Consciousness and Cognition 22 (2013) 1174–1180

Contents lists available at ScienceDirect

Consciousness and Cognition

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

Bias and learning in temporal binding: Intervals between actions and outcomes are compressed by prior bias

Andre M. Cravo [a,*], Hamilton Haddad [b], Peter M.E. Claessens [a], Marcus V.C. Baldo [c]

[a] Center for Mathematics, Computation and Cognition, Federal University of ABC (UFABC), Santo André, Brazil
[b] Department of Physiology, Biosciences Institute, University of São Paulo, São Paulo, SP, Brazil
[c] Department of Physiology and Biophysics, Institute of Biomedical Sciences, University of São, Brazil

ARTICLE INFO

Article history:
Received 19 April 2013
Available online 7 September 2013

Keywords:
Intentional binding
Learning
Time perception
Voluntary action

ABSTRACT

It has consistently been shown that agents judge the intervals between their actions and outcomes as compressed in time, an effect named intentional binding. In the present work, we investigated whether this effect is result of prior bias volunteers have about the timing of the consequences of their actions, or if it is due to learning that occurs during the experimental session. Volunteers made temporal estimates of the interval between their action and target onset (Action conditions), or between two events (No-Action conditions). Our results show that temporal estimates become shorter throughout each experimental block in both conditions. Moreover, we found that observers judged intervals between action and outcomes as shorter even in very early trials of each block. To quantify the decrease of temporal judgments in experimental blocks, exponential functions were fitted to participants' temporal judgments. The fitted parameters suggest that observers had different prior biases as to intervals between events in which action was involved. These findings suggest that prior bias might play a more important role in this effect than calibration-type learning processes.

1. Introduction

Several studies have shown that being agent of an event can affect its perceived timing. Specifically, participants judge the intervals between their actions and outcomes as compressed in time. This phenomena, named intentional binding,[1] was first described ten years ago (Haggard, Clark, & Kalogeras, 2002) and has been largely discussed ever since (for recent reviews see Hughes, Desantis, & Waszak, 2012; Moore & Obhi, 2012; Waszak, Cardoso-Leite, & Hughes, 2011). The conditions for this effect to emerge have been investigated in several studies, and it has been consistently shown that both a sense of causality and temporal predictability of the generated effect are important (Buehner, 2012; Buehner & Humphreys, 2009; Cravo, Claessens, & Baldo, 2009, 2011; Desantis, Roussel, & Waszak, 2011; Dogge, Schaap, Custers, Wegner, & Aarts, 2012; Ebert & Wegner, 2010; Hughes et al., 2012).

However, little is known on how the effect evolves over time. For example, it could be argued that in real life most events we cause have a zero (or close to zero) delay relative to our actions. When confronted with a new action that produces a

* Corresponding author. Address: Center for Mathematics, Computation and Cognition, Federal University of ABC (UFABC), R. Santa Adélia, 166, Room 544-2, 09210-170 Santo Andre, SP, Brazil.

E-mail address: andre.cravo@ufabc.edu.br (A.M. Cravo).

[1] Although the effect was originally named as intentional binding, some studies have questioned the role of intention and suggested different names, as causal binding (Buehner & Humphreys, 2009; Buehner, 2012). Therefore, in the rest of the text the more neutral term temporal binding is used to refer to this effect.

1053-8100/$ - see front matter © 2013 Elsevier Inc. All rights reserved.
http://dx.doi.org/10.1016/j.concog.2013.08.001

delayed effect, a life time experience might bias our timing judgments (Buehner, 2012; Eagleman & Holcombe, 2002). In fact, several studies have investigated how manipulating the causal relation between events have a strong influence on temporal binding (Moore & Haggard, 2008; Moore, Lagnado, Darvany, & Haggard, 2009; Moore, Middleton, Haggard, & Fletcher, 2012). Throughout a experimental session, this bias could either diminish, leading to a more accurate judgment effect timing at the end of the experiment, or it could stay fixed throughout the whole session.

