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Original Contributions - Originalbeiträge

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Synaesthetic Interactions between Sounds and Colour Afterimages: Revisiting Werner and Zietz's Approach

1. Introduction: The Influence of Sounds on Colour Afterimages

In his seminal paper of 1934, 'L'unité des sens', the Austrian psychologist Heinz Werner formulated his radically antielementistic approach to the study of intersensorial perception. According to Werner, many effects of sensory interactions would merge on the existence of perceptual qualities that belong to different sensory modalities, such as intensity, clarity, brightness, acuity, roughness, softness, warmth, motion, etc. When observers are presented with simultaneous events that share one of such common attributes, an effect of synergy would occur by grouping them, and their qualities could be intensified. For instance, it has been showed that a sound with dynamic qualities can improve the perception of a hardly noticeable stroboscopic movement (Zietz & Werner, 1927; Parovel, Bozzi, & Agostini, 1997).

To support this conjecture, Werner (1934) reported and discussed also some findings of mutual influence between sound and colour. In their experiments made in Hamburg Institute (Zietz, 1931; Werner, 1934), for instance, Zietz and Werner presented some observers with coloured circles to induce the corresponding afterimages, which were seen alone or simultaneously with low and high tones, and reported the qualitative descriptions obtained in the different audio-visual conditions. According to Werner and Zietz (Zietz, 1931; Werner, 1934), for instance, for all subjects, colours disintegrate at the hearing of a low sound and concentrate for a high sound. More generally, different pitched sounds change in specific ways the appearances of the colours of the afterimages.

This phenomenon has never been replicated, as far as we know. Therefore, it seemed to us particularly stimulating and theoretically significant to explore more deeply this synaesthetic effect, also in the light of the current knowledge on audio-visual integration, which we will report briefly. Then we will describe the main results obtained through a pilot study carried out with the aim of investigating this effect through a psychophysical methodology.

1.1. Perceptual and cognitive integration between sounds and colours

Anticipated by the intuitions of artists and scientists such as Kandinsky, Goethe, Munsell and Itten, in his writings Werner argued that audio–visual interactions between colour and sounds are possible not only in synaesthetes, but might be common in all of us. Nowadays too, many studies showed that there are strong analogies between the nature of synaesthetic experiences and those reported by non-synaesthetes in imagery, matching tasks or crossmodal interference paradigms (Marks, 2004; Ward, Huckstep, & Tsakanikos, 2006), suggesting the existence of common processes between synaesthetic perception and audio-visual processing of non-synaesthetes (Goller et al., 2009).

Several reviews of the literature on crossmodal correspondences in non-synaesthetes (e.g. Calvert et al., 2004; Martino & Marks, 2001; Spence, 2011; Parise & Spence, 2013) support the fact that normal populations make significant and non-arbitrary associations between certain dimensions of colour and sounds. For example, crossmodal correspondences have been demonstrated between both pitch and loudness in audition and lightness and brightness in vision (Marks, 1974; Marks, 1987; 1989; Hubbard, 1996; Martino & Marks, 1999; see also Melara, 1989); between saturation of colour and timbre; and between visual size and sound duration (Caivano, 1994). Evans (Evans & Treisman, 2010) demonstrated that there were strong crossmodal correspondences between auditory pitch and visual location, size and spatial frequency. Simpson, Quinn, and Ausubel (1956) investigated the correspondence between hue and pitch in children and found that a high-pitch was more likely to be associated with yellow, whereas a midlevel pitch matched orange and a low-pitch blue. Sun et al. (2018), also, recently showed that pitch and tempo associate with colour (hue, lightness, saturation). For example, high-pitch is associated with red, yellow and light colour, whereas low-pitch is associated with blue and dark colour.

Other findings have been the association of different hues or brightness of colours to different emotional music, for instance, dark colour to music in minor tonality and light colours to music in major tonality (Bresin, 2005), and effectively emphasised the significant role of emotional meanings in matching between music and colours (Palmer et al., 2013).

