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Back from the future: Volitional postdiction of perceived apparent motion direction

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ABSTRACT

Among physical events, it is impossible that an event could alter its own past for the simple reason that past events precede future events, and not vice versa. Moreover, to do so would invoke impossible self-causation. However, mental events are constructed by physical neuronal processes that take a finite duration to execute. Given this fact, it is conceivable that later brain events could alter the ongoing interpretation of previous brain events if they arrive within this finite duration of interpretive processing, before a commitment is made to what happened. In the current study, we show that humans can volitionally influence how they perceive an ambiguous apparent motion sequence, as long as the top-down command occurs up to 300 ms after the occurrence of the actual motion event in the world. This finding supports the view that there is a temporal integration period over which perception is constructed on the basis of both bottom-up and top-down inputs.

1. Introduction

Among physical events, the future comprises the set of possible states open to a system, whereas the past comprises events that have already happened and which are no longer possible. A system cannot alter its past. If it could, this would have to be a possibility open to the system, which would then paradoxically place the past in the future of the system. Moreover, changing one's own past would be tantamount to self-causation, which is logically flawed because circular.

In contrast, mental events, such as those underlying visual perception, are constructed on the basis of inputs that are sensorily detected over a finite duration. For example, in order to see apparent motion (Kolers & von Grünau, 1976; Ramachandran & Anstis, 1986), there must be a comparison between an object at one location at time 1 and another object at a different location at a later time 2 such that they get bound together over space and time as a single object that moves from position 1 at time 1 to position 2 at time 2. Information about the position of the stimulus at time 1 must have been held online during the duration before stimulus 2 at time 2 appears. Apparent motion thus implies the existence of a perceptual buffer that spans a finite duration of inputs. Stimuli are compared over this finite duration before a commitment is made concerning what happened to give rise to those inputs. The perceived apparent motion path is then, in a sense, a postdictively constructed cover story about what most likely happened to give rise to the sequence of sensory inputs, given the evidence gathered over some finite duration. This perceptual buffer permits the influence of stages of form analysis (Tse, 2006; Tse & Caplovitz, 2006) and expectations (Tse & Cavanagh, 2000) on the construction of motion paths.

Whatever the duration of this perceptual buffer is, it cannot be very long: if it took twenty minutes to construct the perceived motion path of a tennis ball, we would never be able to hit it. On the other hand, in the absence of any duration over which inputs are integrated, no motion sequences could be constructed at all. Evolution presumably created perceptual systems that occupy a "sweet spot" where an adequate processing duration affords the possibility of inferring accurate motion paths constructed on the basis of discretely sampled, noisy and often ambiguous inputs, without taking so long as to make it impossible to respond to rapid events in the world.

Tse and Logothetis (2002) inferred that this buffer lasted at least ~120 ms, given data that form could influence the perception of transformational apparent motion over this duration. Other studies have also suggested that there is a time window during which subsequent inputs can influence the perception of prior inputs. Eagleman and Sejnowski (2000, 2007) demonstrated that the perceived position of a visual stimulus could be influenced by motion signals that occur up to ~80 ms following its appearance. Choi and Scholl (2006) found that the perception of causality could be influenced by contextual motion presented as late as 200 ms after the event. Sergent et al. (2013) reported that an exogenous attention cue presented 400 ms after the presentation could increase the subjective visibility of the stimulus. Kahneman, Treisman, and Gibbs (1992) found that the object-specific

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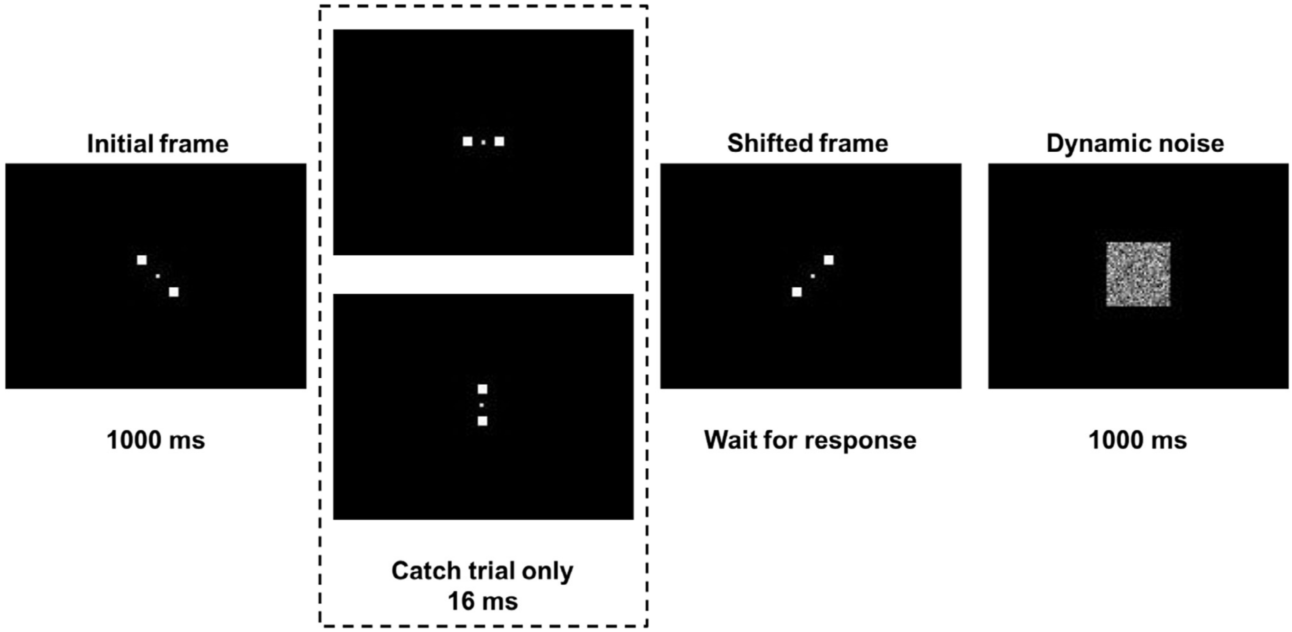

