Cognition 158 (2017) 1–9

Contents lists available at ScienceDirect

Cognition

journal homepage: www.elsevier.com/locate/COGNIT

Original Articles

Temporal distortion in the perception of actions and events

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ARTICLE INFO

Article history:
Received 12 December 2015
Revised 5 October 2016
Accepted 16 October 2016
Available online 20 October 2016

Keywords:
Intentional binding
Temporal binding
Sense of agency
Go/no-go
Time perception

ABSTRACT

In everyday life, actions and sensory events occur in complex sequences, with events triggering actions that in turn give rise to additional events and so on. Earlier work has shown that a sensory event that is triggered by a voluntary action is perceived to have occurred earlier in time than an identical event that is not triggered by an action. In other words, events that are believed to be caused by our actions are drawn forward in time towards our actions. Similarly, when a sensory event triggers an action, that event is again drawn in time towards the action and is thus perceived to have occurred later than it really did. This alteration in time perception serves to bind together events and actions that are causally linked. It is not clear, however, whether or not the perceived timing of a sensory event embedded within a longer series of actions and sensory events is also temporally bound to the actions in that sequence. In the current study, we measured the temporal binding in sequences consisting of two simple dyads of event-action and action-event in a series of manual action tasks: an event-action-event triad (Experiment 1) and an action-event-action triad (Experiment 2). Auditory tones either triggered an action or were presented 250 ms after an action was performed. To reduce the influence of sensory events other than the tone, such as a noise associated with pressing a key on a keyboard, we used an optical sensor to detect hand movements where no contact was made with a surface. In Experiment 1, there appeared to be no change in the perceived onset of an auditory tone when the onset of that tone followed a hand movement and then the tone triggered a second hand movement. It was as if the temporal binding between the action and the tone and then the tone and the subsequent action summed algebraically and cancelled each other out. In Experiment 2, both the perceived onset of an initial tone which triggered an action and the perceived onset of a second tone which was presented 250 ms after the action were temporally bound to the action. Taken together, the present study suggests that the temporal binding between our actions and sensory events occur separately in each dyad within a longer sequence of actions and events.

1. Introduction

Our perception of the timing of an event does not always correspond to the actual time that event occurred. This is particularly true of events that appear to be caused by our own actions. A number of investigators, for example, have shown that, when an individual performs a self-paced action that triggers a stimulus event (e.g., an auditory tone), the perceived time interval between the action and the event is shortened (Cravo, Claessens, & Baldo, 2009; Haggard & Clark, 2003; Haggard, Clark, & Kalogeras, 2002; Kawabe, Roseboom, & Nishida, 2013; Wohlschläger, Haggard, Gesierich, & Prinz, 2003). Put another way, the event is perceived to occur closer in time to the action that triggered it. This phenomenon has been described as intentional binding, a mental "linkage through time of representations of actions and events" (Haggard & Clark, 2003).

Several researchers have attributed this intentional binding to one's sense of agency, whereby one feels a causal role in the occurrence of external events as a result of actions they voluntarily initiate (Haggard & Chambon, 2012). The phenomenon of intentional binding in this context has been proposed to depend on prediction and/or retrospective inference. Initiating a self-paced action allows individuals to predict an outcome, and if the actual outcome matches the prediction (Moore & Haggard, 2008) or the intention (Engbert & Wohlschläger, 2007; Haggard & Clark, 2003), temporal binding of actions and events will occur. Other experiments that involved similar paradigm in which a sensory event follows a

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http://dx.doi.org/10.1016/j.cognition.2016.10.009

self-paced action, but did not allow participants to predict the outcome of their actions, also showed evidence of intentional binding, supporting the idea that retrospective inference after the event can also play a role in the binding of actions and events (Chambon, Sidarus, & Haggard, 2014). Other investigators have suggested that simple temporal contiguity of actions and events is enough to support their binding, by virtue of the perception of their causal relations (Buehner & Humphreys, 2009; Buehner & Humphreys, 2010; Cravo et al., 2009). Indeed, Buehner & Humphreys have suggested that the term "causal binding" might be more appropriate. Finally, a recent study proposed a model for the sense of agency that is based on the grouping of sensory feedback from the action, prediction about what the action might do, prior thoughts about the action, and the apparent effect of the action when it is performed (Kawabe et al., 2013). In short, researchers are still seeking a framework within which temporal binding can be explained.

