Acting and Reacting:

Is Intentional Binding Due to Sense of Agency or to Temporal Expectancy?

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Abstract

Intentional Binding (IB) refers to the phenomenon that we perceive effects we caused by a voluntary action earlier compared to stimuli we did not cause by our action. Although IB has been investigated in numerous studies and is routinely employed as an implicit measure for Sense of Agency, its underlying mechanisms are not yet clear. We investigated whether IB is based on Sense of Agency, or on temporal expectancy. To this end, we compared how delay duration (250 ms vs. 600 ms) and duration predictability (valid vs. invalid) influence IB regarding Sense of Agency, measured as agency judgment (AJ), and temporal expectancy, measured as reaction time benefit (RTB). Results pattern were quite similar for IB and AJ, but different for IB and RTB: IB and AJ decreased for longer delay durations, whereas the RTB increased for longer delay durations. An additional interaction of delay duration and duration predictability was only significant for AJ and RTB. Yet, the interactional pattern of delay duration and duration predictability on AJ did not differ from the result pattern of IB. Overall, results indicate IB to be rather driven by Sense of Agency than by temporal expectancy.

Keywords: sense of agency, intentional binding, delay duration, temporal expectancy

Public Significance Statements

- Stimuli are perceived earlier when they are caused by an action than when they are not caused by an action – an effect referred to as intentional binding.
- We tested whether intentional binding is really driven by the action causing the stimulus, or merely by the action making the stimulus temporally predictable.
- Our results suggest that on the one hand intentional binding is really driven by the action causing the effect, but that on the other hand intentional binding is not strictly dependent on sense of agency.

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We perceive a stimulus (e.g., a sound) we elicited by our intentional action (e.g., a keystroke) earlier in time compared to a stimulus not elicited by our action (Intentional Binding; IB; Haggard, Clark, & Kalogeras, 2002; for a review see Moore & Obhi, 2012). However, it is not yet clear which aspect of an action drives IB. Haggard et al. (2002) suggested Sense of Agency to be the crucial aspect: We perceive the external stimulus earlier because we perceive it to be caused by our own preceding action. More precisely, temporal perception seems to differ if a voluntary action is involved (e.g., Bueti & Walsh, 2010; Haggard et al., 2002; Mioni, Stablum, McClintock, & Grondin, 2014), that is, if the causing instance is a voluntary action (i.e., causation by a vivid aspect of the environment) and not just a mere stimulation (i.e., causation by another stimulus). In fact, besides measuring Sense of Agency explicitly by asking for a judgment of the degree of agency (agency judgment, AJ), many studies also often assess Sense of Agency indirectly, using IB as an implicit measure (Moore, 2016).

Yet, Hughes, Desantis, and Waszak (2013) have argued that IB is substantially driven by temporal expectancy as well: The action serves as a warning signal for the effect (independently from causing it), thereby inducing IB merely by making it temporally predictable that after a certain delay the effect will occur. After temporally predictable stimuli, we are known to be more reliably prepared at the correct moment of target occurrence compared to after less predictable and, thus, less expected stimuli (Näätänen, Muranen, & Merisalo, 1974; Seibold, Fiedler, & Rolke, 2011), independent from any causal relationship between warning signal and predicted stimulus. Studies investigating temporal expectancy typically measure reaction times (RTs) to stimuli following a warning signal with a delay (e.g., a sound) and the duration of the delay is more or less predictable by different means (see Thomaschke & Dreisbach, 2015, for an overview). RTs to stimuli preceded by a warning signal are shorter compared to RTs to stimuli without a warning signal (reaction time benefit; RTB; Wundt, 1874).

Please note, this benefit from expectancy on RT might be due to sped up processing in perceptual (Bueti, Bahrami, Walsh, & Rees, 2010; Rolke, 2008; Seibold, Bausenhart, Rolke, & Ulrich, 2011; Seibold, Fiedler, et al., 2011; Seibold & Rolke, 2014a, 2014b), central (Broadbent & Gregory, 1965; Hackley & Valle-Inclánb, 2003), as well as motor (Mattes & Ulrich, 1997; Sanders, 1980) processing stages (see Thomaschke, Hoffmann, Haering, & Kiesel, 2016; Thomaschke, Kiesel, & Hoffmann, 2011, for discussions). However, we do not make any presumption concerning the exact process responsible for expectancy speeding up RT, because all cited studies agree that RT is a direct measure of expectancy, and the latter aspect is crucial for the present study.