From a methodological perspective, even if audio-visual integration has been mostly explored through the crossmodal matching between sounds and colours, several scholars investigated how crossmodal correspondences influence the speed and the accuracy of human information processing (Bernstein, Eason, & Schurman, 1971; Marks, 1987). For instance, subjects perform more quickly and accurately with 'matching' stimuli than 'mismatching' stimuli from the two modalities (Marks, 1987), and other researchers carried out similar experiments using the speed discrimination task (Marks, 1989; Melara, 1989; Hubbard, 1996; Gallace & Spence, 2006). According to Parise and Spence (2009), both the temporal and spatial aspects of multisensory binding are enhanced when crossmodally congruent, as compared to incongruent, pairs of auditory and visual stimuli are presented to participants.

Also, electrophysiological research suggested that certain forms of crossmodal correspondence between auditory and visual stimuli would result from the peculiarities of the neural systems and can influence performance at a perceptual level (e.g. Kovic, Plunkett, & Westermann, 2009). Additionally, other forms of correspondence appear to operate at a more decisional level and, according to Bayesian integration theory (Ernst, 2007), may reflect the internalisation of the statistics of the natural environment. In this view, crossmodal correspondence would indicate an adaptive response by our brains to the regularities of the world in which we live (Marks, Ben-Artzi, & Lakatos, 2003; Maeda, Kanai, & Shimojo, 2004; Smith, Grabowecky, & Suzuki, 2007; Parise & Spence, 2009).

More generally, all these findings highlight the importance of crossmodal correspondences to both low level and higher levels human processing.

1.2. The Zietz and Werner's target: Obtaining intersensory effects in non-synaesthetes

The approach proposed by Zietz and Werner in the '30s, while being a precursor from a theoretical point of view of the integration between senses, differs substantially from the studies described above from a methodological point of view. According to Werner, in fact, it was possible to reproduce experiences very similar to synaesthesia in non-synaesthetes. The goal of these authors was not to identify a correspondence between certain dimensions of sound and others of colour, or to measure the interference of one sensory modality on the other through specific experimental tasks, but to find the conditions that allow all subjects to *directly perceive* the effect of sound on colour.

We will briefly summarise this theoretical view. According to Werner (1934), it is not possible to obtain evident audio-visual intersensory effects on chromatically stable surfaces, but they can be obtained using transient and fluid phenomena, such as for example unsaturated colours, tachistoscopic images and afterimages. Colours or sound to be effective must not be 'objective' phenomena; they must have the character of 'states'.

Every perceptual experience, suggests Werner, originates in a common synaesthetic layer, before any separation into distinct spheres of sensibility. The intimate connection of the senses, the existence of intersensory qualities such as clarity, intensity and roughness: all this is based on the fact that the psychophysical organism reacts in its totality. 'There are cases where the subjective impression of colour dissolves so well in a bodily reaction that there is no longer any trace of optical *matter*, that the subject can no longer even tell to which modality it belongs, if it is optical or acoustic in nature. We can therefore call this layer of subjective states of consciousness the synaesthetic layer.' (Werner, 1934, p. 166). 'For example, if I present very weak, unsaturated colours, many subjects first feel the colour as a pure bodily reaction. When presented with a very pale blue, one subject said he barely recognized it "with his eyes". It goes down into the body; it cannot therefore be green, which for me is localized at the top, it can only be blue.' (Werner, 1934, p. 166).

Thus—comments Werner describing the protocols of Zietz's experiment—the colour of an afterimage can be modified by a sound, only if the colour is congruent with a bodily and dynamic attitude that responds to this sound. 'An example: a yellow-green afterimage focuses on hearing a high-pitched sound; it takes on a precise outline and becomes golden yellow.' (Werner, 1934, p. 169).

