Interaction of color scheme and noise in the metro interior. Multisensory evaluation and subjective testing

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ABSTRACT

In this paper the results of research, aimed at investigation of the acoustic comfort on board of urban transport systems are presented. A large segment of the research is devoted to the experimental analysis and evaluation of the interaction between the metro car interior color and noise perception, through the use of virtual reality and subjective tests. Several studies showed that vision and audition instead of being independent modalities interact in complex ways. The results of this research showed that, despite of expectations of the interaction of sound and colors impacts on personal judgments, evaluations given to the interior colors were influenced only by the color scheme. Sound environment perception was influenced only by the noise factor.

1. INTRODUCTION

Acoustics is an important component determining the passenger satisfaction. Recently several attempts to assess acoustic comfort aboard rail transport were carried out. Most of them were focused on acoustic parameters and subjective annoyance [1- 4]. Generally during the tests participants were seated in a laboratory room and listened to prerecorded metro or high speed trains sounds, presented through loudspeakers or headphones, indicating their opinion. Usually they were asked to imagine being aboard [3] while seated in a laboratory room [5]. However, these procedures reproduce environmental information in a simplified way and do not take into account the multisensory nature of human perception: sounds are presented to participants without contextual visual scenarios. There is a large body of research showing that vision and audition instead of being independent modalities interact in complex ways [6 - 8]. In our previous study [9] we have seen that visual components seem to modulate the impact of noise on cognitive performances and self-report evaluations. As regards the sound intensity assessment, some researches have shown that visual factors, such as colors, can modulate loudness judgments. For example, colors like red or pink seem to increase perceived loudness, whereas grey or pale green seem to decrease it [10]. In another study, instead, no influence of train color on loudness evaluation was found [11].

In this paper, the investigation of the acoustic comfort on board metros is described. A large segment of the research is devoted to the experimental analysis and evaluation of the interaction between the metro car interior color and noise perception through the use of innovative technology of virtual reality and subjective tests.

The article will cover following steps of the research:

- Survey of existing metro interior colors,
- Interior chromatic solutions design and selection,
- Audio stimuli selection for the experiment,
- Virtual reality design for experiment,
- Immersive Virtual Reality experiments,
- Data analysis and conclusions.

2. SURVEY OF EXISTING METRO INTERIOR COLORS

First of all, to study a current situation of colors utilization inside metro cars, a survey on 150 existing metros was fulfilled. The interior photographs of metro carriages from all over the world were downloaded from the official sources - websites of metros. The survey has shown that in most cases white color was used for the internal side panels, white or grey colors were prevalent for the metro doors (Figure 1); dark tints were used on the floor of carriages: grey, brown, dark blue, black; while the variety of colors were utilized for the chairs: brown, green, black, grey, red and blue, the last one was the most used (30% of metros). As for the accessories, the yellow color is added to the majority of neutral grey and white hues. That is done considering the needs of visually impaired passengers in order to clearly identify important accessories, such as railings, with strong color contrasts.

The conducted survey has shown that not always the interior colors were fairly equilibrated between each other, especially as regards the old metros. The preference of neutral hues choice

