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Intentional Binding for Unintended Effects

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Abstract

We execute most of our movements in order to elicit an intended effect. This kind of intentionality is commonly assumed to drive a temporal illusion, referred to as Intentional Binding (IB): Stimuli intentionally elicited by one's own action (i.e., effects) are perceived as temporally earlier compared to unintentionally occurring stimuli (not elicited by one's own action). It is currently under debate whether intentionality is necessary for IB to occur, or whether causality might be sufficient for IB to occur. In the present study, we investigated the importance of an intention for the occurrence of IB. Employing a Libet Clock paradigm, we assessed IB for effects which participants were instructed to cause by their action (i.e., intended effect) as well as for effects participants were instructed not to cause by their action (i.e., unintended effect). Both effects, the intended as well as the unintended, were subject to IB, with a Bayesian analysis favoring no difference for both effect types. This implies that even an unintended effect is subject to IB and that, thus, causality instead of intentionality might be sufficient for IB.

Keywords

Intentional Binding, temporal binding, causal binding, causality, intentionality, clock paradigm

1. Intentional Binding for Unintended Effects

We perceive stimuli, which we — intentionally — elicit by our actions (i.e., effects) as earlier compared to stimuli not elicited by an action (Haggard et al., 2002a; for a review, see Moore & Obhi, 2012). This temporal illusion is typically referred to as temporal or Intentional Binding (IB; e.g., Haggard et al., 2002b).

Recently, a debate has arisen as to which aspect of the preceding action is decisively driving IB. This debate mainly questions whether an intention, as such,

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is necessary for IB to occur or whether causality between an action and an effect might be sufficient (e.g., Buehner, 2012, 2015; Buehner & Humphreys, 2009; Dewey & Knoblich, 2014; Kirsch et al., 2019). Most approaches to resolving this issue have focused on the action and, for example, manipulated the degree of intentionality of the eliciting action. A number of studies (e.g., Buehner, 2012, 2015; Buehner & Humphreys, 2009; Haggard et al., 2002b) have shown that passively-induced causing actions (e.g., due either to passive movement or to TMS triggering of the movement) revealed less or no IB compared to intentional actions. In the present study, we focused on the intentionality in eliciting a specific effect: we investigated whether IB differs for effects that are intended compared to those that are unintended.

To this end, we assessed IB by employing the typical clock paradigm (Haggard et al., 2002b; for a review see Tanaka et al., 2019; see Fig. 1). In this paradigm, participants see a rotating clock hand while they are asked to press a key (action); this is followed by the effect tone (experimental) or the tone occurs without the preceding action (baseline). In the experimental and baseline conditions, participants estimate the clock hand's position at tone onset and IB is computed as the difference between mean estimates in experimental and baseline conditions. In our study, the clock hand's color randomly changed between one of three possible colors; participants were instructed to act at the moment when the clock hand showed one particular color. The presentation of a following effect tone indicated whether they had succeeded in the task (i.e., intended effect) or not (i.e.,

