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Current Opinion in Behavioral Sciences

Adaptation for multisensory relative timing

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Perception of relative timing for signals arising from different sensory modalities depends on the recent history of experienced asynchrony between the signals. Recent findings suggest that the changes in perceived relative timing following asynchrony exposure parallel the perceptual changes caused by adaptation to non-temporal attributes. In both cases, previous sensory stimulation changes discriminability and briefly presented adaptors are sufficient to produce perceptual changes that, functionally, can be consistent with repulsion and recalibration. Furthermore, a new class of after-effects in which reports are biased in the direction of the adaptor also occur for both temporal and non-temporal attributes. Computationally, the effects of previous sensory stimulation on behavior have been assessed using Bayesian and population code models.

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Current Opinion in Behavioral Sciences 2016, **8**:35–41

This review comes from a themed issue on **Time in perception and action**

Edited by **Warren H Meck** and **Richard B Ivry**

For a complete overview see the Issue and the Editorial

Available online 27th January 2016

http://dx.doi.org/10.1016/j.cobeha.2016.01.005

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Introduction

Determining the relative timing between two signals arising from different sensory modalities — whether the signals are simultaneous or the order in which they occur — might be an important perceptual operation to determine whether the two signals should be causally connected and integrated into a single perceptual event [1].

The perception of relative timing for multisensory signals has been studied since the origins of psychology (see [2]), but only about a decade ago was it discovered that relative timing perception is not fixed, but depends on recently experienced asynchronies [3,4]. In such studies, audiovisual stimuli are repeatedly presented with a fixed asynchrony (e.g. vision leads audition by 235 ms). In subsequent test trials, presentations of a stimulus with a smaller asynchrony (e.g. vision leads audition by 100 ms) are apparently perceived as closer in time and more likely to be reported as having occurred simultaneously than they were before the period of exposure to a fixed asynchrony. (Figure 1a). A corresponding change in subjective simultaneity occurs after repeated exposure to an auditory signal leading a visual signal. The effect of asynchrony exposure on perceived relative timing, lag exposure effects for short, also occurs for other tasks and combinations of signals (Box 1).

Little is known about the mechanisms underlying lag exposure effects (Box 2), but recent studies indicate that lag exposure effects might have properties similar to the classic perceptual after-effects described for visual attributes such as lightness, contrast, color, spatial frequency, orientation, speed or motion direction [5,6]. Consequently, the effect of sensory history on temporal and non-temporal attributes may be described by similar principles.

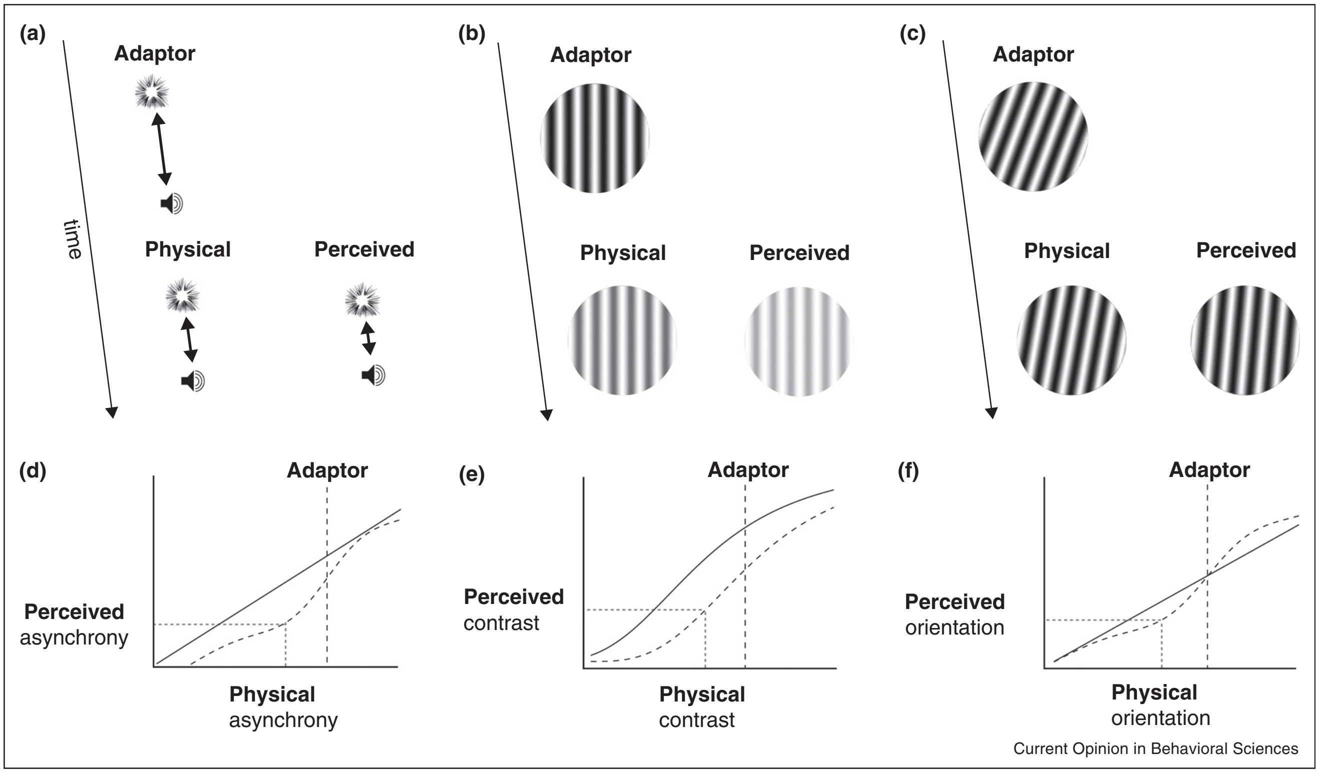
Lag exposure effects are caused by adaptation