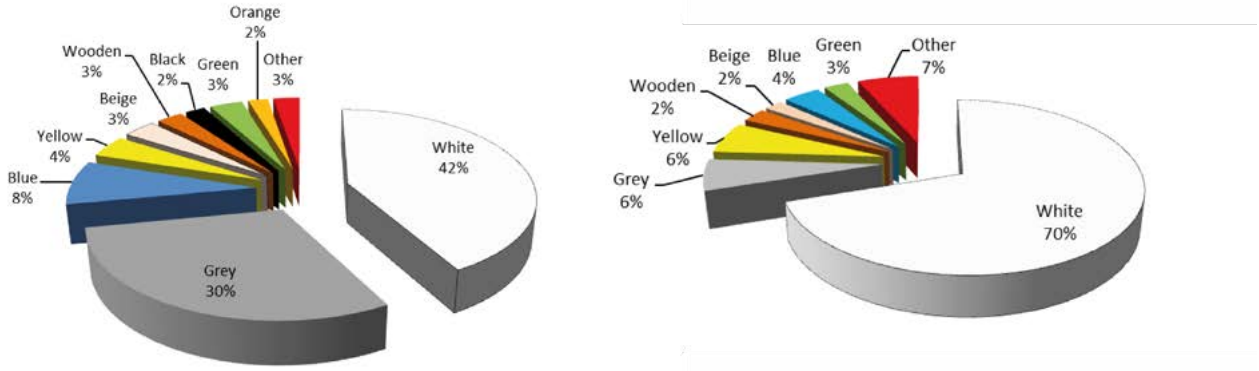


Figure 1 - Statistics on side panel (left picture) and doors (right picture) colors used in the metro interiors

for most elements seems to be quite traditional. It could be caused by the specific materials availability and practicalness, as well as the desirable in public transport means sensation of calmness. But in some cases the neutral colors could evoke the sensation of boredom. Therefore it is necessary to fulfill a subjective evaluation of the internal scenarios. For the research goals it was decided to create several not very typical chromatic dimensions to investigate the reactions of people and to estimate their visual, acoustic and complex comfort.

3. INTERIOR CHROMATIC SOLUTIONS DESIGN AND SELECTION

To propose new interior chromatic solutions for the Immersive Virtual Reality (IVR) tests, a wide study was performed. Forty color palettes from the guidebook [12] were taken as a starting material. They were thoroughly examined on kind of sensations and psychological reactions the different colors combinations should evoke in the people's mind (e.g. calmness or vivacity).

Concept: **Tranquil**	Name: **Beige**	Used colors
		R224 R198 R131 R30 G222 G188 G132 G30 B216 B137 B122 B30
		Tranquil colors invite the viewer to ponder, to daydream and relax. Hues with short wavelengths, such as blue, blue-violet, and blue- green, enter the eye easily and require little energy to process in the brain resulting in a decrease in metabolic rate. Warm neutral colors connote comfort and safety; warm grays are particularly relaxing and offer the added indeterminate quality of that neutrality as an invitation to thoughtfulness. When using colors in combination, a serene quality is imparted by keeping the values of adjacent colors similar, so their edges appear to soften.
Concept: **Innovative**	Name: **Blue**	Used colors
		R224 R206 R142 R0 G222 G214 G144 G53 B216 B75 B143 B45
		The innovative color consists mainly in the search for combinations that haven't been imagined yet, such as the hues which are situated far away from each other on the color wheel, or which appear to have no harmonic relationship: violet and green, blue-violet and brown, olive green and neutral gray. Even the color combinations that have historically been labeled as "gaffes chromatic" give the idea of breaking the tradition for searching for something new. Ultra-bright colors, which refer to the technology as a part of the base of combination, create a contrast effect that may represent a futuristic vision.

Table 1 - Elaborated color schemes

The practicalness and adequacy of their use in the metro environment was also considered. More than thirty design solutions were elaborated by means of Photoshop. The pictures of simulations were proposed to design experts and to ordinary people to get their judgments and suggestions. Finally, four color palettes were selected: tranquil, innovative, corporative and multicultural. Selecting the colors from these chromatic palettes, several color schemes were elaborated for the metro experiments. Considering the security needs, the exit from the car was always emphasized by the doors or other elements color that differed from the side panels. Four chromatic dimensions chosen for the test are represented in the Table 1[12].

4. AUDIO STIMULI FOR THE EXPERIMENT

Binaural audio signals (16 bit/44.1 kHz) which were recorded by a portable two-channel device "M-Audio Microtrack 24/96" and binaural headphones "Sennheiser Noise Gard HDC 451" during the trips in world great cities' metros were used as basic acoustic material for the test. Three soundtracks with different loudness were chosen for this experiment: the quietest one, Berlin S3, which was however characterized by the presence of soft rattling noise; the noise of Turin VAL, belonging to the rubber-tyred metro systems, and the loudest one, Naples L1.