Theoretically, temporal expectancy can be manipulated orthogonally to Sense of Agency. Yet, the majority of empirical studies in IB confound both manipulations, in the way that the Sense of Agency condition is also temporally predictable. Thus, both accounts can potentially explain the majority of existing IB studies.

Interestingly, Sense of Agency in terms of AJ, and temporal expectancy in terms of RTB, do both strongly depend on whether the delay between action and effect – or warning signal and target – is short or long (i.e., the duration). Former investigations on AJ with durations between 0 ms to 1000 ms, observed strong AJ for very short durations (also < 300 ms) with a decrease for longer durations (Wen, Yamashita, & Asama, 2015). On the contrary, former investigations on RTB reliably observed RTB only for durations longer than 300 ms (Bertelson & Tisseyre, 1968; Los & Schut, 2008; Niemi & Näätänen, 1981). In addition, for RTB, the influence of duration depends crucially on the predictability of this duration. With a predictable, constant duration between warning signal and target stimulus, RTs increase with duration (Los & Van Den Heuvel, 2001; Steinborn, Langner, & Huestegge, 2017), whereas, for unpredictable, varying durations, RTs decrease with duration (Steinborn & Langner, 2011). For AJ, predictability had less impact in a previous study (Ruess, Thomaschke, & Kiesel, 2017a). Thus, duration and predictability divergently influence AJ and RTB. Furthermore, for IB, the influence of duration awaits further clarification and results of the influence of predictability on IB are rather mixed (Ruess, Thomaschke, & Kiesel, 2018; Ruess, Thomaschke, & Kiesel, 2017b).

So far, studies tried to reveal the driving aspect of IB mainly by investigating, in a correlative manner, how IB relates to AJ (e.g., Dewey & Knoblich, 2014). Yet, besides Sense of Agency measured by AJ, alternative potential driving aspects, like temporal expectancy measured by RTB, need to be investigated. In addition, instead of assessing mere correlations, the measures' variability depending on manipulated factors (i.e., like duration and predictability) needs to be assessed and compared with IB's variability depending on the same factors in order to more clearly determine which aspect drives IB.

In the present study, we aimed to investigate, whether IB is rather driven by Sense of Agency or by temporal expectancy. To this end, we assessed IB as well as AJ, for Sense of Agency, and RTB for temporal expectancy. We measured all three under the same duration and predictability variations, by employing a duration of 250 ms and of 600 ms and by presenting one of the durations predictably (i.e., in 80% of all trials) and the other one unpredictably (i.e., in 20% of all trials). Thus, we were able to compare the pattern of influence of duration and predictability on IB with the pattern of influence of both variables on AJ and RTB, respectively.[1] On the one hand, if Sense of Agency mainly drives IB, we would expect a similar results pattern for IB and AJ. This would mean strong IB and AJ

[1]Orthogonally manipulating Sense of Agency and temporal expectancy was not possible, because Sense of Agency automatically coincides with temporal expectancy in the applied paradigm.

already for short durations smaller than 300 ms with a decrease of IB and AJ for longer durations and no influence of predictability. On the other hand, if temporal expectancy mainly drives IB, we would expect a similar results pattern for IB and RTB. This would mean, no or less IB and RTB for short durations smaller than 300 ms and an interaction of the duration factor with the predictability factor for IB and RTB, in terms of an increase of both measures for predictable durations, but a decrease of both measures for unpredictable durations.

Method

Participants.

Seventy-eight participants (52 females, mean age = 25.96, *SD* = 6.76) were tested, in exchange for 24 Euros or partial research course credit. Data of one participant was excluded, due to technical problems. Sample size was determined by a power analysis for the interaction of duration and predictability. Based on own previous studies on IB with similar designs (Ruess, Thomaschke, & Kiesel, 2017b), we estimated an effect size of $\eta^2_p = .06$. Thus, in order to detect IB with an α-level of .05, and a statistical power of $1-\beta = .99$, a sample of $N = 74$ was required. Because some more participants had signed in for the study, we finally collected the data of 78 participants.

Apparatus and stimuli.

