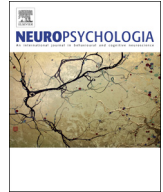




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Seeing music: The perception of melodic 'ups and downs' modulates the spatial processing of visual stimuli



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ABSTRACT

Musical melodies have “peaks” and “valleys”. Although the vertical component of pitch and music is well-known, the mechanisms underlying its mental representation still remain elusive. We show evidence regarding the importance of previous experience with melodies for crossmodal interactions to emerge. The impact of these crossmodal interactions on other perceptual and attentional processes was also studied. Melodies including two tones with different frequency (e.g., E4 and D3) were repeatedly presented during the study. These melodies could either generate strong predictions (e.g., E4-D3-E4-D3-E4-[D3]) or not (e.g., E4-D3-E4-E4-D3-[?]). After the presentation of each melody, the participants had to judge the colour of a visual stimulus that appeared in a position that was, according to the traditional vertical connotations of pitch, either congruent (e.g., high-low-high-low-[up]), incongruent (high-low-high-low-[down]) or unpredicted with respect to the melody. Behavioural and electroencephalographic responses to the visual stimuli were obtained. Congruent visual stimuli elicited faster responses at the end of the experiment than at the beginning. Additionally, incongruent visual stimuli that broke the spatial prediction generated by the melody elicited larger P3b amplitudes (reflecting ‘surprise’ responses). Our results suggest that the passive (but repeated) exposure to melodies elicits spatial predictions that modulate the processing of other sensory events.

1. Introduction

The perception of melodies is based on interpreting successive variations in pitch. A parsimonious way to perceive melodies may consist in mapping acoustic frequencies onto vertical coordinates, as if representing them on the staff (Stumpf, 1883). The fact that musical pitch is formally represented vertically and is described using words with spatial connotations in almost all cultures of the World may not be coincidental (see Fernández-Prieto, Spence, Pons and Navarra, 2017; Parkinson et al., 2012). Concurring with this idea, a robust association has been observed, both in adults and in prelinguistic infants, between high- and low-pitched sounds and high and low positions in the external space, respectively (Bernstein and Edelstein, 1971; Cabrera and Morimoto, 2007; Chiou and Rich, 2012; Deroy et al., in press; Lidji et al., 2007; Maeda et al., 2004; Melara and Brien, 1987; Mossbridge et al., 2011; Rusconi et al., 2006; Sonnadara et al., 2009; Spence and

Deroy, 2013). Additionally, previous findings suggest that experience with music improves performance in spatial tasks (the “Mozart effect”; Rauscher, Shaw, and Ky, 1993). In contrast with listeners with no musical expertise, musicians also show crossmodal correspondence effects between pitch and spatial elevation in indirect testing; that is, when the experimental task does not imply any spatial or pitch-based judgment (Rusconi et al., 2006).

By means of repetitive exposure to melodies, we learn to predict their pitch contour (i.e., the ascending-descending dynamics of sound frequency over time). If experience with music influences both their predictive capability and their spatial connotations, it is reasonable to hypothesize that the repeated exposure to melodies will (1) increase their capability to generate melodic predictions, and (2) generate stronger spatial connotations that can even modulate visuospatial attention. In the present study, we investigated whether the passive listening of melodies biases visuospatial attention towards high and low

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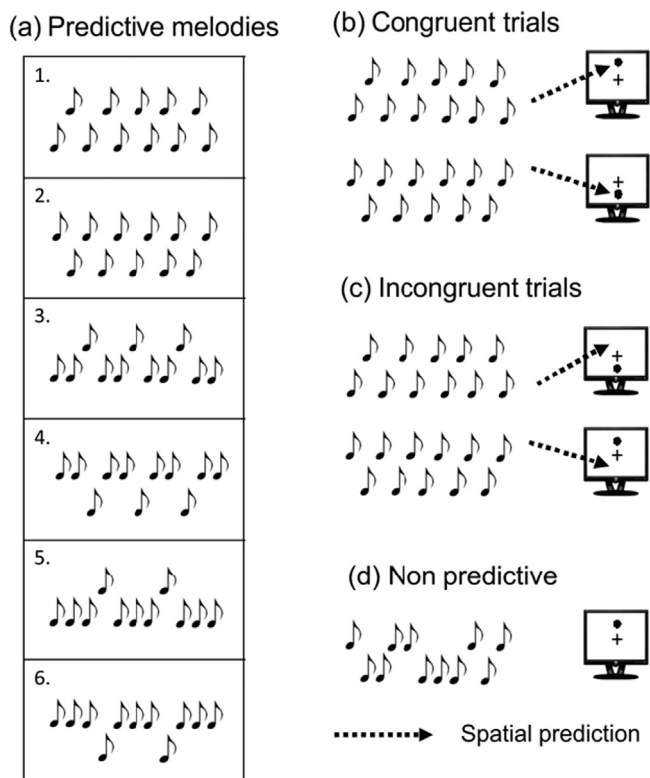


Fig. 1. Schematic representation of the different predictable melodies (a) and experimental conditions. After the presentation of the melody, a visual target (a small filled circle) appeared and the participants performed a speeded colour discrimination task (yellow vs. blue) of the circle. The visual target could either be unpredictable (d) or be crossmodally congruent (b) or incongruent (c) with respect to the possible spatial (vertical) expectancy generated by a predictable melody. Each melody appeared 24 times during the experiment.

spatial positions. Additionally, the role of recent experience to generate these biases was addressed.