Fig. 1. Example of the display sequence. For simplicity, only the central part of the screen is shown and enlarged. The actual stimuli were much smaller, and the size of the black background on the monitor was much larger. From left to right, a typical non-catch trial included an initial frame, a shifted frame (with zero interstimulus time interval between dot positions), and dynamic noise. After the onset of the shifted frame, participants could perceive one-shot apparent motion in either the horizontal or vertical direction. In a catch trial, one of the frames surrounded by the dotted line was added between the initial frame and the shifted frame, in order to make the percept of apparent motion direction unambiguous (e.g. top for vertical motion, bottom for horizontal motion).

preview effect could still be effective 590 ms after the presentation of the preview field.

Given the constructed nature of perception and the fact that this perceptual buffer is of a brief but finite duration, it is possible that a volitionally generated top-down signal could influence how an apparent motion sequence will subsequently be perceived, even if that top-down signal occurs objectively after the completion of the apparent motion sequence in the world. To date no group has tested whether a top-down *volitional* postdictive command is capable of influencing previous ambiguous bottom-up inputs.

In order to test whether such volitional postdiction exists, we modified the paradigm of Mossbridge, Ortega, Grabowecky, and Suzuki (2013). They recruited a one-shot ambiguous apparent motion paradigm to study the time required for volitional control of the perceived direction of motion. They presented two squares, one above and one below fixation. After one second, these were replaced with two horizontally aligned squares with the same eccentricity, one to the right and the other to the left of fixation. Participants could perceive apparent motion as either clockwise or counter-clockwise. A tone presented at a variable time *before* the positional transition instructed participants to voluntarily influence their percept to be clockwise or counter-clockwise. Interestingly, in their study, even when the tone was presented simultaneously with the occurrence of the apparent motion sequence, subjects were able to significantly influence the direction of their perceived apparent motion. We used a similar paradigm to examine whether top-down commands initiated *after* the occurrence of the apparent motion sequence could influence the perceived direction of apparent motion. Since the tone begins at a variable delay after the apparent motion, and because it takes time for the tone to be processed, any ability to influence perceived motion would suggest the possibility of volitional top-down control over the percept of prior inputs.

Two experiments were performed. In Experiment 1, participants tried to influence their perception of apparent motion at several timepoints before and after the physical shift of the stimuli. In Experiment 2, additional timepoints after the positional stimulus shift were included in order to measure how long volitional control can influence the perception of apparent motion.

2. Experiment 1

2.1. Method

2.1.1. Participants

Forty-seven students (21 males, 26 females; 18–32 years old) from the Dartmouth College community consented to participate in the study for either course credit or monetary reward. The experiment was conducted in agreement with the Code of Ethics of the World Medical Association (Declaration of Helsinki). All participants had normal or corrected-to-normal vision. Participants had to pass two control tests in order to be included for the analysis (see Stimuli and Procedure). Thirty of forty-seven participants (17 males, 13 females; 18–32 years old) passed the first test and twenty-two of those participants (13 males, 9 females; 18–32 years old) passed the second control test. Data from participants who did not pass the first and the second control tests were not analyzed initially (but see Supplementary material for analyses that did not exclude participants).

2.1.2. Apparatus

The experiment was performed in a dark testing room. Stimuli were presented using Psychtoolbox (Brainard, 1997; Pelli, 1997), running in MATLAB (The MathWorks, Natick, MA, USA) on a LCD monitor (15-in, 40.0° × 30.0°, 60 Hz). Participants held their head on a chin rest at a viewing distance of 57 cm. Auditory stimuli were played through a Sennheiser HD 428 headphone (Sennheiser Electronic GmbH & Co. KG, Germany). The calibration of audio to video synchronization was carried out by a Rigol DS1052E digital oscilloscope (Rigol USA, Beaverton, OR, USA) with a customized photodiode device.

2.1.3. Stimuli and Procedure

Each trial began with two white squares (0.44°; 118 cd/m^2; CIE xy: 0.351, 0.366) around a white fixation point (0.1°) on a black background (Fig. 1). The centers of the two squares were 0.49° away from the fixation point. Thus the entire apparent motion sequence happened in the foveated zone, within a radius of half a visual degree from the point of fixation. One square was placed to the upper left of the fixation