In their researches (Zietz, 1931; Werner, 1934), the authors produced some colour afterimages alone or together with low and high tones, and reported the changes in the quality of colour described by each participant. A consecutive image was created by staring at a coloured circle (5 cm in diameter; red, orange, green and blue) for 30 s in a darkened room. The model was a coloured disc that was illuminated from the inside like the front wall of a box (Zietz, 1931). The instructions recommended not to listen to the sound just as a side effect but to absorb it deeply, and to 'try to relate the sound to the impression of colour, feeling it, so to speak, in the colour'.

The results, based on the participants' qualitative descriptions, showed that with the low tone (200 hz), the colour generally becomes darker, warmer, softer and sometimes even more intense and purer. Moreover, for all subjects, colours disintegrate at the hearing of a low sound and concentrate for a high sound. More specifically, and coherently with the reviewed literature (see for instance Sun et al., 2018), with low-pitched sounds, red becomes dark red/purple, whereas with high-pitched sounds, the red tends towards orange/yellow. With low-pitched sounds, green becomes blue green, blue, with a purple border, whereas with high-pitched sounds, it becomes light green, yellow.

2. The Present Work

We ran a pilot experiment to explore, using a new psychophysical method, the hypothesis proposed by Zietz and Werner in the '30s, that a sound presented simultaneously with an afterimage can change its phenomenal appearance in non-synaesthetes. As this is an exploratory research that adopts a new methodology specially designed to collect the immediate impressions of the participants as they observe the afterimages, the number of subjects is reduced and the results will be presented and discussed only from a qualitative point of view.

We chose to test afterimages elicited by the prolonged observation of four colours—Blue, Red, Green and Yellow—that are antagonistic each other, as the opponent process theory states (Goethe, 1808/2008; Hering, 1878/1964; Hurvich & Jameson, 1957). Sound tracks are obtained by synthesiser. We chose low- and high-pitched tones and bass and soprano (synthesised human voices); 110 Hz was chosen for low-pitched tones and bass, whereas 1,760 Hz for high-pitched tones and soprano, and these were compared to a silent control condition.

2.1. Methods

2.1.1. Observers

Ten observers participated to this experiment (5 males and 5 females). They were all undergraduate or graduate students of the University of Trieste who had no knowledge of the purpose of the study. They had normal or corrected-to-normal vision. No observer reported colour-blindness.

2.1.2. Apparatus and stimuli

All the conditions were tested by using a PC (Asus UX310 U) with Windows 10 controlling a MSI Optix G241VC monitor. Sounds were administered through headphones (Sony MDR-XB950). There were four coloured squares (Blue, Green, Red and Yellow). The side of each square measured on the screen was 10 cm, corresponding to a visual angle of about 11° (see Figure 1). The four squares generated four afterimages, each of which was perceived together with four different sounds (bass, soprano, low- and high-pitched tones) plus a control condition 'no sound'. Each condition was presented twice for a total of 40 presentations.

The dependent variable was measured by a linear sliding digital potentiometer. The custom-made slider is comprised of a linear potentiometer between 0 kΩ and 10 kΩ, supported by a 3D-printed custom platform fixed with tape to the experiment desk. The potentiometer is connected to a programmable device, Arduino UNO. The programmable unit converts the analogue signal to digital data (with a total resolution of 1,024 points and 200 samples per second) and through a USB cable sends it to the laptop with a dedicated custom .NET app. The app is capable of playing the selected video on the experimental monitor and the sound into the earphones. The app could also save the potentiometer data on the computer hard drive and synchronise it with the start and end of the video.