Even if the activation of specific space-related areas of the brain such as the intra-parietal sulcus (IPS) is observed when people perform complex musical tasks (see Foster and Zatorre, 2010a, 2010b), it is still unknown whether the spatial connotations of melodic ascents and descents also arise in conditions of repeated passive listening or not. To test this possibility, a group of participants heard simple 11-tone melodies several times during the study. These melodies could or could not generate predictability (e.g., "low-high-low-high-low..." vs. "low-low-high-low-high-high..."; see Fig. 1). After each of the auditory streams, a visual target (either a blue or a yellow filled circle) was presented in an upper or a lower spatial position on a computer screen. No task was performed in relation to the melodies. Regarding the visual target, an indirect (i.e., non-spatial) task, consisting of judging the colour of the stimuli, was performed by the participants.

In the predictable conditions, the visual target could either be crossmodally congruent or else incongruent with respect to the prediction generated by the melody. For example, a visual target appearing on the upper (high) position after the melody "low-low-high-low-low-high-low-low-high-low-low" led to a congruent trial, while a visual target appearing on the lower spatial position after the presentation of this melody was incongruent. In the unpredictable condition, the participants were not able to predict the pitch changes during the presentation of the melody.

The possible effect of gaining experience with the melodies on their capability to modulate visuospatial processing was explored by comparing the possible crossmodal effects (e.g., faster reaction times -RTs- in congruent trials) in the first and the last trials of the experiment. We

expected that RTs would be faster in congruent trials than in incongruent and unpredictable trials, especially in the last trials of the experiment (see Nobre et al., 2007). This would reflect the effect of recent experience with the melodies on their capacity to modulate spatial attention. On the other hand, no differences were expected, in terms of RTs, between the incongruent and the unpredictable conditions when considering the first and last trials of the experiment, because incongruities in a predictable melody may cause similar response slowness than unpredictable melodies.

In order to address the possible influence of auditory prediction on visuospatial attention, we analysed the event-related potentials (ERPs) from the onset of each visual target. The decision to use ERPs was based on their high temporal resolution, which allowed us to explore the processing of the visual targets after the presentation of the different melodies. If a task-irrelevant rhythmic stream of sounds can bias visuospatial attention and then modulate the processing of forthcoming visual stimuli even in non-musician listeners, larger amplitudes could be expected in attention and memory-mediated components such as P2 (Federmeier and Kutas, 2002), P3a (Guo et al., 2006; McEvoy et al., 2001; Rugg and Doyle, 1992) or P3b (Brázdil et al., 2003, 2001; Conroy and Polich, 2007; Hartikainen and Knight, 2003; Knight, 1996; Kok, 2001; Polich, 2007, 2003; Squire and Kandel, 1999). For instance, the P2 component has been related to the use of contextual cues to prepare for the visual analysis of upcoming stimuli (Federmeier and Kutas, 2002). Hence, we would expect larger P2 amplitudes for predictive than unpredictable melodies, since predictive melodies should allow participants to prepare for the upcoming targets. Somewhat related, the P3a component has been observed to index stimulus representations maintained in memory from previous exposures, being this component larger for recurring than for novel stimuli (Guo et al., 2006; McEvoy et al., 2001; Rugg and Doyle, 1992). Therefore, since our predictive melodies were more easily remembered than the unpredictable melodies, we would expect larger P3a amplitudes for the former. In addition, the P3a amplitude is sensitive to the amount of attentional resources that are recruited during the performance of a task. For instance, as primary task difficulty is increased, the P3a amplitude decreases (Isreal et al., 1980; Kok, 2001; Kramer et al., 1985; Polich, 1987; Wickens et al., 1983). Accordingly, if unpredictable melodies make the processing of the visual target more difficult, we would also expect that this crossmodal factor might modulate the P3a amplitude (i.e., larger amplitude for predictive than for unpredictable melodies). This prediction would be somewhat congruent with previous literature showing that, when processing audiovisual rhythmic streams, the primary visual cortex entrains to the rhythm of the stream, resulting in decreased reaction times to targets (Lakatos, Karmos, Mehta, Ulbert, and Schroeder, 2008), and, importantly, that the degree of entrainment depends on the predictability of the stream (Besle et al., 2011). Finally, while the P3a component is usually related to the engagement of focal attention during stimulus evaluation, the P3b component is supposed to occur when subsequent attentional resources are needed to carry out context-updating operations and subsequent memory storage (Brázdil et al., 2001, 2003; Conroy and Polich, 2007; Hartikainen and Knight, 2003; Knight, 1996; Kok, 2001; Polich, 2003, 2007; Squire and Kandel, 1999). Consequently, we would expect similar P3a amplitudes for congruent and incongruent visual targets (similar focal attention during stimulus processing). However, we would also expect differences between congruent and incongruent visual targets in the P3b amplitude, since incongruent trials would require further context-updating operations.

In addition, we also analysed the N50 and N100 ERP components, as the amplitude of these components is modulated by selective attention on visual processing (e.g., Rugg et al., 1987). Following previous literature, larger amplitudes were expected, in these components, for targets following unpredictable (as compared to predictable) melodies (Rugg et al., 1987).

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