Proceedings of 20th International Congress on Acoustics, ICA 2010

23–27 August 2010, Sydney, Australia

Colour-influences on loudness judgements

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PACS: 43.66.Cb, 43.66.Lj

ABSTRACT

Judgements of loudness play an important role in basic and applied psychoacoustics, for example in the fields of sound-quality engineering or noise abatement. Although loudness mainly depends on physical properties of the sound like level, duration, or spectrum, studies have shown that also visual factors may play a role during the perception and/or judgement of loudness. This contribution focuses on visual stimuli of different colours presented synchronously to sounds during loudness judgements. A number of studies were conducted to better understand this phenomenon and shed some light on possible factors influencing these audio-visual interactions. Results of selected studies are given and discussed with regard to the type of visual stimulus (e.g. synthetic images, pictures of objects), mode of presentation (e.g. monitor, projection screen), connection with the acoustical stimulus (plausible/implausible scenario), and other factors. In general, it was found that some colours are able to increase or decrease loudness judgements, but the effects showed large interindividual variability. Some subjects were apparently not influenced by the presented visual stimuli, while others over- or underestimated loudness by about 1 to 5% with maxima up to 9%. Colours like red or pink seem to cause an increase in loudness, grey or pale green were observed to decrease loudness.

INTRODUCTION

Auditory sensations are not only determined by acoustic stimuli reaching the ear, other modalities have to be taken into account as well (Blauert and Jekosch 1997). For example, Viollon and Lavandier (1999) studied the influence of images of natural and urban environments on ratings of sound quality: when viewing natural images, sounds, e.g. singing birds, were rated as pleasant, when viewing urban environments they were rated as unpleasant. The topic of this contribution, the influence of different colours on loudness judgements, was first examined by Patsouras et al. (2002), where it was found that images of red trains caused an increase in the loudness judgement compared to pale green trains. This also seemed to be the case for Japanese and American subjects (Fastl 2004, Fastl et al. 2010, Rader et al. 2004).

Here, more recent experiments will be presented showing different aspects of audio-visual interactions between colour and loudness judgements. The use of depictions of objects in contrast to abstract colour patches will be discussed. Also, the mode of presentation, e.g. still vs moving images or the size of the optical stimulus, will be varied and results concerning its influence on audio-visual interactions will be shown.

EXPERIMENTAL PROCEDURE

Set-up

The experiments were performed in a sound proof booth, which was additionally darkened to avoid any unwanted light. Sounds were presented diotically via electrodynamic headphones (Beyerdynamic DT48A) with free-field equalisation according to Fastl and Zwicker (2007, p. 7). To avoid clicks, Gaussian shaping with 5 ms rise and fall time was applied to the beginning and end of all sounds. The presentation of optical stimuli was performed using a calibrated $21''$ LC display (Eizo CG211, colour temperature 6500 K, luminance 100 cd/m^2, $\gamma = 2.2$). The viewing distance was 70 cm.

Subjects and method

At least eleven subjects took part in each experiment. All subjects had normal hearing and no subject showed signs of colour vision defects (tested ac. to Ishihara 1990). The basic experimental task was to rate the loudness of combined audio-visual stimuli. Each stimulus was repeated at least twice in pseudo-random order. The method used for loudness rating was either a method based on the principle of line length (see e.g. Fastl et al. 1989) or free magnitude estimation. The first method uses a horizontal line (length 24 cm) displayed on a touch sensitive screen separate from the main LC display and marked "extremely soft" on the left end and "extremely loud" on the right end with no additional subdivisions. Subjects indicated their loudness judgement by pressing on the line at a position according to their loudness perception. For the second method, subjects were instructed to rate the presented sounds with positive numbers according to their perceived loudness ratios.

To minimise memory effects, i.e. subjects remembering previous sounds and ratings, multiple sounds were chosen for each experiment.

