analysis.

Figure 2 shows a summary of the results. The median and interquartile ranges of each stimulus pair over all subjects are depicted. Regarding the median values, it seems that in most cases the sounds associated with images of red or dark-green vehicles were rated louder than those combined with light-green or blue ones.

To test the significance of these findings, a three-way repeated measures analysis of variance with session (1 and 2), level [90, 86, 82, and 78 dB(A)], and color (R, G, B, and DG) as within-subject factors was performed, which showed a significant interaction between session and color [$F(3,45)=2.82$, $p<0.05$]. Therefore, the two sessions were analyzed separately using a two-way repeated measures analysis of variance with level [90, 86, 82, and 78 dB(A)] and color (R, G, B, and DG) as within-subject factors. Apart from the expected highly significant main effect of level [Session 1: $F(3,45)=222.24$, $p<0.0001$; Session 2: $F(3,45)=204.34$, $p<0.0001$], a significant main effect of color [Session 1: $F(3,45)=3.71$, $p<0.05$; Session 2: $F(3,45)=3.33$, $p<0.05$] was found, indicating that subjects were influenced in their loudness judgment by the color of the visual stimuli. No significant interaction (sound level by color) was found in either session ($p>0.05$).

To further investigate the influence of the visual conditions, a post-hoc comparison was performed using Scheffé's procedure. As can be seen in Table I, significant differences only occurred in Session 1 between the stimuli R and G ($p<0.05$) and in Session 2 between R and B ($p<0.05$). In both

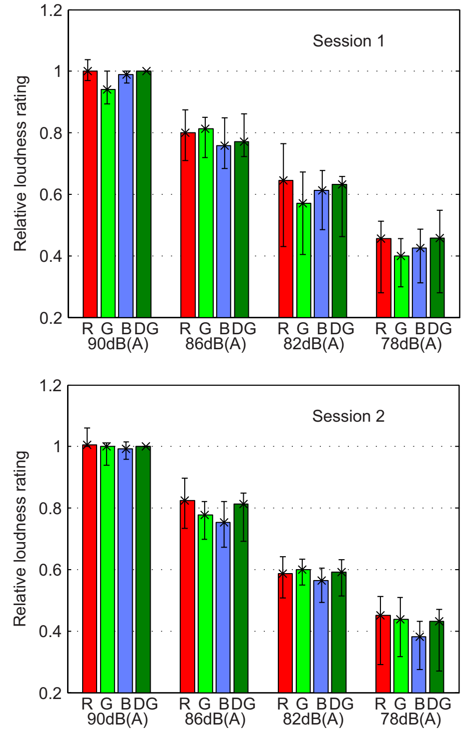

FIG. 2. (Color online) Median relative loudness ratings with interquartile ranges, grouped by level and normalized relative to the stimulus pair 90 dB(A)/DG.

TABLE I. Mean differences (D) between visual conditions. Critical differences (D_{crit}) were calculated according to Scheffé (α=0.05). Significant differences are marked with an asterisk.

	Session 1		Session 2	
	D	D_{crit}	D	D_{crit}
R-G	0.0359	0.0343*	0.0171	0.0331
R-B	0.0164	0.0343	0.0345	0.0331*
R-DG	0.0044	0.0343	0.0088	0.0331
G-B	−0.0195	0.0343	0.0174	0.0331
G-DG	−0.0316	0.0343	−0.0083	0.0331
B-DG	−0.0120	0.0343	−0.0257	0.0331

cases, sounds heard during the presentation of a red car produced higher loudness ratings. All other color combinations failed to reach statistical significance.

The mean difference between visual conditions R and G corresponds to a change in sound level of about 1 dB. Some subjects, however, seemed to be more strongly influenced by different colors and showed larger equivalent level differences of up to 3 dB.

III. CONCLUSIONS

In this experiment, small differences in magnitude estimates of loudness were found depending on visual stimulation by images of differently colored sports cars. These differences are equivalent to a change in sound level of about 1 dB, with maximum observed differences of 3 dB. Previous research concerning color influences on loudness was confirmed: Still images of red vehicles seem to elicit higher loudness ratings compared to light-green or blue vehicles. Similar tendencies were observed for dark green.

As light green and blue are rather untypical colors for sports cars, a tentative explanation could involve the degree to which the image displayed to the subjects gives the impression of a typical sports car. The general real life experience is that sports cars have certain visual and acoustical attributes, which separate them from "normal" cars. On the one hand, sports cars are usually built to reach high speeds, which requires for example a streamlined design and a powerful engine. On the other hand, certain colors like bright red are traditionally associated with premium sports cars. A visual stimulus that looks like a sports car (streamlined body structure, bright red color) thus could cause subjects to assume the vehicle possesses a powerful and therefore loud engine, which in turn could lead to higher loudness ratings. To test this hypothesis, other visual features of the vehicle apart from color could be modified to give the impression of more or less sportive cars. For example, race numbers on the door could suggest a professional racing car (with a corresponding powerful engine), and thus might influence loudness judgment even more. An additional questionnaire could give insight into introspection of the subjects, for example whether a particular vehicle during the experiment was identified as a sports car or not. A similar case of differences in loudness judgments caused by visual expectations was described by Aylor and Marks (1976).

There is evidence that the red/loud combination can raise physiological arousal and induce the perception of excitement (Wolfson and Case, 2000). Such a feeling of excitement may contribute to an overestimation of loudness.

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