All materials were presented to participants in German. The experiment was run using E-Prime 2.0 (Schneider, Eschmann, & Zuccolotto, 2012) and presented on a standard PC with a 24” LCD screen (1920 pixels x 1080 pixels, 144 Hz refresh rate). For reasons of comparability, the so-called Libet Clock (Libet, Gleason, Wright, & Pearl, 1983; Wundt, 1887; see Figure 1) was presented in all three parts of the experiment (i.e., IB, AJ, and RTB), although it was relevant only to assess IB. It involves the visual display of an analogue clock (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, Cubillas, & Matute, 2016). In the experimental conditions, the keys “1” and “2” of the keyboard (main board, not number pad) were operated with the index and the middle finger of the left hand (as action; Barlas, Hockley, & Obhi, 2017). As effect (and as stimulus in the baseline conditions) a sinusoidal tone of 400 Hz was presented for 150 ms by Auna ANC-10 10028682 headphones.

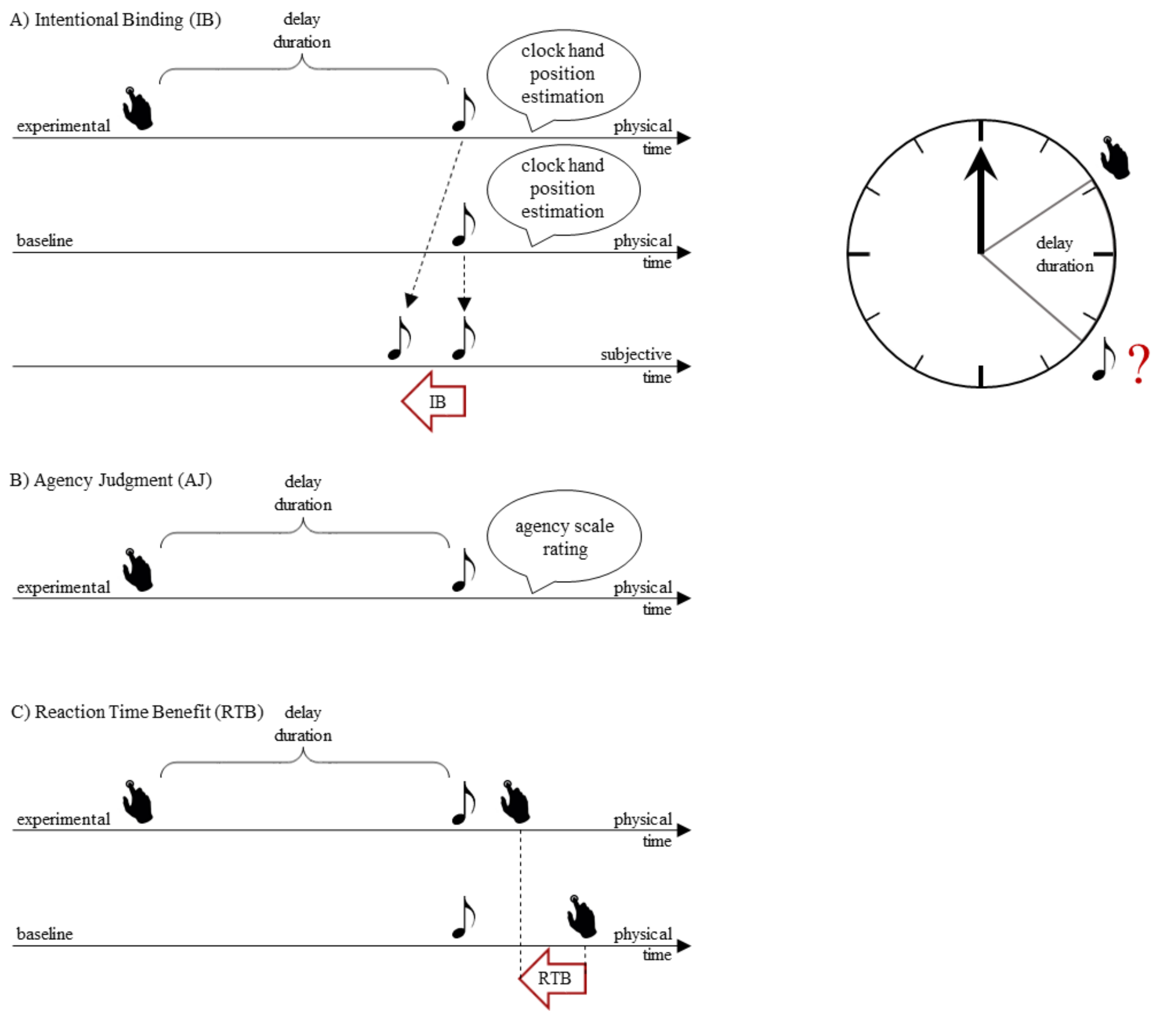

Figure 1. Clock paradigm for assessing Intentional Binding (IB; upper panel, A), Agency Judgment (AJ; middle panel, B) paradigm for assessing Sense of Agency, and Reaction Time Benefit (RTB; lower panel, C) paradigm for assessing temporal expectancy.