In almost all these cases, the experiments have involved situations in which self-paced actions trigger sensory events. In everyday life, however, not only do humans experience events that are caused by their own actions, but they also perform actions in response to external events. Haggard, Aschersleben, Gehrke, and Prinz (2002) were the first to measure the perceived timing of sensory events that trigger actions. In their study, however, the perceived time of the triggering event showed little evidence of being shifted either towards or away from the action it triggered. Perhaps for this reason, later studies by Haggard and his colleagues (as well as others) focused entirely on the perceived timing of events that were apparently triggered by a voluntary self-paced action. Recently, however, we returned to the question as to whether or not there was any temporal distortion in the timing of events that trigger actions. We were able to show that, when one carefully controls the sensory feedback associated with making an action, the perceived timing of a sensory event that triggers an action is indeed attracted towards the action (Yabe & Goodale, 2015). This result challenges the idea that temporal binding is due to the sense of agency that arises when an event is perceived to be the results of one's action. In our experiments, the individuals were not triggering a stimulus event but were instead responding to one over which they had no control. Furthermore, in our experiments, we showed that temporal binding occurred even when an individual cancelled an action in response to a no-go signal. This suggests that temporal binding depends, not on the execution of the action, but rather on its programming (Yabe & Goodale, 2015).

In sum, although previous studies have focused on the temporal binding that occurs when a self-paced action triggers an event, it is also the case that temporal binding occurs when an external event triggers an action. The demonstration that temporal binding occurs in an event-action dyad as well as in an action-event dyad offers a new approach to understanding the underlying mechanism of temporal binding by opening the door for us to ask a new question: Will our sense of agency or our perception of a causal link between events and actions be disrupted when we are required to respond to sensory events in succession – or will they simply summate in some fashion? In the real world, we typically experience, not simple dyads of actions and events in isolation, but rather multiple actions and multiple events in longer sequences – such as what might occur on a football field, a crowded street, or in a busy factory or office. In the present study, therefore we attempted to emulate these real-world sequences by studying the perceived timing of a sensory event embedded within a series of actions and sensory events. The approach was straightforward; we combined the event-action sequence based on the paradigms of Yabe and Goodale (2015) and the action-event sequence based on the paradigms of Haggard, Aschersleben, et al. (2002). In Experiment 1 (Fig. 1C), we measured the perceived onset of an auditory tone in a sequence in which a voluntary hand movement triggered a tone after a 250 ms delay (Haggard, Clark, et al., 2002) and then that tone in turn triggered another hand movement. In Experiment 2 (Fig. 3), an auditory tone triggered a hand movement. Following that movement, another tone was presented 250 ms later. In this experiment, participants were required to report the timing of the first tone in one condition and the timing of the second tone in another condition.

Our experiments also included one other important methodological feature. In previous studies of intentional binding, the key-press/release tasks that have typically been used could have resulted in movement-related sensory feedback, including noise from the finger hitting or releasing the keyboard and/or changes in tactile input from the fingers, both of which could have been perceived as the effect of the action. This additional sensory feedback could have modulated the amount of the temporal binding between the action and either the triggering or the triggered sensory event of interest. Thus, in the present study, we used an optical sensor device to detect hand movements which resulted in far less movement-related sensory feedback than would be associated with a key-press.

2. Experiment 1

2.1. Materials and methods

2.1.1. Participants

We tested 20 naïve participants (15 females) aged 18–44 years with normal or corrected-to-normal vision. All participants were required to read a letter of information about the study and then to sign a consent form. The study was approved by the Ethics Review Board of The University of Western Ontario.

2.1.2. Apparatus

Experiments were carried out in a quiet, dark room. Participants sat on an adjustable chair with their chin in a chin rest to maintain stability. On the table in front of them was computer monitor (G90f, ViewSonic, USA; resolution: 1024 × 768 pixels; refresh rate: 100 Hz) on which the clock used to measure the perception of time was presented. The clock was viewed binocularly at a distance of 60 cm. Auditory tones were presented on a pair of speakers located on the left and right of the monitor. Programming of the presentation of the clock and the auditory tones was done in MATLAB 8.1.0.604 (MathWorks), assisted by Psychotoolbox 3.0.9 (Brainard, 1997; Pelli, 1997).

2.1.2.1. Hand movement recording. The hand movements that were used in each task were detected by a special optical sensor device (Fig. 1A). In both experiments, subjects held a stiff piece of felt cloth in their right hand that was positioned between emitter and sensor of the optical sensor, interrupting the infrared beam. During action-execution trials, participants lifted their hand up from the line of the infrared beam, thereby registering the hand movement but at the same time minimizing auditory and tactile feedback.

2.1.3. Tasks

Participants were instructed to place the piece of felt in the optical sensor. The word 'Rest' was displayed on the monitor. Participants initiated a trial by lifting the piece of felt and then placing it back immediately in the optical sensor. Following this, the phrase 'Hold still' was displayed for 2 s. At the end of this 2 s period, a clock (1.8° in diameter) was displayed at the centre of the monitor. Participants were required to fixate their eyes on a black dot (1° in diameter) in the centre of the clock. The second hand of the clock rotated around the black dot at a frequency of 2560 ms/