The parts of soundtracks between two successive stations, with duration approximately one minute, were extracted from the original sound records of these three metro lines. Each soundtrack was analyzed in terms of Equivalent noise level (Leq), Loudness (N), 5 percentile Loudness (N5), Sharpness (S), Roughness (R) and Fluctuation Strength (FS), and Psychoacoustic Annoyance (PA) [13] was calculated for each track, the data are reported in Table 2. Values are the average of the left and right channels.

Concept: **Corporate**	Name: **Yellow**	Used colors
		R201 R251 R92 R151 R30 G202 G212 G127 G35 G30 B200 B118 B146 B63 B30
		The gray and blue are the favorite corporate colors, which communicate to the public the essential business qualities of competence, reliability and calmness. The red, tending to burgundy, adds a sense of power to reinvigorate the neutrality and reliability of gray and blue and also contains authorities and vitality. The deeper greens and soft violets bring respectively a feeling of growth and economic status or royal authority. The gray, combined with a variety of colors makes them look more sophisticated and unified. Combining several similar hues of the same value and with a reduced saturation, is used to create a sensation of elegance, of submission and control.
Concept: **Multicultural**	Name: **Red**	Used colors
		R209 R55 R196 R129 G212 G66 G38 G138 B211 B74 B46 B143
		The multicultural color schemes can be severely limited or fairly open in terms of number and variety of colors they use. A reduced palette composed of gray, black, white, red and golden yellow represents a common approach to a design that should be as international as possible. A wide range of mixed colors in a very essential presentation can transmit an idea of a mixture of numerous kinds of visual tradition. In the combination of colors with similar value, the interaction of hue is emphasized and more openly expresses their cultural union.

Table 1 - Elaborated color schemes

Table 2 - Characteristics of noise tracks chosen for the experiment.

Noise track	Leq, dB(A)	N, soneGF	N5, Sone	S, Acum	R, cAsper	FS, cVasil	PA
1. Berlin S3	64,10	15,56	20,92	0,99	25,29	24,44	24,29
2. Naples L1	80,53	35,96	64,33	1,05	30,86	39,73	73,45
3. Turin VAL	73,45	30,10	37,23	1,19	28,12	22,34	42,16

5. VIRTUAL REALITY DESIGN FOR EXPERIMENT

3D graphic virtual reality scenarios of a metro and platform were created. The graphic model was designed by means of Google SketchUp 7.0 software, simulating geometrical constructions according to actual dimensions, and elaborated color schemes. The virtual metro train was composed of two coaches attached to each other. Along the virtual platform several avatars simulated passengers waiting for the train. In the metro coaches some avatars appeared seated and some were standing (Figure 2). The WordViz software for virtual reality development allowed the simulation of the train movement, opening/closing of doors and the changing of environment outside the metro coach during the tunnel passage. As well, the sounds from the chosen tracks of acoustic signals were inserted. Twelve virtual scenarios were organized to test all the combinations of color schemes and noises (four color schemes vs. three noise tracks). Following names were given to the color schemes for convenience: the first color scheme – Beige, the second one – Blue, the third – Yellow and the fourth – Red.

6. IMMERSIVE VIRTUAL REALITY EXPERIMENTS

6.1. EXPERIMENT LOCATION AND INSTRUMENTATION

The IVR experiments were carried out in the Built Environment Control laboratory Ri.A.S. of the Second University of Naples, in a room arranged for the IVR subjective testing (Figure 3). The IVR set includes a work station supplied with software Vizard 4.0 and linked to the following devices: eMagin Z800 3DVisor, Polhemus PATRIOT, position tracking and 3D digitalizing system and Pioneer Bass Boost headphones.

6.2. TEST PROCEDURE

During the test participants were submitted to twelve scenarios, described supra, representing virtual journeys between two metro stations. Before starting the test, participants were asked to pay attention to the color schemes of the interiors and sounds they perceive, and feeling of comfort or discomfort they got. During the journey they could seat or stand, turning the head and moving normally in the virtual environment. The order of presentation of the scenarios was quasi-randomized and counterbalanced within

Figure 2 - A metro train model designed in Google SketchUp (section).

Figure 3 - Participants in the laboratory of IVR testing.

each subject and across subjects. At the end of each scenario participants were required to fill in a self-report questionnaire in Microsoft Excel. In this questionnaire they expressed their judgements on the interior colors, sounds and overall atmosphere, estimating sound volume and annoyance.