A) In the experimental conditions of the clock paradigm (Haggard et al., 2002), participants saw a rotating clock hand while we asked them to press one of two possible keys. The keystroke (action) was followed by the effect tone either after a short (250 ms) or after a long (600 ms) duration. This duration was either validly predicted by the keystroke (in 80% of the trials), or invalidly predicted (in 20% of the trials; complementary probabilistic mapping for the two key alternatives). In the baseline condition, the tone occurred without preceding action (keystroke). In the experimental and baseline conditions of the IB part, participants estimated the clock hand's position at tone onset. IB was calculated as the difference between mean estimates in experimental and baseline conditions (separately for all four duration conditions: short vs. long, valid vs. invalid).

B) In the AJ part, there was only an experimental condition, in which the participants' action caused the effect tone. Participants judged to which degree their action had influenced the occurrence of the following tone by selecting the respective position on a scale (Haering & Kiesel, 2016). We calculated AJ as mean AJs on effect occurrence, separately for all four duration conditions.

C) In the RTB part, there was an experimental and baseline condition, similar to the IB part. Yet, instead of asking for temporal estimates of tone occurrence, we asked participants to react after tone occurrence as fast as possible by pressing a key. RTB was calculated as the difference between mean reaction times in experimental and baseline conditions (separately for all four duration conditions: short vs. long, valid vs. invalid).

Procedure.

In three sessions (à 1 h) on separate days, we assessed all, IB, AJ, and RTB. We held the order of the three parts constant in all three sessions for each participant, but counterbalanced across participants.

At trial start, we presented the clock and the clock hand immediately started to rotate at a random position. In the experimental conditions, participants had to wait until the clock hand had revolved at least once before pressing one of the two possible keys at a freely chosen point in time (the action). We instructed them not to press at a pre-planned clock position or point in time and to randomly choose which key to press, merely trying to press each key roughly equally often. In the breaks between blocks, participants received feedback on how often they had pressed the right and left key (only after experimental blocks). The action (keystroke) caused the effect (tone occurrence) after a delay duration of either 250 ms or 600 ms. In the baseline condition, we did not ask for a keystroke (no action) and presented the tone randomly 2560 ms to 5120 ms after trial start. In experimental and baseline conditions, the clock hand disappeared 2000 ms to 3000 ms after tone occurrence.

The rest of the trial procedure differed for the three parts: In the IB part, 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 (right hand, in minutes 1 – 60; cf. Haggard et al., 2002). In the AJ part, participants had to indicate their AJ on a visual analogous scale ranging from 0% to 100% (cf. Haering & Kiesel, 2016; see Figure 2). Participants chose the desired position on the scale by tracing and left pressing the mouse cursor. In the RTB part, participants had to react as fast as possible after tone onset (while the clock was still visible) by pressing the “k” key of the keyboard (right hand). If participants did not react within 3000 ms, we reminded them to react as fast as possible and, after confirming by pressing the space key, the trial restarted. If participants reacted before tone occurrence, we reminded them not to (re)act before tone occurrence and the trial restarted.