Presentation of results

As, for this contribution, the differences between loudness ratings performed while viewing different colours are of major interest, the graphical representations of the experimental results focus on this aspect. For each experiment, results are presented as (absolute or relative) *shifts in loudness judgement*. First, shifts of loudness judgement are calculated individually per sound as the difference between loudness ratings of a certain sound associated with a certain colour and the average rating of that sound regardless of colour. Then, the medians of the calculated shifts are taken for each colour over all sounds to obtain a global estimate of how much a particular colour influenced a subject. For rating methods following the principle of line length, the shifts in loudness judgement are absolute differences in cm, for methods using magnitude estimation relative shifts in percent are used.

Results are displayed as interindividual medians and interquartile ranges. Where applicable, analysis of variance and t-tests with Bonferroni correction are used to indicate statistical significance, with ∗ and ∗∗ representing thresholds of 0.05 and 0.01 respectively. Additionally, using hierarchical clustering (Ward method), the results were examined to find indications for groupings of subjects. For groups consisting of more than two subjects, additional analysis of variance and t-tests as mentioned above are calculated.

Specific colours used in the experiments are numbered sequentially and will be identified by c_i. The numbers i have no other specific meaning apart from uniquely identifying a colour.

USING DEPICTIONS OF OBJECTS

In this series of experiments, 15 colours were evaluated regarding their ability to influence loudness judgements when presented as abstract colour patches or as drawings of coloured radios (see also Menzel et al. 2009).

The 15 colours were combined with Uniform Exciting Noise (UEN) according to Fastl and Zwicker (2007, p. 170) with a duration of 1.5 s and levels between 50 and 80 dB in 5 dB steps. Loudness was rated using the principle of line length. Figure 1 shows the resulting shifts in loudness judgement (averaged over all sound levels) if the colours are presented as full screen colour patches.

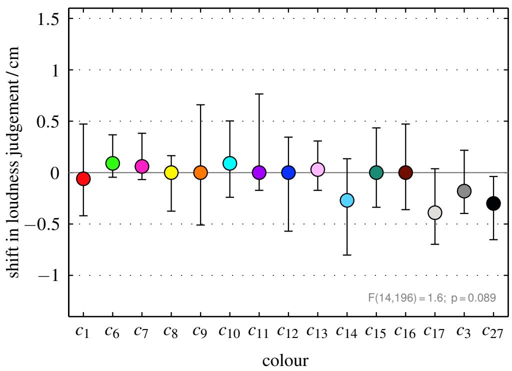

Figure 1: Change in loudness judgements of UEN (using a method of line length) combined with 15 colours presented as full screen patches.

It can be seen that colours with low chroma (i.e. "grey-like" colours), e.g. c_{17} ("grey"), c_3 ("dark grey"), and c_{27} ("black") seem to cause a slight decrease in loudness judgement, in this case measured in cm along the line. The effects of colour however were not significant.

In contrast to abstract colour patches, drawings of radios were chosen as depictions of everyday objects which are plausible sound sources and which are available in many different colours (see figure 2). If these stimuli are presented together with

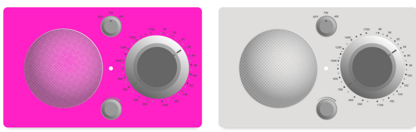

Figure 2: Examples of coloured drawings of radios. Colours: left c_7, right c_{17}

UEN, similar results as before are obtained, as shown in figure 3. Here, a significant difference between loudness ratings

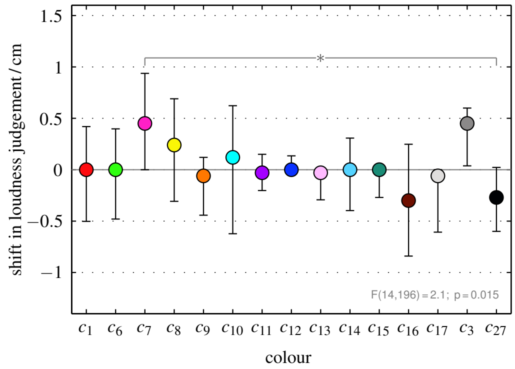

Figure 3: Change in loudness judgements of UEN (using a method of line length) combined with 15 colours presented as drawings of radios.

