



Newly acquired audio-visual associations bias perception in binocular rivalry



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ABSTRACT

When distinct stimuli are presented to the two eyes, their mental representations alternate in awareness. Here, such “binocular rivalry” was used to investigate whether audio-visual associations bias visual perception. To induce two arbitrary associations, each between a tone and a grating of a specific color and motion direction, observers were required to respond whenever this combination was presented, but not for other tone-grating combinations. After about 20 min of this induction phase, each of the gratings was presented to one eye to induce rivalry, while either of the two tones or no tone was played. Observers were asked to watch the rivaling stimuli and listen to the tones. The observer’s dominant percept was assessed throughout by measuring the optokinetic nystagmus (OKN), whose slow phase follows the direction of the currently dominant grating. We found that perception in rivalry was affected by the concurrently played tone. Results suggest a bias towards the grating that had been associated with the currently presented tone and prolonged dominance durations for this grating compared to the other. Numerically, conditions without tone fell in-between for measures of bias and dominance duration. Our data show that a rapidly acquired arbitrary audio-visual association biases visual perception. Unlike previously reported cross-modal interactions in rivalry, this effect can neither be explained by a pure attentional (dual-task) effect, nor does it require a fixed physical or semantic relation between the auditory and visual stimulus. This suggests that audio-visual associations that are quickly formed by associative learning may affect visual representations directly.

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1. Introduction

Perceptual rivalry is characterized by a situation in which a constant sensory stimulus evokes distinct perceptual interpretations that alternate in their access to awareness over time (e.g., Boring, 1930; Breese, 1899; Necker, 1832; Rubin, 1921). Binocular rivalry occurs when two distinct images are presented to the two eyes (Wheatstone, 1838). The dynamics of both forms of rivalry share several statistical properties (Brascamp, Klink, & Levelt, 2015; Klink, van Ee, & van Wezel, 2008; O’Shea, Parker, La Rooy, & Alais, 2009). Besides being a research topic in its own right, rivalry has become a tool to study the perceptual consequences of many perceptual, cognitive and action-related factors. Since the stimulus remains unchanged, such effects can then be attributed to a direct operation of the respective factor on the perceptual representation.

Examples of this endeavor include the demonstration of direct effects of attention on ambiguous-motion perception (Blaser, Sperling, & Lu, 1999), effects of eye movements on the perception of ambiguous figures (Einhäuser, Martin, & König, 2004; Glen, 1940; Kawabata, Yamagami, & Noaki, 1978; Necker, 1832), effects of manual movements on dynamic rivalry stimuli (Beets et al., 2010; Maruya, Yang, & Blake, 2007; Wohlschläger, 2000), and also effects of higher-level concepts, such as value, on binocular rivalry (Marx & Einhäuser, 2015; Wilbertz, van Slooten, & Sterzer, 2014). Here, we follow this logic and use binocular rivalry to study the effect of a learnt arbitrary audio-visual association on perceptual representations.

Visual stimuli can have profound influences on auditory perception and vice versa. This is probably most famously evidenced by the McGurk effect, where conflicting visual and auditory information on a spoken syllable lead to a unique audio-visual perception that is a compromise between both modalities but consistent with neither unimodal stimulus (McGurk & MacDonald, 1976). In the “ventriloquist effect”, a sound source is spatially linked to visual

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motion even if it does not spatially coincide with the visual stimulus (Pick, Warren, & Hay, 1969). This precedence of vision over audition for a spatial judgement is consistent with an optimal integration of both modalities, when – as it is typically the case – visual localization is more reliable than auditory localization; indeed, spatial localization can be dominated by audition when visual acuity is sufficiently reduced experimentally (Alais & Burr, 2004). Especially in transient presentations, audition frequently dominates vision: when accompanied by multiple tones, a single visual flash is perceived as multiple flashes (Shams, Kamitani, & Shimojo, 2002). Similarly, the visual “flash-lag” illusion – a brief flash is perceived to lag behind a moving object that is in fact presented at the same location – is reduced by a sound preceding the flash (Vroomen & de Gelder, 2004). Ambiguous visual perception can also be biased by auditory stimulation. The streaming/bouncing stimulus presents a striking example; when two opaque moving discs approach each other and continue their trajectory after the point of contact, two distinct perceptual interpretations are possible (Metzger, 1934): the discs can be perceived to stream by each other or to bounce off each other. While visual factors influence the percept, the co-occurrence of a sound with the time of visual contact shifts the bias profoundly towards the bouncing interpretation (Sekuler, Sekuler, & Lau, 1997). In sum, visual and auditory perception influence each other, and illusions or ambiguous situations in either modality present a good means to reveal such effects.