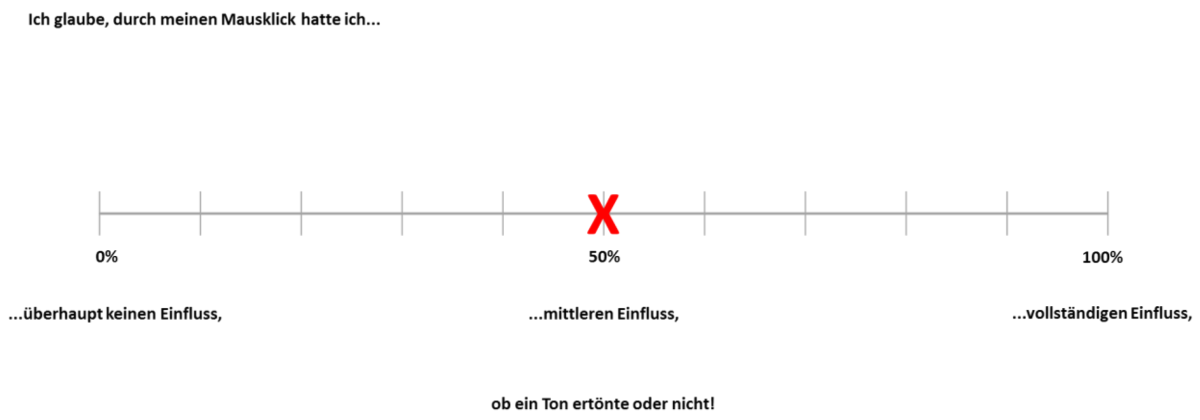

Figure 2. Scale for judging the degree to which the participants' action (keystroke) influenced the occurrence of the following effect tone (i.e., "I think with my mouse click I had … influence on tone occurrence"; Agency Judgment, AJ; Haering & Kiesel, 2016). The scale ranged from 0% ("no influence at all"), 50% ("medium influence"), up to 100% ("total influence"). The AJ part consisted only of an experimental condition where the effect was elicited by one of two action alternatives either after a short (250 ms), or long (600 ms) duration, and this duration was either valid (high predictability; in 80% of the trials), or invalid (low predictability; in 20% of the trials).

Participants were not informed about the hypotheses, though the effects under scrutiny operate typically below participants awareness (e.g., Moore & Obhi, 2012; Thomaschke & Dreisbach, 2015). The IB and RTB part started with 2 practice trials for the baseline and experimental conditions, respectively (in the experimental practice trials, effects occurred after a delay of 425 ms). It was followed by a baseline condition block of 15 trials, two experimental condition blocks of 50 trials (50 trials x 2 blocks x 3 sessions = 300 trials overall), and it concluded with another baseline condition block of 15 trials (15 trials x 2 blocks x 3 sessions = 90 trials overall). The AJ part also comprised the same structure, except that it did not include a baseline condition, because it would not make any sense to ask for AJ if no action was required.

In the experimental conditions, each of two key alternatives caused the effect either after a valid (high predictability; in 80% of the trials; 40 trials x 2 blocks x 3 sessions = 240 trials overall for each part) or after an invalid (low predictability; in 20% of the trials; 10

trials x 2 blocks x 3 sessions = 60 trials overall for each part) duration. The probabilistic mapping of key alternative to duration was constant throughout the whole experiment for each participant, but counterbalanced across participants.

Data analysis.

For IB, for each participant, we computed the trial-wise differences between estimated and actual clock hand position at effect occurrence , and transformed the resulting angle differences into temporal differences (angle difference * 2560 ms/60). We discarded trials in which the temporal difference deviated more than +/– 2.5 *SD* from participant’s mean difference in the respective condition (baseline vs. experimental; short vs. long, valid vs. invalid duration; on average 2.08%; cf. Ruess, Thomaschke, & Kiesel, 2018, 2017b). We averaged temporal differences separately for each condition. Finally, we calculated IB separately for all four duration conditions (short vs. long, valid vs. invalid), subtracting experimental from baseline values (cf. Haggard, Clark, & Kalogeras, 2002). Thus, positive values indicate IB occurrence (the time point of a tone was perceived earlier if it was caused by an action than if it was not caused by an action).

For AJ, for each participant, we transformed the trial-wise mouse cursor position into percentage values. We discarded trials in which these values deviated more than +/– 2.5 *SD* from participant’s mean value in the respective duration condition (on average 2.08%). Finally, we averaged the trial-wise percentage values separately for all four duration conditions.

For RTB, for each participant, we excluded from analyses every first trial of a block and all trials after too fast reaction trials (keystroke before effect). In addition, we discarded all trials in which the RTs deviated more than +/– 2.5 *SD* from participant’s mean RTs in the respective condition (on average 3.13%). We averaged RTs separately for each condition. Finally, we computed RTB separately for all four duration conditions, subtracting experimental from baseline RTs. Thus, positive values indicate RTB occurrence (RTs were faster after action effects than after stimuli not caused by an action).

