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Robust intentional binding for causally-linked sequences of naturalistic events but not for abstract event sequences

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ABSTRACT

Past studies have shown that when a voluntary action produces a sensory effect, the action and the effect will be perceived as being closer in time. This subjective temporal 'attraction' is known as intentional binding (IB). Induction of IB is dependent on the intentionality of one's actions, the predictability of the effect, and the causality between the action and the effect. Previous investigations of IB have utilized abstract stimuli (e.g., flashes and beeps) with adaptation so as to associate the abstract action-effect link. Yet, events from our everyday experiences already have an inherent action-effect link. We, thus, investigated, for the first time, IB under naturalistic, multisensory stimulation by manipulating the intentionality, predictability, and causal event link. A total of five experiments without adaptation were conducted examining IB with: abstract stimuli (Experiment 1), naturalistic effects (Exp. 2), naturalistic action cue and effect matching (Exp. 3), naturalistic action cue and effect mismatching (Exp. 4), and naturalistic action cue and effect matching but mismatched response mapping (Exp. 5). Analyses of the data showed the absence of IB for abstract stimuli without action-effect adaptation (Exp. 1) and for effects that were not inherently causal or predictable of one's action (Exp. 2, 4, and 5). IB, however, was induced when the naturalistic sequence of action cue-effect was casually linked and predictable in terms of timing (Exp. 3). Overall, our results showed that induction of IB is dependent on the inherent causal and predictable association of an event from the cue to act to the consequence of that action, an association that is already present in everyday multisensory events.

1. Introduction

Our sense of timing can be distorted by a wide range of factors, which can, in turn, produce illusory percepts (Wenke & Haggard, 2009). One such illusory percept is that of the intentional binding (IB) phenomenon (Haggard, Clark, & Kalogeras, 2002) that refers to the perceived temporal "closeness" of an action and its effect when a voluntary action is involved. Specifically, it has been shown that voluntary actions causing an effect are being perceived later in time, while their effects are being perceived earlier in time (e.g., Haggard et al., 2002; Tsakiris & Haggard, 2003; Wenke & Haggard, 2009). The successful induction and robustness of IB is dependent on a number of factors such as those of intentionality (which is tied with the execution of a voluntary action, or else a goal-directed behavior; Engbert, Wohlschlager, & Haggard, 2008; Haggard et al., 2002; Hommel, 2003; Tsakiris & Haggard, 2003), causality (i.e., the percept that an observed effect is causally related or produced by a given action; e.g., Buehner & Humphreys, 2009; Cravo, Claessens, & Baldo, 2009), and a variety of temporal attributes (Cravo, Claessens, & Baldo, 2011; Engbert & Wohlschlager, 2007; Moore & Haggard, 2008).

Research on IB have shown that the phenomenon can only be observed in the presence of a voluntary action, while it disappears (i.e., no temporal displacement is observed) when involuntary actions (e.g., via transcranial magnetic stimulation, TMS, -induced twitch of a body part) or no actions are involved (e.g., Cravo et al., 2009, 2011; Engbert et al., 2008; Haggard et al., 2002; Tsakiris & Haggard, 2003). For instance, Engbert et al. (2008) had participants to either perform an action (i.e., pressing a lever or moving their right index finger) or just observe the execution of the same action by the experimenter (i.e., voluntary action by another agent), while using a time estimation task for the interval between the action and its effect. The results showed that interval judgments were significantly shorter for the cases where participants

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intentionally performed an action as compared to the cases of observing the experimenter's action (i.e., IB effect; Engbert et al., 2008; Engbert, Wohlschlager, Thomas, & Haggard, 2007). Intentionality of one's action, therefore, appears to be central in IB given that voluntary actions contain intent (or goal-directed behavior; Hommel, 2003), while involuntary actions do not. This was further demonstrated in a task requiring recall of previously produced actions, while voluntary and involuntary (TMS-induced twitches of the hand) movements were made using the same or different hands (i.e., congruent or incongruent conditions, respectively; Jensen, Vagnoni, Overgaard, & Haggard, 2014). In the incongruent conditions, where voluntary responses interfered with involuntary ones, only the latter were strongly influenced by the former and not the reverse (i.e., worst performance for involuntary actions, by incorrectly recalling the hand movements involved in the voluntary action). Such findings reveal the critical role of intentionality, which can even lead to altered involuntary action experiences, as participants responded mostly based on their intentions rather than on their actual body movements (Jensen et al., 2014). It must be noted, however, that some studies also showed a dissociation of intentionality from the biological agent of the intentional action (Buehner, 2012; Moore, Teufel, Subramaniam, Davis, & Fletcher, 2013; Poonian & Cunnington, 2013; Poonian, McFayden, Ogden, & Cunnington, 2015). Specifically, these studies showed that self-generated and observed actions resulted in a significant shortening of the temporal interval between the action and the effect for both conditions (Buehner, 2012; Moore et al., 2009; Poonian & Cunnington, 2013). These studies argued that the presence of IB even in the case of observed actions could indicate the recruitment of similar processes for causal attributions between self-generated actions, observed others' actions, and sensory events (Poonian et al., 2015).