6.3 SUBJECTIVE ASSESSMENT

The subjective assessment of every scenario was fulfilled by means of specially elaborated questionnaire in Italian, divided into the following categories: interior colors assessment, sound volume rating and sound annoyance rating, and overall opinion of the scenario environment. The interior colors assessment and overall assessment were carried out by means of Semantic Differentials (SDs). Several seven-point bipolar scales were elaborated for the description of sensations provoked by the metro. Participants chose the correct ones according to their ratings from the window of multiple choice. The sound volume and noise annoyance of each scenario was evaluated by means of the scrollbar on which the participants could choose the value corresponding to their opinion. The sound volume was quantified from 0 («very low») to 100 («very high»), and sound annoyance was quantified from 0 («not at all») to 100 («greatly»).

6.4. PARTICIPANTS DESCRIPTION

32 persons (16 males and 16 females) recruited from the students and personnel of the Second University of Naples participated voluntarily in the study. Mean age of the participants was 25.4, SD = 3.9 (range 19 to 42 years). All participants reported normal hearing and normal or corrected to normal vision.

7. DATA ANALYSIS

7.1. INTERIOR COLORS ASSESSMENT

The mean values of the SDs estimating internal colors are represented on the graphs in the Table 3. The scores of all three metros were averaged. To analyze the effects of Scenarios on mean values of six SD internal colors assessments, two 3×4 ANOVAs that treated noise as three-level within-subject factor and color as four-level within-subject factor, was carried out. The results showed that no one of the SD variables was influenced by the metro noise factor: D1: $F(2, 9) = 1.71$, $p = .24$; D2: $F(2, 9) = 0.47$, $p = .64$; D3: $F(2, 9) = 0.55$, $p = .59$; D4: $F(2, 9) = 0.28$, $p = .76$; D5: $F(2, 9) = 0.23$, $p = .80$; D6: $F(2, 9) = 0.60$, $p = .57$.

The semantic differentials were influenced by the color scheme. The analysis revealed that: the Beige metro was judged more relaxing than Blue one; Beige color scheme was more harmonious than Blue and Yellow, and Red color scheme was evaluated as more harmonious than Blue one. Beige metro was more equilibrated than Blue and Yellow, Beige and Red metros were assessed as more adequate than Blue, and, finally, Red color scheme was rated as more familiar than Beige and Yellow ones.

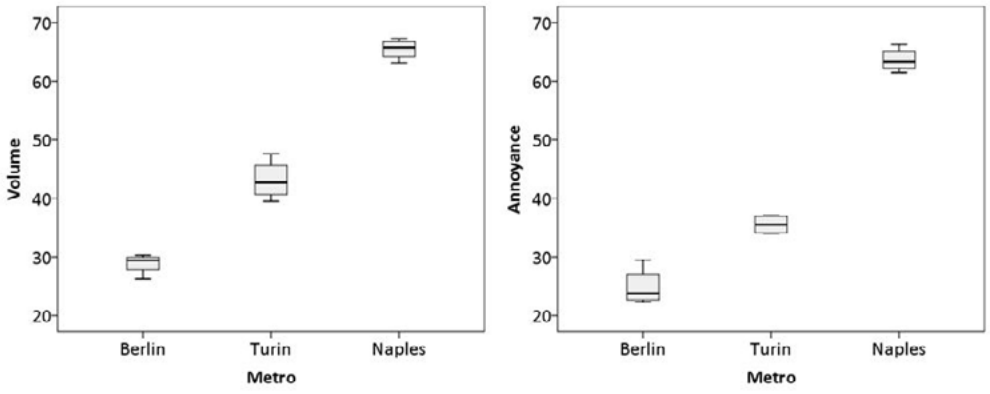


Figure 4 - Mean values of subjective assessments of Sound Volume and Annoyance for three metro noises