while viewing the radio coloured in c_7 (i.e. a very colourful hue with high chroma) and the radio coloured in c_{27} (with low chroma) can be seen. The use of objects in contrast to just presenting colour patches thus seems to cause a slight increase in the effect of colours, especially for colours with high or low chroma. In both cases, no clear grouping of subjects was evident.

STILL VERSUS MOVING IMAGES

In this set of experiments, still images and short video sequences of differently coloured cars were presented combined with appropriate car sounds. Subjects rated the loudness of the car sounds using free magnitude estimation.

Still images

Images of sports cars in four different colours were used (see figure 4, also Menzel et al. 2008). The original colour was c_{21} ("British Racing Green"). The sound of an accelerating sports car with a duration of 4 s was used as auditory stimulus. It was presented with sound levels of $L_{AF,max} = 78$, 82, 86, and 90 dB(A). The experiment was repeated in a second session with the same subjects.

Figure 4: Presented still images of sports cars. Colours (top left to bottom right): c_{18}, c_{19}, c_{20}, c_{21}

Resulting relative shifts in loudness judgements are shown in figure 5 for both sessions. As mentioned above, results per sound are averaged for each colour to obtain a global indicator of colour influences regardless of sound. In the first session (left), a significant difference between c_{18} and c_{19} can be seen. c_{19} caused a decrease in loudness rating of about 3% compared to the average rating of all colours. In the second session, c_{18} seemed to increase loudness ratings while c_{20} was associated with lower loudness judgements.

In both sessions, subjects could be clustered in two groups, which are shown in figure 6. The first group in the first session (top left) consists of two subjects with large colour in-

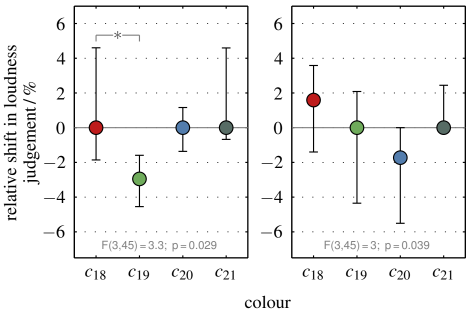

Figure 5: Relative change in loudness judgements of sports cars while viewing differently coloured still images. Left: session 1, right: session 2

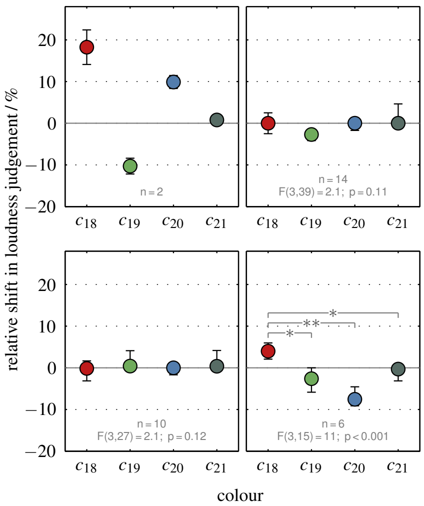

Figure 6: Grouping of subjects for loudness judgements of sports cars combined with still images. Data for session 1 (top row) and session 2 (bottom row) is shown separately.

fluences on their loudness judgements up to about 20%. The second group (top right) shows essentially the same behaviour as already mentioned for figure 5. Subjects in the second session can be split into ten subjects who on average are not influenced by the presented images (bottom left) and six subjects who show (highly) significant difference between their ratings for c_{18} and all other colours. Group membership was not consistent: one of the two subjects of the first group of the first session (with strong effects of colour, see figure 6 top left) showed no effects of colour in the second session (figure 6 bottom left).