This dependence of IB on the voluntary movement produced by the agent implies the role of the sense of agency (i.e., the sense of controlling one's own actions; Haggard & Chambon, 2012). The sense of agency consists of two levels, those of the attribution of an action to one's self (which can either be an explicit evaluation, i.e., judgment of agency, or an implicit process, i.e., feeling of agency) and the link of this action with the produced effect (Engbert et al., 2008; Synofzik, Vosgerau, & Newen, 2008). The direct link between attribution and voluntary action as seen in the previous studies (e.g., Engbert et al., 2007, 2008; Tsakiris & Haggard, 2003) has led researchers to utilize IB paradigms as an implicit measure of agency (Haggard et al., 2002). The second, however, level of agency that deals with the association of an action and the produced effect, has not as yet been linked with IB. For example, in the work conducted by Engbert et al. (2007), no differences of perceived action-effect time interval were found, when somatic stimulation was induced to the participant's or the experimenter's finger, or when identical movement kinematics were induced to a rubber hand.

The association of an action and its effects appears to be more depended on causal beliefs rather than intentionality. For instance, larger IB effects were observed when participants were adapted to believe that their actions were responsible for producing a tone as compared to identical cases but with the effects (i.e., tone) being attributed to another person (Desantis, Roussel, & Waszak, 2011). In general, the higher the association of an effect as a consequence of one's action, the higher the probability of temporal action-effect binding (i.e., IB effect; Buehner & Humphreys, 2009; Eagleman & Holcombe, 2002). Buehner and Humphreys (2009), therefore, re-named the IB phenomenon to “causal” binding, supporting that temporal binding is primarily a product of causality even when intentionality is also present. Specifically, in a stimulus anticipation task, participant groups were matched in terms of the intentionality of their actions (both groups had to synchronize two key responses with their respective tones), but differed in the causal action-effect link (i.e., one of the groups was adapted to associate the first key press with the second tone). Temporal binding was noted only for the adapted group as compared to the non-adapted group, thus strengthening the causal link of the action-effect rather than the intentionality of one's action for IB induction (Buehner & Humphreys, 2009). Some researchers, however, support that causality alone is not sufficient to lead to a temporal “compression” between the cause and effect of one's actions (e.g., Cravo et al., 2009; Moore & Haggard, 2008; Moore, Lagnado, Deal, & Haggard, 2009). In a more elaborate attempt to dissociate causality and voluntary action, Cravo et al. (2009) used two discs that either moved towards (collision condition) or away (non-collision condition) from each other. Participants' performance in a temporal estimation task (i.e., participants had to judge the interval between the movement offset and onset of the left and right disc) and a causality-rating task (i.e., participants had to rate the extent in which the first object caused the second object's movement) revealed a dissociation. That is, causality ratings were depended on the temporal contiguity of the two events, but not on the voluntary action, while temporal binding was obtained only when both voluntary action and high causality ratings were present. Thus, both causality and intentionality (as stated through voluntary actions) were crucial, but not sufficient in isolation, for the experience of IB (Cravo et al., 2009).

Research on IB has mainly used adaptive strategies to create a causal link between abstract events that lack an inherent causal relationship (e.g., Buehner & Humphreys, 2009; Cravo et al., 2009; Desantis et al., 2011). A common strategy to increase causal linking in an event is to manipulate the temporal attributes that determine the action-effect relation (see Moore & Obhi, 2012, for a review) such as temporal contiguity (i.e., temporal proximity of action-effect; Cravo et al., 2011; Haggard et al., 2002) and temporal predictability (i.e., ability to predict when in time a sensory event will appear; Cravo et al., 2011; Haggard et al., 2002; Hughes, Desantis, & Waszak, 2013). Temporal contiguity has been studied directly through the manipulation of the temporal proximity of the action-effect with successful induction of IB in the presence of small intervals in the range of 200 to 300 ms (Engbert & Wohlschlager, 2007; Engbert et al., 2007). In some cases, however, intervals of up to 650 ms have also been reported, but with the size of the IB effect to decrease as the intervals increased (Haggard et al., 2002; but see Humphreys & Buehner, 2009, 2010, for intervals of up to 4 s). As for temporal predictability, Haggard et al. (2002) showed a larger decrease in the IB effect when random temporal intervals were presented (i.e., low temporal predictability) as compared to fixed intervals, where larger perceptual shifts were observed even for the longer intervals tested. Thus, IB appears to not only be depended on the temporal proximity of the action-effect but also on the temporal predictability of this association. This notion was further elaborated in a study by Cravo et al. (2011). Specifically, in this study, the effect of a participant (i.e., finger lift) or a computer-initiated action (Action vs. No Action condition) was a tone and a temporally independent flash, in which tone-flash pair participants had to complete a simultaneity judgment (SJ) task. They also introduced different levels of predictability by utilizing fixed and random time intervals (Fixed vs. Random condition) between the action and its effect. The SJ analysis showed that the mere presence of voluntary action (Action condition) was not sufficient to produce IB, while its combined presence with temporal predictability (i.e., Fixed condition) did induce the phenomenon. Furthermore, in the absence of a voluntary action (No Action condition) neither temporal predictability nor temporal contiguity was able to temporally compress the audiovisual event sequence (Cravo et al., 2011), suggesting the necessary but not sufficient character of predictability in producing IB.

The intentionality, causality, and temporal predictability of an event are, therefore, the core factors determining the experience of IB. To date, however, the vast majority of studies that have investigated IB, have mainly focused on the utilization of abstract stimuli of low informational content (i.e., unisensory stimuli such as flashes or auditory tones of different frequencies etc.; e.g., Buehner & Humphreys, 2009; Cravo et al., 2009, 2011; Desantis et al., 2011; Engbert et al., 2008) ignoring multisensory, naturalistic events that already have an inherent causal link. For example, the image and sound of a hand hitting a