We excluded one participant's data from analyses due to a significant deviation of IB from the mean IB of all participants (Tukey, 1977). We report all results with α-level of .05.

Results

IB results.

All conditions (short vs. long, valid vs. invalid) showed significant IB, *p*s < .001 (see Appendix A). In a within-subjects 2 x 2 ANOVA (duration and predictability), we observed a significant main effect of duration, $F(1, 75) = 6.78$, $p = .011$, $\eta^2_p = .08$, $M_{250\ ms} = 58$, $SE_{250\ ms} = 6.30$, $M_{600\ ms} = 42$, $SE_{600\ ms} = 5.90$. The main effect of predictability and the interaction duration x predictability were not significant, $p > .250$, $\eta^2_{p\ (predictability)} < .01$, $\eta^2_{p\ (duration\ x\ predictability)} = .01$ (see Figure 3).[2]

[2]The average action time after trial start was $M = 3414$, $SE = 1037.43$.

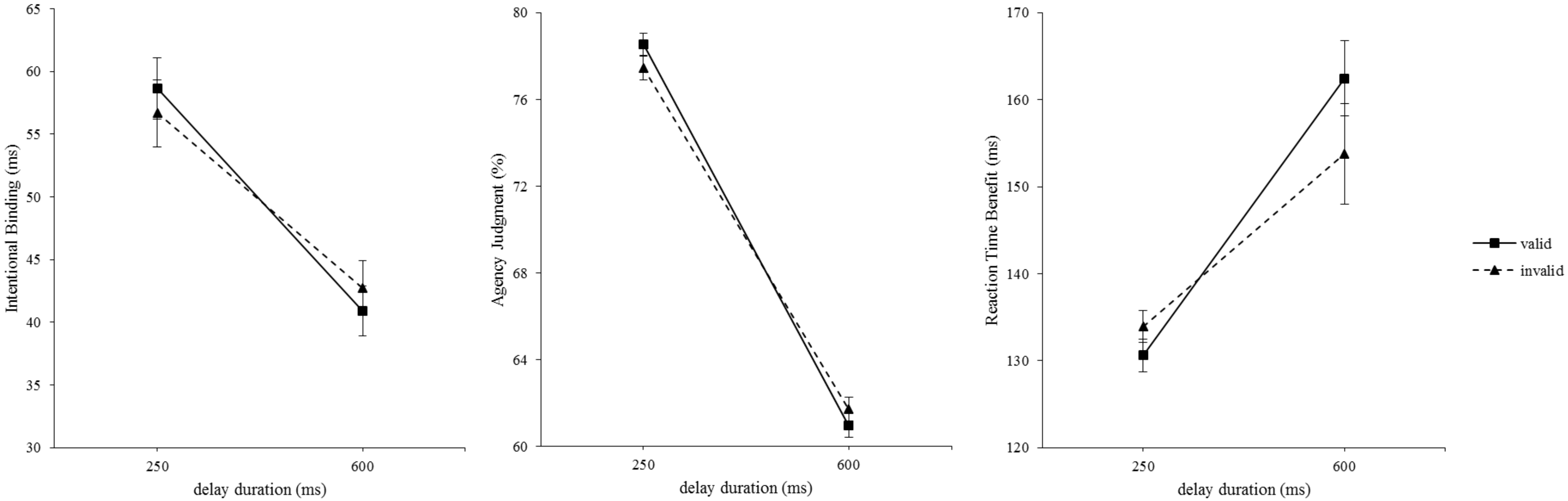

Figure 3. Intentional Binding (IB), Agency Judgment (AJ), and Reaction Time Benefit (RTB), depicted as separate graphs (from left to right). Each graph shows the measures depending on duration (250 ms vs. 600 ms) and predictability (valid vs. invalid). We indicate IB by positive values (baseline minus experimental conditions), AJ in percentage (%) of perceived influence on effect tone occurrence, and RTB (baseline minus experimental conditions) by positive values (see Method). Error bars represent inferential confidence intervals, according to Tryon (2001). The intervals are analogous to paired-sample *t*-tests between valid and invalid conditions.

AJ results.