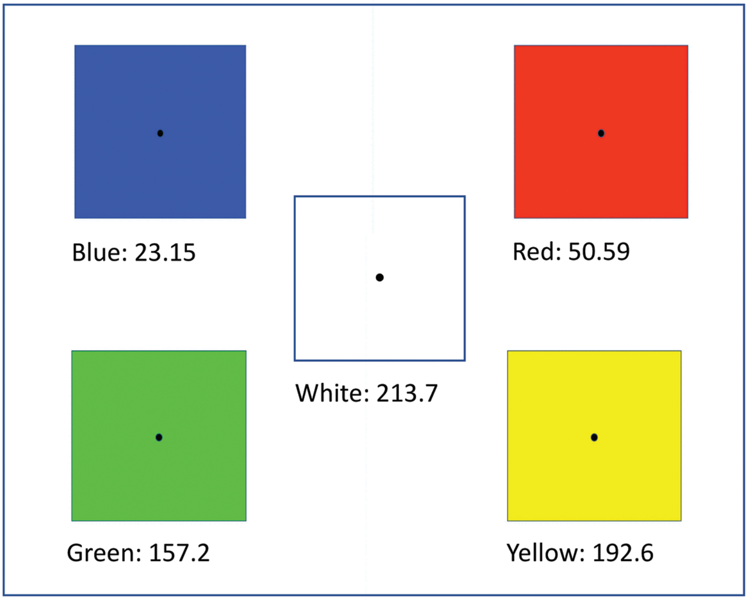

Fig. 1. Luminance values measured for each colour stimulus and for the empty frame.

2.1.3 Procedure

Observers waited in a normally illuminated area. They were than taken into a dimly illuminated experimental room. The subject sat comfortably 50 cm away from the screen. The centre of the screen was placed at eyes' height. The dominant arm of the subject operated the custom slider with the index finger, and the slider was placed on the monitor's desk at about halfway distance between the subject and the screen. The room was kept dark, except for the monitor glow, and there were no external noises during the experiment.

Before starting the experiment, observers had to read the instructions, where the procedure was explained. Then, they were placed in front of the monitor and asked to wear the headphones. In sequence, one at a time, the selected colours were displayed on the screen within a square delimited by a narrow black frame with a black dot located in the centre. The frame and the dot were present in all the conditions. Observers were asked to look at the black dot trying to move their eyes as little as possible.

After 30 s, the colour disappeared from the screen, leaving visible only the frame and the dot on a white background. At the same time, the corresponding sequence sound starts to play in the headphones. The sound and the black dot will disappear after 30 seconds. The slider recording is stopped after ten additional seconds, for a total recording time of one minute and ten seconds. For each one of the selected colours, all the observers reported having perceived the corresponding afterimage. Their task was to adjust the cursor placed horizontally on the table top in accordance with the change of perceived saturation of the afterimage. If the perceived colour saturation increased, they had to move the cursors forward, and if it decreased they had to move it backwards, setting the cursor to zero when the afterimage disappeared completely. They had to repeat the same procedure for all the conditions. In total, for each observer, the experiment lasted about 40 min. The colours were presented in five sequences, according to increasing luminance (Blue ⇒ Red ⇒ Green ⇒ Yellow). The first sequence was presented without sound, whereas the other four were presented together with the sound tracks (low-pitched tones ⇒ high-pitched tones ⇒ bass ⇒ soprano).

2.2. Results

Overall, the results of this exploratory experiment run within a small sample of subjects indicate that a sound presented simultaneously with a coloured afterimage can affect the perceived colour saturation and the decay time of the afterimage, although the effects vary depending on the inducing colour and the type of sound. In particular, these first findings suggest a stronger effect of the low-pitched tone on the decay of the afterimage in comparison with the other sounds. This effect is particularly evident with the Yellow stimulus (i.e. inducing a blue/violet afterimage). Figure 2 shows the average path of each colour in the different sound conditions for all the subjects.

As regards the Red stimulus, the recordings show that the subjects tend to report a faster negative change in perceived colour intensity in absence of any sound, and with sound stimuli assuming the forms of bass and low-pitched tone.

As regards the Green stimulus, the presence of sound hardly substantially alters the decay time of the afterimage, except for sound stimuli assuming the form of low-pitched tone, in which case there is a tendency to have a faster drop in the initial phase; however, in the second half, a slower negative change is recorded than with the other sound stimuli.