For non-temporal attributes, there is solid evidence that after-effects are indeed perceptual, caused by sensory adaptation, rather than changes in decision processes [7]. First, after-effects have neural correlates in sensory areas [6]. Second, after-effects are behaviorally associated with changes in the discriminability of the attribute [6,8,9]. For relative timing, to our knowledge only one study has examined the neural correlates of lag exposure effects [10], and until recently there was no evidence of changes in discriminability. In the absence of such evidence, it has been suggested that lag exposure effects could be caused entirely by decisional changes [11]. A recent study by Roseboom and colleagues [12••], however, showed that exposure to audiovisual asynchronies changes asynchrony discrimination, supporting the idea that lag exposure effects are perceptual after-effects similar to those reported for non-temporal attributes and that asynchrony exposure causes adaptation.

Function

As described in the introduction, lag exposure effects reduce the perceived asynchrony for relative timings in which the order of presentation of the signals matches the order of the adaptor (Figure 1a). Phenomenologically, this

Figure 1



(a) Lag exposure effects. Adapting to repeated presentations (only one presentation shown) of a visual signal leading an auditory signal reduces the perceived asynchrony between a visual and auditory signal making them to appear more simultaneous. **(b)** Contrast adaptation. Presenting a high contrast grating reduces perceived contrast. **(c)** The tilt after-effect. Adapting to a grating far from vertical makes a slightly tilted grating to appear more vertical. **(d)** Transduction of physical asynchrony, contrast **(e)**, and orientation **(f)** into perceived asynchrony, contrast and orientation. In each case, the continuous black line indicates transduction before adaptation (assuming linear transduction for asynchrony. See [12••] for more realistic transducers for asynchrony) The dotted black lines show transduction following adaptation (assuming recalibration followed by repulsion for asynchrony, [12••]), recalibration for contrast, and repulsion for orientation. The blue dotted lines show the physical and the perceived asynchronies, contrasts and orientations illustrated in a, b, and c.

Box 1 In addition to simultaneity judgments, lag exposure effects have been measured using other subjective tasks such as temporal order judgments [3,4], magnitude estimation [22], multisensory integration [3,17,69] and, more recently, an objective three-alternative forced choice task [12••]. Lag exposure effects occur not only for audiovisual stimuli, but also for audiotactile [60], visuotactile [60,70,71], and even unimodal signal combinations [72–74]. Some studies, however, fail to find lag exposure effects for non-audiovisual stimuli [31,32•,41,58,75].

Lag exposure effects have also been reported for relative timings defined by a sensory signal and an action [45,68•,76–82]. Such sensorimotor lag exposure effects may be equivalent to multisensory lag exposure effects as the critical signals for adaptation appear to be the sensory signal produced as a consequence of action — an auditory beep, for example — and the sensory feedback of the committed action — the tactile sensation of having pressed a button [83]. However, sensorimotor lag effects are generally larger in magnitude than other multisensory effects [76] and can exhibit a strong subjective phenomenology of illusory temporal reversal that is absent for other multisensory effects [76,77]. These results suggest that the mechanisms underlying sensorimotor and multisensory lag exposure effects may be distinct.

reduction is similar to the reduction caused by adaptation to non-temporal attributes such as color or contrast [5,6]. For example, adaption to a high contrast grating causes a subsequently presented lower contrast grating to be perceived as even lower contrast (Figure 1b). These changes in appearance are descriptively consistent with a lateral shift of the transducer function in the direction of the adaptor ([12••]; Figure 1e) and functionally associated with recalibration [5,6]. For non-temporal attributes, recalibration is associated with enhancement of sensitivity around the adaptor [5,6]. By contrast, for relative timing, the emphasis has been placed on how recalibration can reduce perceived asynchrony to facilitate the integration of signals that might have different perceptual latencies despite having a common source [3,4,13,14,30••]. However, while some findings support the idea that perceptual integration depends directly on relative timing perception [1,3,15–17], other findings are at odds with this hypothesis [17–21]. Consequently, whether and how perceptual integration depends on perceived relative timing remains unclear at present.

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