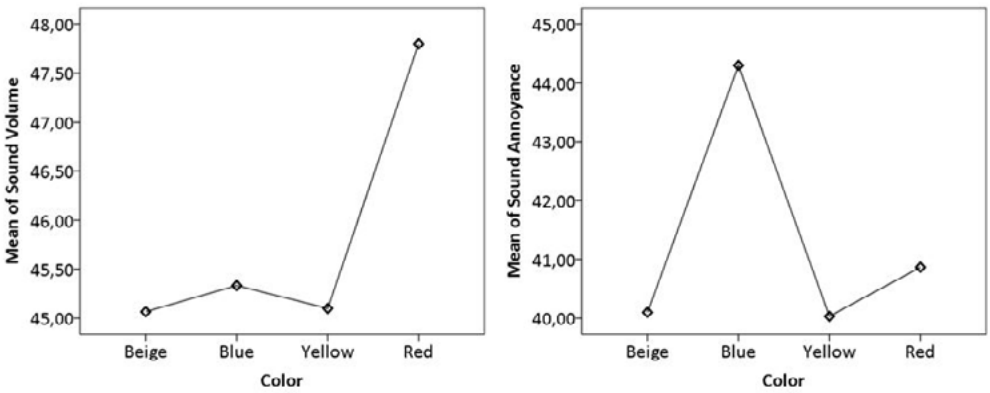
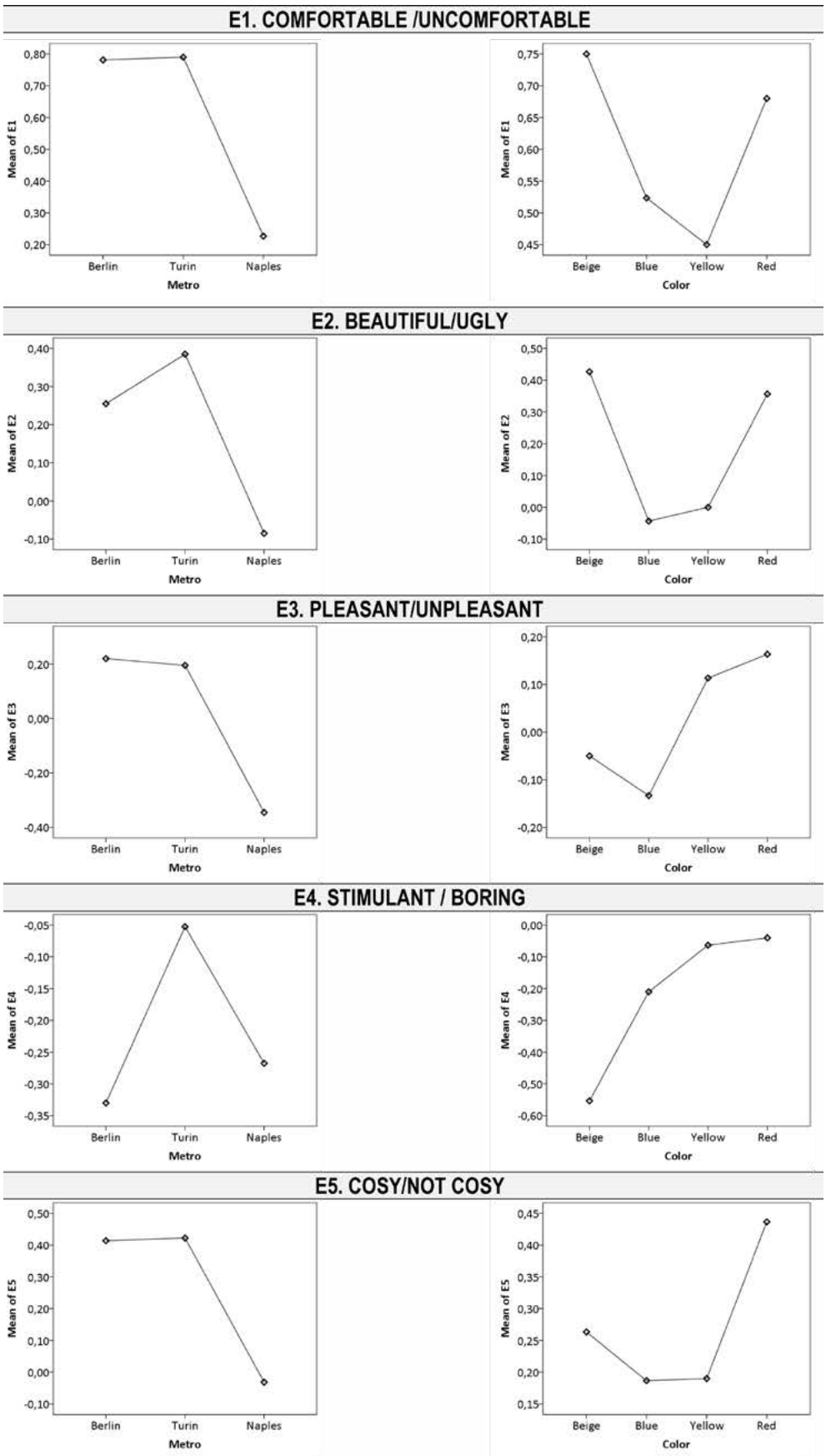