The Yellow stimulus' afterimage is the most affected by sounds. Subjects tend to perceive a distinctly faster negative change in colour intensity only with the low-pitched tone sound stimulation, whereas on the other end of spectrum, the soprano sound elicits a slower negative change.

Conversely, the recordings concerning the stimulus with the colour Blue show a sudden drop, meaning an extremely faster negative change in perceived colour intensity. Sound stimulation does not alter this trend in any way. A possible explanation to better understand this last result can be found in the fact that the afterimage induced by the prolonged observation of Blue corresponds to a very

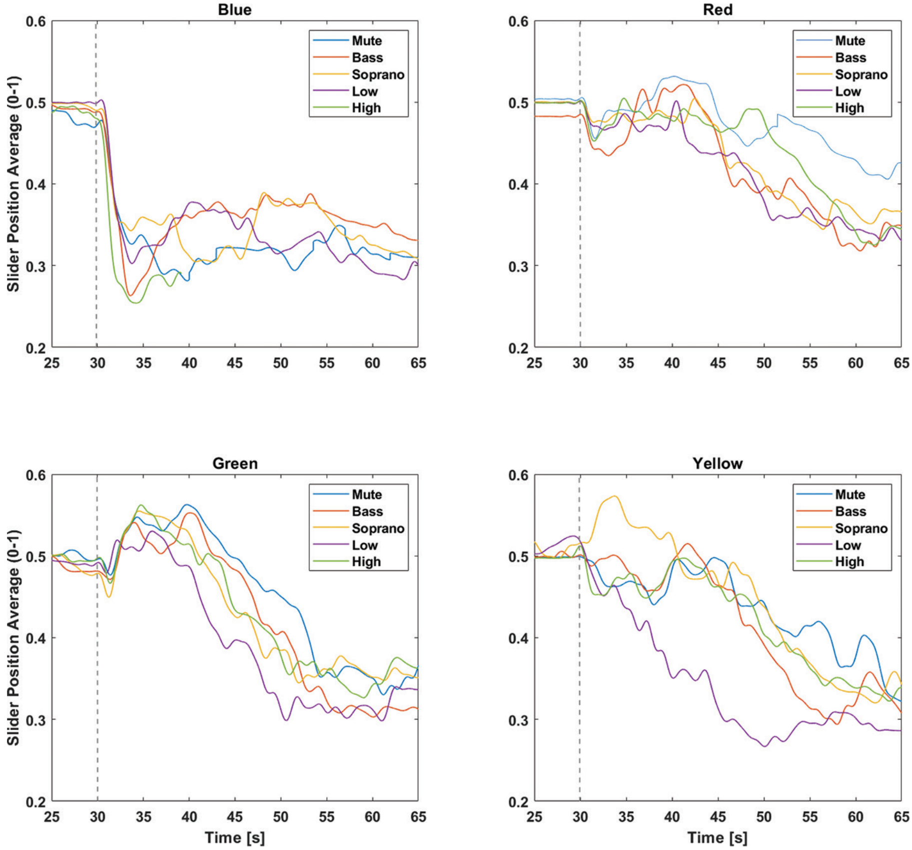

Fig. 2. Average position of the slider during the task, divided by sound and colour stimulation. The slider total excursion is between 0 and 1. In the x-axis is shown the total time of the single task; the dotted line (at 30 s) represents the timing of the disappearance of the colour in the video and the start of the sound stimulation. Mute is the task without sound ('no sound').

light and bright yellow colour. The effect of the sounds could therefore have been to intensify the brightness of the image, thus weakening at the same time its chromatic saturation.

Regarding the pure excursion of the slider (the difference between the maximum and minimum values that the slider has reached, without taking into account the velocity of such change), the absence of sound (mute condition) tends to provoke a smaller change in height, whereas the low-pitched tone sound tends to elicit the maximum height excursion, confirming a general influence of sounds on colour afterimages. In this pilot work, however, we have limited ourselves to describing in a qualitative way the main relative differences between the effects of different sounds on the intensity of colours, and thus further studies are needed to deeply investigate and understand them in a quantitative way.