On the other hand, one could argue that temporal binding is partially caused by other temporal effects, as temporal recalibration. In this effect, repeated exposure to a consistent delay between events can lead to a recalibration of simultaneity judgments (Fujisaki, Shimojo, Kashino, & Nishida, 2004; Keetels & Vroomen, 2008; Stetson, Cui, Montague, & Eagleman, 2006). Recent studies have found that recalibration can also occur between actions and their outcomes (Arnold, Nancarrow, & Yarrow, 2012; Stekelenburg, Sugano, & Vroomen, 2011; Stetson et al., 2006; Sugano, Keetels, & Vroomen, 2010). Translated to temporal binding, repeated exposure to action-effect interval throughout the experiment might lead to an adaptation of temporal delays, leading to a sense of temporal approximation between action and effect. Here, temporal binding would not be caused by an existing bias, but rather emerge as result of a faster and/or stronger recalibration between action-effect than between two external events. Although it is not clear why action would facilitate temporal recalibration, it has been proposed that this might be the case (Eagleman, 2008; Stetson et al., 2006).

Although neither account excludes the possibility of learning, it is in the very first contacts with a new action-effect delay that different predictions between bias and recalibration accounts emerge. If bias is the major cause of the binding effect, then participants should have shorter estimates of these intervals since the very beginning of the experiment. If, on the other hand, temporal recalibration is the major determinant, then compressed estimates between action and consequence should initially be absent to develop only throughout the experimental session.

Finally, both views are not mutually exclusive, and a mixture is possible. In this third account, a zero-interval bias exists, but at the same time, the perception of temporal interval can be modulated in a calibration-type mechanism through exposure to action-effect delays. Because most experiments measure temporal binding as a mean judgment of the whole experimental session, it is not possible to distinguish between these views based on currently published results. However, this differentiation is important since it has direct implications in determining which factors modulate temporal binding. For example, if bias plays an important role in this effect, then as long as participants have a strong sense that they are causing the outcome, the temporal compression between action and effect should occur. Importantly, this compression should be present in the very first exposures of the participant to the outcome. If, alternatively, action-effect learning is essential, then temporal binding should evolve as participants are exposed to a consistent temporal relation between action and effects.

In the present work, we investigated how temporal binding evolves throughout an experimental session. Specifically, we were interested whether temporal binding was result of a prior bias volunteers had about the timing of the consequences of their actions, or if it was result of an adaptation that occurred during the experimental session.

2. Materials and methods

Fourteen volunteers participated in a procedure approved by the University Ethics Committee. The experiment took place in a dimly lit room. Stimuli were presented on a 19" monitor (refresh rate 100 Hz). Stimulus presentation was controlled by a program for psychophysical experimentation—E-prime software (Schneider, Eschman, & Zuccolotto, 2002).

Each trial started with the presentation of fixation point (Fig. 1A). In Action trials, participants were instructed to press a button at the moment of their choice, which caused the immediate disappearance of the fixation point. After 250 ms, 300 ms or 350 ms of the button press, a target (a white central disk with a radius subtending a visual angle of 1°) was presented. In No-Action trials, the target was presented 250 ms, 300 ms or 350 ms after the disappearance of the fixation point, without any intervention of the observer.

In both conditions, participants made temporal estimates of the duration of the interval in milliseconds, between the button press and target onset (Action), or between fixation point disappearance and target onset (No-Action), by typing the estimate on a keyboard. Participants were told that none of the intervals would be longer than one second, thus only judgments between "1" and "1000" ms were considered valid answers. No reference or training was given in either task.

Each interval (250/300/350 ms) was presented 60 times, with a total of 180 trials in each condition (Action and No-Action). Participants performed three blocks of the same condition in sequence, with half of the participants performing the Action blocks first and the other half starting with No-Action blocks. Each block contained 20 trials for each interval, in randomized order, totalizing 60 trials per block. After each experimental block an interval screen was presented, indicating that the participants should take a short break and start the next block when ready.

3. Results

3.1. Exploratory ANOVAs

For each participant, the mean judgment of each condition and interval was calculated (Fig. 1B). The results were subjected to a repeated measures ANOVA with Action/No-Action and Interval (250/300/350) as within-subjects factors. There was a main effect of Action/No-Action ($F(1,13) = 7.82$, $p < .05$), with judgments from the Action condition being smaller.