For all conditions (short vs. long, valid vs. invalid), AJ was significantly larger than 50%, *p*s < .05 (see Appendix A). In a within-subjects 2 x 2 ANOVA (duration x predictability), we observed a significant main effect of duration, $F(1, 75) = 74.04$, $p < .001$, $\eta^2_p = .50$, $M_{250\ ms} = 77.99$, $SE_{250\ ms} = 2.36$, $M_{600\ ms} = 61.35$, $SE_{600\ ms} = 2.78$, and a significant interaction of duration x predictability, $F(1, 75) = 4.14$, $p = .045$, $\eta^2_p = .05$. The short valid compared to the short invalid condition differed significantly, $t(65) = 2.15$, $p = .035$, but not the long valid compared to the long invalid condition, $t(65) = -1.33$, $p = .186$. The main effect of predictability was not significant, $p > .250$, $\eta^2_p < .01$ (see Figure 3).

RTB results.

All conditions (short vs. long, valid vs. invalid) showed significant RTB, *p*s < .05 (see Appendix A). In the within-subjects 2 x 2 ANOVA (duration x predictability), we observed a significant main effect of duration, $F(1, 75) = 51.15$, $p < .001$, $\eta^2_p = .41$, $M_{250\ ms} = 132.30$, $SE_{250\ ms} = 5.53$, $M_{600\ ms} = 158.13$, $SE_{600\ ms} = 4.64$, and a significant interaction of duration x predictability, $F(1, 75) = 5.39$, $p = .023$, $\eta^2_p = .07$. The short valid compared to the short invalid condition, $t(65) = -1.80$, $p = .077$, and the long valid compared to the long invalid condition, $t(65) = 1.71$, $p = .091$, did not differ significantly from each other. The main effect of predictability was not significant, $p > .250$, $\eta^2_p = .07$ (see Figure 3).

Correlations.

We did not observe significant correlations of participants' mean IB, mean AJ, and mean RTB values, *p*s > .05, $r_{(IB\ AJ)} = -.20$, $KI_{(IB\ AJ)}$ = [- .43; .03], $r_{(IB\ RTB)} = .05$, $KI_{(IB\ RTB)}$ = [-.17; .28], $r_{(AJ\ RTB)} = -.09$, $KI_{(AJ\ RTB)}$ = [-.32; .13]; see Appendix B.

Discussion

We investigated whether IB is rather driven by Sense of Agency or by temporal expectancy. Therefore, we assessed whether the pattern of influence of duration (between keystroke, i.e., action, and effect tone; 250 ms vs. 600 ms) and predictability (valid vs. invalid) on IB is akin to the influence of both variables on AJ (explicit Sense of Agency) or akin to their influence on RTB (temporal expectancy). We observed a similar influence of duration for IB and AJ, with a decrease of both measures for longer durations, whereas RTB increased for longer durations. However, we observed an influence of predictability in terms of an interaction of duration and predictability only for AJ and RTB, whereas for IB we did not find an influence of predictability.

Overall, results pattern were quite similar for IB and AJ: The stronger IB and AJ for the short compared to the long duration is in line with previous studies investigating the influence of duration on IB (e.g., Haggard et al., 2002; Ruess, Thomaschke, Haering, et al., 2017) and AJ (e.g., Wen, et al., 2015), respectively. However, for AJ, we observed a modulation by predictability in that we observed an influence of predictability only for shorter durations. For IB, numerically, we observed a similar interaction. Yet, this did not reach significance.[3]

The different influence pattern of duration and predictability on IB and RTB indicates that IB is rather independent from temporal expectancy. It speaks against a functional role of IB for eliciting RTB of action effects. Either IB has some other functions or it may be rather a byproduct of action execution that could be interpreted as a detrimental distorted time perception in action contexts. In all four conditions, we observed a RTB with the mere presence of a warning signal in the sense of an action, relative to when there is no such signal. Yet, like the common RTB, with a stimulus as warning signal instead of an action (Wundt, 1874), we observed that a RTB needs time to build up: The RTB was weaker for short compared to longer durations. This results pattern is often referred to as *variable*

[3]The difference between IB and AJ with regard to the significance of the predictability x duration interaction might suggest at first sight a true difference between IB and AJ. Yet, a follow up analysis revealed that the difference in significance is more likely due to random than to a true underlying difference. We calculated the numeric size of the interaction for each participant for IB and for AJ and compared these scores by a *t*-test. The test was not significant: $t(75) = 1.29$, $p = .201$. An analogous Bayes test (Rouder, Speckman, Sun, Morey, & Iverson, 2009) provided even moderate evidence in favor of the Null: $\lambda = 4.24$.

foreperiod effect (e.g., Bertelson & Tisseyre, 1968; Los & Schut, 2008; Niemi & Näätänen, 1981; Steinborn, Rolke, Bratzke, & Ulrich, 2009). Additionally, for short durations the RTB was stronger for unpredictable compared to predictable durations, whereas for long durations it was the opposite. Yet, both tendencies were only marginally significant.