Moving images

Short video sequences of a van passing by were used in this experiment. The videos were modified so that the car appeared in five different colours (see figure 7). The colour c_{22} ("pale green") was taken from Patsouras et al. (2002). The videos

Figure 7: Five images taken from video clips used in the experiment on moving pictures. Colours (top left to bottom right): c_1, c_6, c_7, c_{22}, c_{17}.

were recorded with a stationary camera and had a duration of about 5 s. Sounds of the shown vehicle and five other cars passing by were also recorded at the same location and combined with the video. The sounds had levels ($L_{AF,max}$) between 73 and 77 dB(A).

Shifts in loudness judgements occurring while viewing the moving audio-visual stimuli are shown in figure 8. Although no

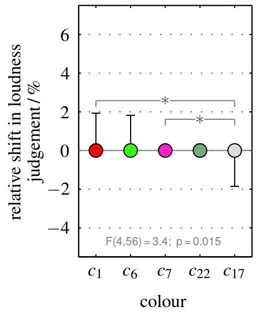

Figure 8: Relative change in loudness judgements of cars while viewing differently coloured video sequences of a car passing by.

differences can be seen according to the calculated medians, statistical analysis indicates different arithmetic means for colours c_1 and c_7 compared to c_{17}. This is also evident when examining the grouping of subjects for this experiment (figure 9). The first group with ten subjects shows no colour influence,

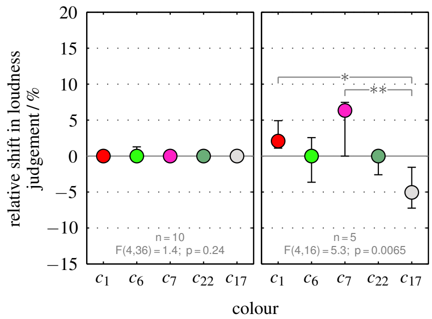

Figure 9: Grouping of subjects for loudness judgements of cars combined with differently coloured video sequences of a car passing by.

while the second group with five subjects rates sounds combined with c_1 and c_7 as louder compared to c_{17}.

Comparison

Qualitatively and quantitatively the presentation of moving images seems to be comparable to the presentation of still images for the purpose of eliciting influences on loudness judgements. In each case, larger groups of subjects could be identified who showed no effect of colour regarding their relative shifts in loudness judgement, while other groups exhibited effects similar to results found when using other optical stimuli (see e.g. figure 3). Especially colours like c_1 ("bright red") and c_7 ("bright pink") seem to cause higher loudness ratings.

SIZE OF THE OPTICAL PRESENTATION

In this section, experiments are described which examined loudness judgements made during the presentation of moving images on an LC display compared to the presentation on a larger projection screen.

Presentation on a monitor

Video sequences of trains passing by (duration 5 s) were recorded and modified to represent five different colours (see figure 10). Appropriate sounds of six trains passing by ($L_{AF,max}$ between 71 and 85 dB(A)) were used as acoustical stimuli.

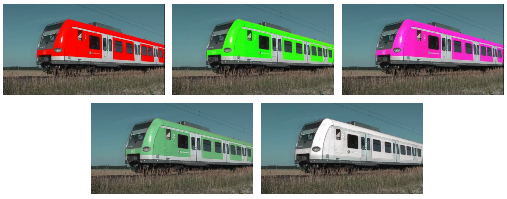

Figure 10: Five images taken from video clips used in the experiment on size of optical presentation. Colours (top left to bottom right) c_1, c_6, c_7, c_{22}, c_{17}.

Figure 11 shows the resulting shift in loudness judgement. On average, no influence of colour can be seen. As before, subjects could be clustered in different groups. In this case, three groups were found (figure 12). The first group with nine subjects again has no apparent effect of colour. The second group with four subjects however shows similar behaviour to the second group of figure 9, with higher loudness judgements for colours c_1 and c_7 compared to c_{17}. Three subjects form a third group with increased loudness ratings for c_6.