Cross-modal effects on visual rivalry have recently become an area of intense research. Besides using the other modality for the presentation of a distracting task (e.g., Alais, van Boxtel, Parker, & van Ee, 2010), several studies build on intrinsic relations between auditory, tactile or olfactory stimuli on the one hand to a visually ambiguous stimulus on the other hand, to address whether other modalities can bias perception in visual rivalry. In the case of tactile-visual interaction, the rotation of an invisible physical sphere in the participant’s hands biases the concurrent perception of an ambiguous kinetic depth (structure-from-motion) sphere towards the direction of the tactile stimulus (Blake, Sobel, & James, 2004). This effect may exploit the sensitivity of a visual brain area, the medio-temporal visual complex in human (MT+), to such tactile motion (Blake et al., 2004). Remarkably, the effect of touch on rivalry does not require the conscious percept of the visual stimulus: presenting a tactile stimulus that is congruent to the suppressed stimulus fosters its breakthrough to dominance (Lunghi, Binda, & Morrone, 2010) and the presence of a congruent tactile stimulus decreases the detection threshold of a probe on the suppressed stimulus (Lunghi & Alais, 2015). In these cases, the matching across modalities needs to be remarkably precise, for example, down to a few degrees in the case of orientation (Lunghi & Alais, 2013). Together with the observation that passive touch suffices to facilitate the suppressed stimulus (Lunghi & Morrone, 2013), the specificity and the modulation of the suppressed percept indicate that cross-modal effects on rivalry may occur at early processing stages prior to awareness. Nonetheless, these studies not only find effects on the suppressed but also on the dominant stimulus, suggesting that both processes – facilitating the suppressed stimulus and extending the dominance of the currently dominant stimulus – contribute to cross-modal effects on binocular rivalry.

Physical similarity to an auditory stimulus can also bias binocular rivalry: an auditory stimulus implying motion biases the perception of conflicting random-dot kinematograms in the direction of the auditory stimulus (Conrad, Bartels, Kleiner, & Noppeney, 2010). A bias towards visual motion congruent with a simultaneously presented sound is also observed for looming/receding stimuli, and stronger when these stimuli are more naturalistic than simple sounds (Conrad et al., 2013). Extending on such physical

relatedness across domains, a semantically related stimulus, such as a bird sound or a car sound when images of cars and birds are competing, biases perception towards the visual stimulus that is congruent with the auditory stimulation (Chen, Yeh, & Spence, 2011). A similar effect is observed for congruent odors: the smell of a rose (induced by phenylethyl alcohol) and the smell of a text marker (induced by butanol) increase dominance of the respective picture (Zhou, Jiang, He, & Chen, 2010). Besides spatial and semantic similarity, a match in temporal structure also facilitates cross-modal effects on visual rivalry: when a visually looming stimulus is paired with an auditory looming stimulus, the former can be held in awareness more easily, and this effect to some extent generalizes to other sounds as long as the rhythmicity helps to keep up attentional control (van Ee, van Boxtel, Parker, & Alais, 2009). van Ee et al. (2009) show similar effects also for tactile stimulation with the appropriate temporal pattern. Tactile and auditory stimulation can bias perception in binocular rivalry towards the visual stimulus that shares the temporal frequency with the other domains; importantly this still holds when perceiving the frequency requires integration across the non-visual domains, which argues that such supramodal integration precedes biasing rivalry (Lunghi, Morrone, & Alais, 2014). Temporal and spatial specificity can also be combined: when an auditory stimulus is presented concurrently with two rivalry gratings, the grating whose spatial frequency is perceptually matched to the amplitude modulation of the auditory stimulus dominates over a grating of a different spatial frequency (Guzman-Martinez, Ortega, Grabowecy, Mossbridge, & Suzuki, 2012).

All of the aforementioned examples have in common that the stimulus in the other modality (or modalities) has some intrinsic commonality with the visual stimulus to be biased: the tactile rotation describes the same physical object as the visual stimulus, the temporal and/or spatial frequencies are matched between modalities, the bird and vehicle pictures are semantically matched to their corresponding sounds, motion patterns share the same direction, and the visual spatial frequency is a priori perceived to be more similar to one amplitude modulation pattern than to another. Here we ask, instead, whether an arbitrary audio-visual association that is acquired through a brief period of training (induction) suffices to exert similar influences on visual perception in binocular rivalry. Complementary to previous studies, such effects would provide evidence that cross-modal associations strong enough to interfere with perception do not require a life-long period of training or relatedness to the same physical object, but can instead be arbitrary and formed quickly. This in turn would indicate that cross-modal representations interfering with rather early stages of vision are highly plastic even in adult observers. Importantly for the interpretation of our data, we circumvent the issue of response bias by using a no-report paradigm (Tsuchiya, Frässle, Wilke, & Lamme, 2015 for a review). Specifically, we use moving gratings as stimuli and exploit the observation that the direction of the slow-phase of the optokinetic nystagmus (OKN) follows the perceived stimulus motion (Enoksson, 1963; Fox, Todd, & Bettinger, 1975; Frässle, Sommer, Jansen, Naber, & Einhäuser, 2014; Marx & Einhäuser, 2015; Naber, Frässle, & Einhäuser, 2011). This allows us to have observers watch a binocular-rivalry stimulus without reporting their percept, while we nonetheless determine their perception at any point in time. In a first step, we induce two audio-visual associations, each between a tone and a grating, by requiring observers to respond to these combinations of tone and grating, but not to other combinations. In a second phase, we present the two gratings, one to each eye, and play either one of the tones or no tone. We hypothesize that playing a tone increases the relative perceptual dominance of the grating associated with the tone at the expense of the other grating’s dominance.

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