Overall, our results indicate that IB is rather driven by Sense of Agency (i.e., similarity to AJ) than by temporal expectancy (i.e., no similarity to RTB).

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Appendix A: Mean Baseline and Experimental Condition Values and Resulting Intentional Binding and Reaction Time Benefit, and Mean Experimental Condition Values of Agency Judgment

Table A

Results in baseline (BL; only for intentional binding, IB, and reaction time benefit, RTB; not for agency judgment, AJ), experimental (EX; only for IB and RTB) conditions, and dependent measure (DM; for IB and RTB calculated as difference of BL - EX)

	Delay Validity	Delay Duration	BL *M*	EX *M*	DM *M*
IB					
			55 (9)	/	/
	Valid	250 ms	/	-4 (12)	59 (6)
		600 ms	/	14 (10)	41 (6)
	Invalid	250 ms	/	-2 (12)	57 (7)
		600 ms	/	12 (10)	43 (6)
AJ					
	Valid	250 ms	/	/	79 (2)
		600 ms	/	/	61 (3)
	Invalid	250 ms	/	/	77 (2)
		600 ms	/	/	62 (3)
RTB					
			429 (4)	/	/
	Valid	250 ms	/	299 (6)	131 (6)
		600 ms	/	267 (5)	162 (4)
	Invalid	250 ms	/	295 (5)	134 (6)
		600 ms	/	276 (7)	154 (6)

Note. Two different delay durations between action and effect were employed (250 ms vs. 600 ms) and mapped to response keys either validly (in 80% of the trials) or invalidly (in 20% of the trials). All IB and RTB results are displayed in ms. All AJ results are displayed in %. Standard errors are depicted in parentheses behind means.

Appendix B: Correlations of Intentional Binding, Agency Judgment, and Reaction Time Benefit

Table B

Correlations of mean IB, mean AJ, and mean RTB and of each IB, AJ, and RTB delay condition (valid vs. invalid, short vs. long)

			IB	AJ	RTB	IB				AJ				RTB			
						Valid		Invalid		Valid		Invalid		Valid		Invalid	
			mean	mean	mean	250 ms	600 ms	250 ms	600 ms	250 ms	600 ms	250 ms	600 ms	250 ms	600 ms	250 ms	600 ms
IB		mean	1	-.197	.053	.877**	.858**	.838**	.828**	-.168	-.201	-.161	-.173	.028	.07	.058	.053
AJ		mean		1	-.09	-.185	-.151	-.205	-.132	.916**	.943**	.898**	.938**	-.136	-.038	-.114	.028
RTB		mean			1	.104	-.018	.065	.025	-.029	-.124	-.009	-.16	.959**	.907**	.927**	.695**
IB	Valid	250 ms				1	.512**	.923**	.497**	-.145	-.2	-.153	-.161	.13	.085	.116	-.031
		600 ms					1	.496**	.945**	-.144	-.143	-.117	-.139	-.092	.038	-.026	.124
	Invalid	250 ms						1	.451**	-.163	-.218	-.188	-.166	.084	.032	.088	.021
		600 ms							1	-.12	-.13	-.103	-.12	-.037	.077	.027	.088
AJ	Valid	250 ms								1	.732**	.981**	.738**	-.06	-.014	.043	.084
		600 ms									1	.714**	.981**	-.175	-.05	-.155	-.019
	Invalid	250 ms										1	.703**	-.054	.024	-.037	.095
		600 ms											1	-.202	-.097	-.174	-.044
RTB	Valid	250 ms												1	.773**	.945**	.594**
		600 ms													1	.739**	.564**
	Invalid	250 ms														1	.603**
		600 ms															1

Note. Two different delay durations between action and effect were employed (250 ms vs. 600 ms) and mapped to response keys either validly (in 80% of the trials) or invalidly (in 20% of the trials). All correlations coefficients are Pearsons` correlations. Asterixes behind correlation coefficients indicate significant two-sided correlations ($p < .01$).