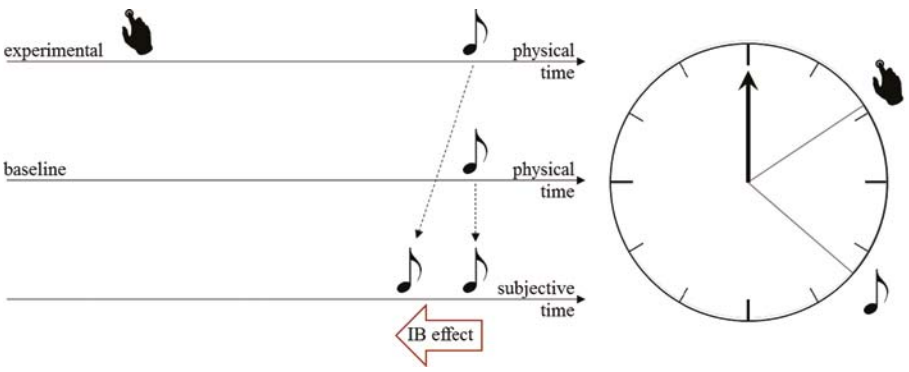

Figure 1. Clock paradigm (Haggard et al., 2002b). Participants saw a clock with a rotating clock hand; the clock hand randomly changed its color. In the experimental condition, they were asked to press a key the moment the clock hand showed a specific color. Participants were instructed that the following effect tone would indicate their success (i.e., intended effect) or failure (i.e., unintended effect). In the baseline condition, the tones were presented without any preceding action. After a randomly distributed additional 2 to 3 s of rotation, the clock hand stopped and participants were asked to estimate the position of the clock hand at the moment of tone onset. Intentional Binding (IB) was calculated as the differences between mean estimates in experimental and baseline conditions.

Table 1.
Mean estimated time points (relative to true event time) in baseline and experimental conditions and resultant Intentional Binding for intended and unintended effects.

	Baseline M	**Experimental M**	**Intentional Binding M**
Intended effect	21 (9.30)	−134 (21.13)	155 (16.49)
	[2.27; 39.73]	[−176.72; −91.59]	[121.95; 188.36]
Unintended effect	20 (10.11)	−136 (21.11)	157 (15.92)
	[−0.12; 40.61]	[−178.91; −93.86]	[124.56; 188.70]

Effects were either intended or unintended and this was manipulated by two different tone pitches which indicated (according to the instructions) either that the action succeeded (i.e., intended) or did not succeed (i.e., unintended). All numbers are displayed in ms. Please note that IB is displayed by positive values (see Method). Numbers in parentheses behind the mean estimates refer to the standard error and numbers in square brackets below estimates refer to 95% confidence intervals.

unintended effect). Thus, we conjecture that participants intend to comply with the instruction and solve the task correctly, that is, pressing at the right moment. The tone only signals that their intention was actually realized. In that sense the 'success' tone itself becomes a desired outcome, and is, thus, intended. Success signals are a common operationalization of 'intended' effects in the related literature (e.g., Desantis et al., 2011).

With this design, we were able to ask participants for time estimates for both effects, the intended and the unintended one. If intentionality is essential for IB, we would expect stronger IB for the intended effects in comparison to those that were unintended. If, however, causality is sufficient, we would expect no difference in the magnitude of IB for intended and unintended effects.

2. Method

2.1. Participants

In order to detect IB with a reasonable power ($1 - \beta = 0.95$), we would have needed at least 45 participants. Thus, in order to have an equal distribution between conditions, 48 participants were tested and received course credit for compensation. The data of two participants had to be excluded due to technical problems. The mean age of the remaining 46 participants was 23 ($SD = 7.07$, range 18–63 years; 29 females; 40 right-handed).

2.2. Apparatus and Stimuli

All materials were presented in German. The whole experiment was run using E-Prime 2.0 (Schneider et al., 2012) and presented on a standard PC (24" LCD

screen, 1920 × 1080 pixels, 144 Hz refresh rate). Parallel testing of two participants was possible (two computers were in the laboratory room). The so-called Libet Clock (Libet et al., 1983; Wundt, 1887; see Fig. 1) was presented. It involves the visual display of an analog clock with the clock hand revolving over the dial at a continuous pace (diameter 4.4 cm, 12 labeled 'minute' intervals, clock hand 1.5 cm, 2560 ms/full rotation; for a new open-source tool, see Garaizar et al., 2016). The background screen was white and the clock face black, whereas the clock hand changed its color each 150 ms, randomly switching between red, green, and blue (no direct color repetitions). In the experimental condition, the keys '1' and '2' of the standard computer keyboard (main board, not number pad) were operated with the middle and index finger of the left hand (as action); participants could choose between two key press alternatives because stronger IB in conditions with multiple action alternatives compared to only one fixed action has been reported in previous studies (Barlas & Obhi, 2013; Barlas et al., 2017, 2018) As intended or unintended effects (and as stimuli in the baseline condition), two sinusoidal tones (400 Hz or 800 Hz) were presented using Auna Base DJ 10014216 headphones for 150 ms. Participants entered time point estimates with their right hand using the number pad of the keyboard (1–9). The next trial started when participants confirmed the time point estimate using the enter key. The space key was pressed to confirm instructions and to continue with the procedure.