3. Conclusions

In conclusion, these first findings support some of the most significant observations reported by Werner and Zietz (Zietz, 1931; Werner, 1934), according to which the colours of the afterimages 'disintegrate' at the hearing of a low sound and 'concentrate' for a high sound. This relationship is particularly evident with the Yellow stimulus, where the perceived colour intensity of its (violet) afterimage seems to have a faster negative change with the low-pitched tone sound, and an increase in intensity and duration when perceived simultaneously with a soprano sound.

These data are also coherent with the crossmodal correspondences between both pitch and loudness in audition and lightness and brightness in vision reported in the reviewed literature (Marks, 1974; Marks, 1987; 1989; Melara, 1989; Hubbard, 1996; Martino & Marks, 1999).

To thoroughly explore this phenomenon of sound–colour afterimage interaction, almost unknown in scientific literature, we designed a novel methodological approach capable of directly measuring and visualising the apparent changes in intensity of the afterimages by recording the paths that the observers generated by moving a cursor. Using this method, the visual impressions of the participants can be immediately shaped in a specific path through the use of a physical feedback mechanism, and recorded without referring to verbal descriptions, memory processes or cognitive associations, which would need further analysis before the impact of the audio-visual stimuli can be ascertained.

Most importantly, our findings reinforce Werner's conjecture, according to which it is possible to prompt experiences very similar to synaesthesia in non-synaesthetes, by adopting the appropriate stimulus conditions that allow subjects to *perceive* the effect of sound on colour. As argued by Werner (1934), the optimal conditions to get audio-visual intersensory effects seem to be very transient and fluid, not-objective, phenomena, as afterimages for example are. Colours or sound to be effective must have the character of 'states', in which qualities such as 'intensity' and 'acuity' or 'softness' and 'loudness' can be spread and transferred from one sensory modality to another, and similar audio-visual attributes, if temporally contingent, can be perceptually grouped. According to Werner, in fact, these synaesthetic and intersensory qualities have their root in the *dynamism of bodily reaction* where the purely sensory fact and the purely motor fact are not yet differentiated (Werner, 1934).

Actually, as regards the choice of afterimages in the study of the interaction between sound and colour, other researches confirmed the assumption that afterimages perceptually are more susceptible to modulation by contexts. For instance, it has been shown that classic afterimage illusions, such as the recent illusion by van

Lier, Vergeer, and Anstis (2009), demonstrate compelling effects of contextual modulators on afterimage visibility, and that luminance edges enhance the perceived saturation of afterimages more than physical stimuli of similar appearance (Powell, Bompas, & Sumner, 2012). Generally, afterimages can be considered as an ambiguous coloured surface, fluid and visibly changing and fleeting, and for this reason it may be more susceptible to be modulated by a sound context, as Zietz and Werner almost a 100 years ago ingeniously suggested.

Abstract

We ran a pilot experiment to explore, using a new psychophysical method, the hypothesis proposed by Zietz and Werner in the '30s, that a sound presented simultaneously with an afterimage can change its phenomenal appearance in non-synaesthetes. The method we adopted is able to directly collect and visualise the apparent changes in intensity of the afterimages, by recording observers' interactions with a physical feedback mechanism (the paths that the observers generated by moving a cursor), without referring to verbal descriptions. These first findings support some of the most meaningful observations reported by Werner (1934) and Zietz (1931), according to which the colours of the afterimages 'disintegrate' at the hearing of a low sound and 'concentrate' for a high sound. This relationship is particularly evident with the Yellow stimulus, where the perceived colour intensity of its afterimage seems to have a faster negative change with a low-pitched tone sound, and an increase in intensity and duration when perceived simultaneously with a soprano sound. These data are also coherent with the crossmodal correspondences between both pitch and loudness in audition and lightness and brightness in vision reported in the literature.

Keywords: crossmodal perception, audio-visual integration, colour afterimages, sound–colour interaction.

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