

# **Time and Causality: Mutual Constraints**

## **Insights from Event and Time Perception, Motor Control, and Gaming**

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**Keywords:** Causality, Time, Perception, Learning, Reasoning, Binding, Event Segmentation, Sensory Integration

### **General Background**

The problem of how humans and other intelligent systems construct causal representations from non-causal perceptual evidence has occupied scholars in cognitive science since many decades. Most contemporary approaches agree with David Hume that patterns of covariation between two events of interest are the critical input to the causal induction engine, irrespective of whether this induction is believed to be grounded in the formation of associations (Shanks & Dickinson, 1987), rule-based evaluation (White, 2003), appraisal of causal powers (Cheng, 1997), or construction of Bayesian Causal Networks (Pearl, 2000). Recent research, however, has repeatedly demonstrated that an exclusive focus on covariation while neglecting contiguity (another of Hume's cues) results in ecologically invalid models of causal inference. Temporal spacing, order, variability, predictability, and patterning all have profound influence on the type of causal representation that is constructed (Greville & Buehner, 2010; Young & Cole, 2012).

The influence of time upon causal representations could be seen as a bottom-up constraint (though current bottom-up models cannot account for the full spectrum of effects). However, causal representations in turn also constrain the perception of time: Put simply, two causally related events appear closer in subjective time than two (equidistant) unrelated events. This reversal of Hume's conjecture, referred to as Causal Binding (Buehner, 2012) is a top-down constraint, and suggests that our representations of time and causality are mutually influencing one another. At present, the theoretical implications of this phenomenon are not yet fully understood. Some accounts (e.g. Haggard, Clark, & Kalogeras, 2002) link it exclusively to human motor planning (appealing to mechanisms of cross-modal temporal

adaptation, or forward learning models of motor control), while others adopt a broader perspective in line with models of Bayesian Evidence Integration (e.g. Buehner, 2012).

Causal beliefs influence not only time perception, but also judgments of temporal order, event segmentation, and phenomena related to multi-sensory integration. This symposium brings together researchers from various disciplines and backgrounds who all explore the interrelations between time, causality and perception, and do so applying learning theory, Bayesian approaches, physiological considerations, and high-level theories of cognition.

### **Participant Abstracts**

#### **Temporal Binding: Causality, Intentionality, or Both? (Buehner)**

Since the first demonstration of temporal binding between actions and their consequences (Haggard et al., 2002) more than ten years ago, various theories have been put forward to account for it, ranging from modifications of an internal clock to sensory-specific re-adaptation. The common denominator across all demonstrations of the effect appears to be causality: binding in time and space occurs when there is a causal relation linking an action and its effect. I will discuss evidence of temporal binding in the complete absence of motor action. These results are at variance with theories based on sensuo-motor realignment and thus rule out intentionality as the basis for the effect. Instead, they can be accommodated by a Bayesian Framework of event perception. Intentionality could be included in this framework as an additional predictor.

## **Constructing Time and Cause (Lagnado & Bechlivanidis)**

The notions of time and causality are intimately linked. Previous research shows that temporal information provides critical cues for causal inference (Greville & Buehner, 2010; Lagnado & Sloman, 2006) and that causal beliefs modulate judgments of temporal duration (Buehner, 2012). Using a novel experimental paradigm, where participants actively engage with a software-based ‘physics world’, we show both that temporal order guides causal judgments, and that causal judgments can themselves determine perceptions of temporal order. These findings highlight the constructive nature of causal and temporal perceptions.

## **Asymmetries in Processing and Recalibration of Visuo-Motor Time Perception (Ernst & Rohde)**

If a voluntary movement event (e.g., a button press) and a sensory event (e.g., a visual flash) belong together, the button press has to happen before the flash, as a cause always comes before its effect. We investigated in a series of experiments whether this causal asymmetry also leads to a perceptual asymmetry in the perceived timing of visual and motor events. Participants had to judge the temporal order and the temporal interval of a visual flash and a button press after being trained to vision-lead and movement-lead temporal discrepancies. To be able to present visual stimuli both before and after motor events, we tracked participants' finger movement in real time and predicted the moment of a button press to time a visual flash with respect to this estimate. While the perception of temporal order is recalibrated symmetrically around the point of actual simultaneity, there are strong asymmetries in the recalibration of interval perception, which is mostly confined to the movement-lead side of the range of discrepancies. In a second study, participants had to rate simultaneity and action authorship, where again asymmetries around the point of actual simultaneity were observed. The temporal order of cause and effect thus has profound influences on human time perception of visual and voluntary motor events.

## **Causal choice in the face of environmental complexity (Young)**

Prior research on causal judgment and choice has focused on situations in which the events either lack temporal extent, only one candidate cause and effect are being judged, or events are presented as a series of discrete trials. All of these approaches help to manage the complexity of the interaction being judged, and evidence suggests that people engage in forward inference under these simplified conditions. I will discuss evidence from Video-game based research that suggests that greater environmental complexity appears to produce backward, rather than forward, inference.

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