2.3. Procedure

At trial start, we presented the clock and the clock hand immediately started to rotate at a random position, with the clock hand randomly changing its color. In the experimental condition, we asked participants to press the response key only if the clock hand showed a specific color (which of the three colors was counterbalanced between participants). Further, we instructed them to wait until the clock hand had revolved at least once before pressing the response key, not to press at a pre-planned point in time or clock position, and to use both key alternatives approximatively equally often. The action (keystroke) caused one of two effect tones after a delay duration of 250 ms. We instructed participants that the pitch of the tone (low vs high) would indicate whether they succeeded in acting at the point in time of the right color of the clock hand (i.e., intended effect) or whether they failed (i.e., unintended effect; which tone pitch would indicate success or failure was counterbalanced between participants). In the baseline condition, we did not ask for a keystroke (no action) and presented one of the two tones randomly 2560–5120 ms after trial start. In both conditions, the clock hand disappeared 2000–3000 ms after tone occurrence. Participants had to, retrospectively, estimate the position of the clock hand at the moment of tone onset by using the number pad of the keyboard (in minutes 1–59; cf. Haggard et al., 2002b).

The whole experiment lasted about 45 minutes. The experiment started with four practice trials for the baseline and experimental conditions, respectively. It was followed by a baseline condition block of 20 trials, four experimental

condition blocks of 20 trials (four blocks × 20 trials = 80 trials overall), and it concluded with another baseline condition block of 20 trials (two blocks × 20 trials = 40 trials overall).

In the experimental conditions, effect tones were presented randomly (not action contingent), each just occurring approximately equally often. The instruction which tone would indicate success (i.e., intended effect) and which failure (i.e., unintended effect) was counterbalanced between participants. In the breaks after experimental blocks, participants received feedback on how often the intended and unintended effects had occurred (i.e., summed feedback was oriented at presented tone pitch occurrences, not at actual success/failure in acting at the right color); they also were told how often they had pressed the '1' and '2' key.

3. Results

For each participant, the differences between estimated and actual clock hand positions were computed trial-wise and transformed into temporal differences (angle difference * 2560 ms/60). We discarded trials in which the temporal difference deviated more than ±2.5 *SD* from the participant's mean difference in the respective condition (baseline vs experimental; low- vs high-tone pitch; on average 1.92%; cf. Ruess et al., 2017, 2018). We averaged temporal differences separately for each condition and calculated IB separately for intended and unintended effects (i.e., low- vs. high-tone pitch in baseline condition), subtracting experimental from baseline values (cf. Haggard et al., 2002b). Thus, positive values indicated IB occurrence (the time point of a tone was perceived earlier if it was caused by an action than when it was not caused by an action). We report all results with an α-level of 0.05. Two-tailed one-sample *t*-tests were conducted.

The IB was significant for both the intended, $t_{45} = 9.41, M = 155.15, SE = 16.49$, $p < 0.001$ and unintended effect, $t_{45} = 9.84, M = 156.63, SE = 15.92, p < 0.001$.

A *t*-test revealed that IB did not differ significantly for intended and unintended effects, $t_{45} = 0.252$, $p > 0.250$, $\underline{d} = 0.037$. An analogous Bayesian test (Rouder et al., 2009) provided substantial evidence in favor of the null: BF01 = 6.25.

4. Discussion

In the present study, we investigated whether intentionality impacts on IB. Instead of manipulating the intentionality of the action, as was the case in previous studies (e.g., Buehner, 2015; Haggard et al., 2002b), we manipulated whether an effect was the one intended by the actor or not. We observed IB not only for intended effects, but also for unintended effects. Above that, the magnitudes of IB for intended in comparison to unintended effects did not differ.

From a theoretical point of view, these results add to the debate about the importance of intentionality for IB. Whereas IB is still widely employed as one of the most important implicit indicators for Sense of Agency (Berberian et al., 2012;

Moore, 2016), some authors (e.g., Buehner, 2015) have questioned whether intentionality is necessary for IB effects to occur at all. Buehner suggests that IB is rather due to mere causality, without necessarily involving any intentionality. Our results are in line with the latter perspective, that is, suggesting that IB is driven by mere causation — without necessarily the involvement of an intention to elicit a specific effect.