Figure 5 - Mean values of subjective assessments of Sound Volume and Annoyance for four color schemes

Table 3 - Mean values of semantic differentials for overall metro environment assessment.



7.2. ESTIMATIONS OF SOUND VOLUME AND SOUND ANNOYANCE

On the Figure 4 the average for four color schemes values of Sound Volume (left) and Annoyance (right) estimation of three metros are depicted by means of box-plot diagrams. From these diagrams we see that the assessment seems to be strongly correlated with Leq. The average values of these assessments for four color schemes, cumulative for all metros are represented on the Figure 5.

To analyze main and interactive effects of

Scenarios on subjectively assessed Sound Volume and Annoyance, two mixed factorial 4×3 ANOVAs that treated a color scheme as four-level within-subject factor and metro noises as three-level within-subject factor was carried out. The results showed that Sound Volume was influenced only by the noise factor $F(2, 62) = 84.50$, $p<.001$, $\eta_p^2 = 0.73$. There was no color scheme effect $F(3, 93) = 0.526$, $p = .665$, $\eta_p^2 = .017$. The effect of the noise-color interaction was not found $F(6, 186) = 0.852$, $p = .532$, $\eta_p^2 = .027$. And similarly, for the Sound Annoyance, the results showed that it was influenced only by the noise factor $F(2, 62) = 46.52$, $p<.001$, $\eta_p^2 = 0.60$. There was no color scheme effect $F(3, 93) = 0.97$, $p = .41$, $\eta_p^2 = .03$. The effect of the noise-color interaction was not found $F(6, 186) = 0.24$, $p = .96$, $\eta_p^2 = .008$.

7.3. ESTIMATIONS OF OVERALL ENVIRONMENT

The scores for the SDs estimating overall environment are represented on the graphs in the Table 3. In the left column of the table values, averaged as a function of metro are depicted, while in the right one the values averaged as a function of colors are given. So we can easily see, for example, that metros with color scheme number 4, called «Red» were judged as more stimulating, while metro environments characterized by the Naples' metro noise, were assessed as more unpleasant and uncomfortable then others.

To analyze main and interactive effects of Scenarios on Overall Metro Environment estimation, a mixed factorial 4×3×2 ANOVA that treated a color scheme as four-level within-subject factor, metro noises as three-level within-subject factor and gender of participants as two-level between subject factor, was carried out. The results showed that the assessments of Comfort, Beauty, Pleasantness, and Coziness were influenced by the noise factor. In all these cases the Naples metro ratings were lower than those of Berlin and Turin. Instead, the assessment of Stimulation was influenced by the color factor. The Beige metro was judged as the most boring.

8. CONCLUSIONS

The results showed that evaluations, given to the interior colors were influenced only by the color scheme. Sound Volume and Sound Annoyance estimations were influenced only by the noise factor. The overall metro environment assessments of Comfort, Beauty, Pleasantness, and Coziness were influenced by the noise factor, while Stimulation was influenced by the color factor. The Beige metro was judged as the most boring. In all these cases the Naples metro ratings were lower than those of Berlin and Turin. No gender effect on overall metro environment estimation was discovered.

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