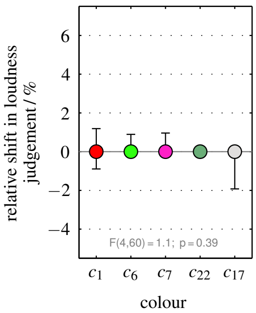

Figure 11: Relative change in loudness judgements of trains while viewing differently coloured video sequences of a train passing by shown on a monitor.

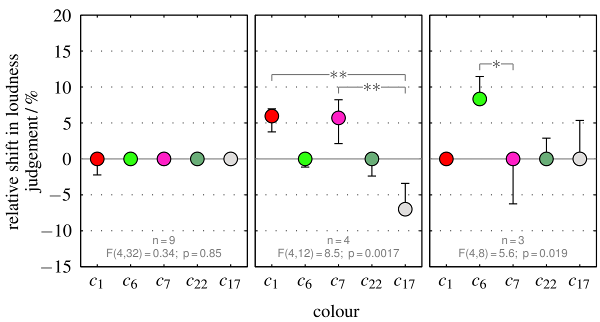

Figure 12: Grouping of subjects for loudness judgements of trains combined with differently coloured video sequences of a train passing by shown on a monitor.

Presentation on a projection screen

The same video sequences were now presented using a calibrated video projector (Epson EMP-TW700) and a screen with a diagonal of 2.6 m located in a darkened laboratory room. The viewing distance was 2.4 m. Sounds were again presented diotically through headphones.

Evaluating the results of all subjects shows no direct effect of colour, however large interquartile ranges can be seen in figure 13. The large variability can be explained when examining the grouping of subjects. A group of ten subjects were not influenced by colour (see figure 14), another group of six subjects had strong effects especially for c_7.

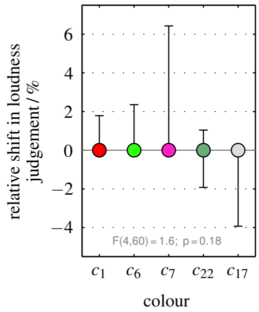

Figure 13: Relative change in loudness judgements of trains while viewing differently coloured video sequences of a train passing by shown on a larger projection screen.

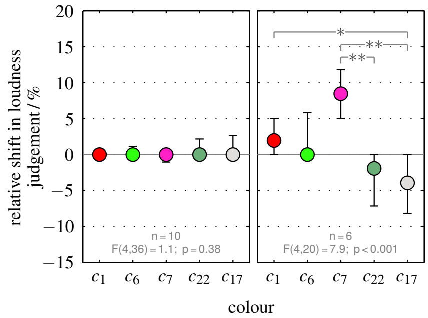

Figure 14: Grouping of subjects for loudness judgements of trains combined with differently coloured video sequences of a train passing by shown on a larger projection screen.

Comparison

For both modes of optical presentation, small and large, about 60% of subjects were not influenced by colours associated with the sounds. Other subjects showed effects corresponding to relative shifts in loudness judgement of up to 9%. A larger optical stimulus did not seem to increase the influence of presented colours. The colours c_1 ("bright red") and c_7 ("bright pink") again exhibit large influences on loudness ratings of those people who are affected by the optical presentation, eliciting higher loudness judgements. Additionally, c_6 ("bright green") was observed to also cause an increase in loudness rating for three subjects.

The grouping of subjects was relatively stable. All but one person who were part of the group which was not influenced by colours seen on a monitor (figure 12 left) also were part of the group not influenced by the projection of stimuli on a larger screen (figure 14 left). On the other hand, all subjects of the group who rated c_1 and c_7 as louder during monitor-presentation (figure 12 middle) also were members of the group which rated c_1 and c_7 as louder when presented with the enlarged optical stimuli (figure 14 right).