Yet, whereas Buehner observed IB as well for effects elicited by an unintentional instance (e.g., a movement; Buehner, 2015), we observed IB even for unintended effects. More precisely, previous results showed that effects caused by a movement without intending any effect do in fact trigger IB. We, however, show that IB also occurs even when one did actually intend something else; yet, what eventually occurred was explicitly different from one's intention. Consequently, IB not only occurs for non-intended stimuli, but also for decidedly unintended effects.

This is also surprising with regard to some previous results of similar but not the same interest: On the one hand, some studies showed less IB for effects of negative valence (Takahata et al., 2012; Yoshie & Haggard, 2013). These results could be interpreted as inconsistent with our findings in the sense that we observed no change in IB for an unintended effect with, assumedly, negative valence.

On the other hand, a recent study observed different duration perception for an intended in comparison to an unintended effect with longer duration for an intended one (Makwana & Srinivasan, 2017). Accordingly, one might have expected differences in the temporal perception of the effect occurrence, yet, we did not observe any. As we asked participants to estimate the time point at effect onset, it might indicate, speculatively, that rather the end of the effect is perceived later for an intended compared to an unintended effect.

One might argue that the color changed too fast for participants to react in time, which might have resulted in participants not intending to press the response key in time anymore. Thus, the insignificance of the difference for intended and unintended effect IB might be rather due to a failure to manipulate intention. However, in a post-survey participants reported to make a similar effort for reacting in time as in estimating correctly the time point of action execution.

Please note, recent approaches trying to explain IB discuss postdictive processes to contribute to IB together with predictive processes. Whereas postdictive processes refer to rather higher-order influences, predictive processes are often explained in terms of pre-activation of the representation of an effect elicited by an action, due to motor predictions. This results in the activation threshold to be achieved earlier for an action-elicited effect compared to a stimulus occurring without preceding action (cf. Synofzik et al., 2013). Another account which can be interpreted in line with these predictive processes is the Ideomotor Theory (cf. Greenwald, 1970; Herbart, 1825; James, 1890; for more recent works see, e.g., Dignath et al., 2014; Hommel et al., 2001; Kiesel & Hoffmann, 2004; Shin et al., 2010; Thomaschke et al., 2012). It assumes that actions and effects are

bidirectionally bound; thus, an anticipated effect can activate the execution of the specific action. This anticipation is considered to result in the observed IB (Haggard et al., 2002b). In our study, about 50% of effects were unintended; thus, participants might have anticipated even an unintended effect. Consequently, our results do not speak against anticipation as essential for IB, even though the results show that unintended effects are subject to IB in a similar way as intended effects are.

Moreover, the fact that even unintended effects are subject to IB might be important for the acquisition of new action–effect relationships. In our everyday life, we do not always elicit the same effect by an action; indeed, necessarily, we have to flexibly adapt to changes in the environment. Thus, it is important that our represented action–effect relationships stay dynamic and can be changed or new ones acquired. In line with this, IB might not just be a detrimental byproduct of action execution; rather, it might be functional in the sense of essentially contributing to the construction of our causal perception.

From a methodological point of view, it has to be considered that just the identity of the effect was unintended, whereas overall, an effect was expected and thus, even the unintended effect — at least to some degree — was expected. This might be interpreted in line with previous results (Haering & Kiesel, 2014) observing no influence of the effect identity on the magnitude of IB. However, in those studies, the identity was uninformative and, hence, irrelevant, while in the present study the non-intended effects were clearly unintended. Future studies might try to investigate in more detail whether or not a totally unexpected effect is subject to IB as well.

Overall, our results support the idea that intentionality is less important for IB to occur than some previous theories (e.g., Buehner, 2012) have suggested: Even an unintended effect can show IB with the same magnitude as an intended one; thus, IB, does not seem to be specific for intended effects but rather specific for causal effects.

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Supplementary Material

Raw data are available at Open Science:
https://osf.io/p4jua/?view_only=f329b077ccc74b84a9cad3dcf8bb9934

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