UNREALISTIC SCENARIOS

Contrary to the previously described studies, the aim of this experiment was to generate implausible or unrealistic optical stimuli. The confrontation of a subject with an unexpected implausible scenario might elicit different reactions regarding audio−visual interactions.

For this purpose, short video sequences of a waterfall were used. In addition to the original appearance of the waterfall, one plausible colouring (c_{22}) and three unrealistic colourings (c_1, c_{20}, c_7) were used (see figure 15).

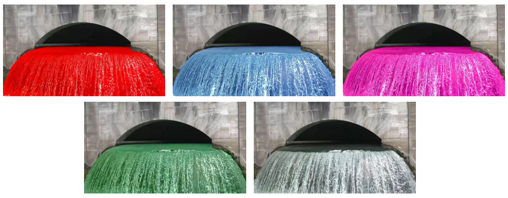

Figure 15: Five images taken from video clips used in the experiment on unrealistic optical stimuli. Colours (top left to bottom right) c_1, c_{20}, c_7, c_{22}, original

Combined with six recordings of different waterfalls ($L_{AF,max}$ between 63 and 74 dB(A)), and analysed over all subjects, no shifts in loudness judgement (as depicted in figure 16) were observed. Again, a grouping of subjects reveals two clusters,

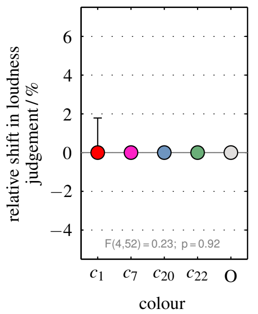

Figure 16: Relative change in loudness judgements of waterfalls while viewing realistically and unrealistically coloured video sequences of a waterfall.

the first with nine subjects and no colour influences, the second with five subjects and small effects (figure 17).

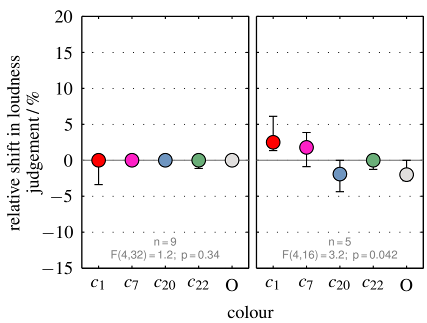

Figure 17: Grouping of subjects for loudness judgements of waterfalls combined with realistically and unrealistically coloured video sequences of a waterfall.

Three subjects of this second group previously showed no effects of colour regarding their loudness ratings. Perhaps these subjects normally concentrated more on the acoustical stimulus than on the images presented to them, so that now the unexpected colouring of the waterfalls caused increased attention to the visual modality and an increased interaction between the optical and acoustical modalities.

DISCUSSION

Compared to the presentation of abstract colour patches, the use of depictions of coloured objects seemed to cause slightly stronger effects especially between colours with high and low chroma. Regarding different modes of stimulus presentation (still vs moving images, size of image), comparable results were found: in each case, larger groups of subjects were not influenced by colours during their loudness judgements. However, in each experiment about one third of the subjects did show shifts in their loudness judgements which depended on the presented colours. The relative shifts were in the order of 2 to 9%, with c_1 (“bright red”) and c_7 (“bright pink”) often causing an increased loudness rating, and c_{17} (“grey”) and c_{19} (“light green”) associated mainly with lower loudness ratings. For the experiments involving coloured trains, subjects could be identified who consistently either did or did not show colour related effects. In other cases, e.g. loudness judgement of sports cars, subjects had no clear repeatable effect of colour. An unrealistic visual appearance might additionally draw attention to the optical stimulus and cause subjects, who otherwise were not influenced by colours, to exhibit increased audio-visual interactions. Results of Patsouras et al. (2002) and Rader et al. (2004) could only be replicated if the grouping of subjects was taken into account.

ACKNOWLEDGEMENTS

This work is supported by Deutsche Forschungsgemeinschaft by grant FA140/5.

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