Earlier Effects Are More Often Perceived as Own Action Effects

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Abstract

When changes occur in our environment, we usually know whether we caused these changes by our actions or not. Yet, this feeling of authorship for changes — the so-called sense of agency (SoA) — depends on the temporal relationship between action and resulting change (i.e., effect). More precisely, SoA might depend on whether the effect occurs temporally predictable, and on the duration of the delay between action and effect. In previous studies, SoA was measured either explicitly, asking for the perceived control over external stimuli, or implicitly by measuring a characteristic temporal judgement bias (intentional binding, i.e., a shortening of the perceived interval between action and effect). We used a novel paradigm for investigating explicit SoA more directly by asking participants in a forced-choice paradigm whether they caused the temporally predictable or the temporally unpredictable effect by their action. Additionally, we investigated how the temporal contiguity of the effects influenced the participants' explicit SoA. In two experiments (48 participants each), there was no influence of temporal predictability on explicit SoA. Temporally predictable and unpredictable effects were equally often rated as own effects. Yet, effects after shorter delays were more often perceived as own effects than effects after longer delays. These findings are in line with previous results concerning the influence of effect delay on other explicit measures of SoA concluding that explicit SoA is stronger for early effects.

Keywords: sense of agency, intentional binding, temporal binding, effect delay, action-effect interval, temporal predictability, causality

1. Earlier Effects Are More Often Perceived as Own Action Effects

It is one of the most essential prerequisites of human action control to mentally relate perceived environmental changes to executed actions. This enables us to perceive external stimuli as being caused by our actions, thereby constituting a set of effects we can achieve in our environment by executing certain, goal-directed actions. Thus, although these causal relations between actions and environmental effects are not directly perceivable, we commonly refer to this ability as a ‘sense’; the so-called sense of agency (SoA; Moore & Obhi, 2012).

SoA is an important and intensely investigated factor in action cognition and action control (e.g, Ebert & Wegner, 2010; Sidarus, Chambon, & Haggard, 2013; Sidarus & Haggard, 2016). For example, SoA has been investigated recently in studies on ergonomics or human-machine interfaces, such as the arrangement of airplane cockpits (Berberian, Sarrazin, LeBlaye, & Haggard, 2012) or speech interfaces (Limerick, Moore, & Coyle, 2015). Typically, in studies investigating SoA participants are asked to rate their perceived control or agency over certain stimuli (e.g., Haering & Kiesel, 2016; Sidarus et al., 2013; Sidarus & Haggard, 2016), interpreting higher control or agency ratings as stronger SoA. Besides this explicit measure of SoA, there are studies which investigate SoA indirectly, by the employment of an implicit measure — the so-called temporal, or intentional binding effect (IB; Haggard, Clark, & Kalogeras, 2002). IB is a phenomenon of biased time perception, that is, stimuli caused by an action are perceived earlier in time compared to stimuli not caused by an action (Haggard, Aschersleben, Gehrke, & Prinz, 2002). Consequently, the elapsed time between an intentional causing action and its resulting effect is underestimated in comparison to the elapsed time between an involuntary action and an effect stimulus (e.g., Engbert, Wohlschläger, & Haggard, 2008; Nolden, Haering, & Kiesel, 2012). As this phenomenon of biased time perception is specific for intentional (Engbert &

Wohlschläger, 2007), causally-linked (Cravo, Claessens, & Baldo, 2009; Moore, Lagnado, Deal, & Haggard, 2009), action-effect settings, it serves as an implicit measure of SoA (for a review, see Moore & Obhi, 2012).

One factor that has been shown to strongly influence SoA is the temporal relationship between the causing action and its resulting effect (e.g., Cravo, Claessens, & Baldo, 2011; Haggard, Clark, et al., 2002; Humphreys & Buehner, 2009; Kawabe, Roseboom, & Nishida, 2016; Nolden et al., 2012; Wen, Yamashita, & Asama, 2015). This temporal relationship consists of two major components: first, the temporal predictability of the effect — that is, whether the effect follows its causing action always after the same, temporally predictable delay, or after different, temporally unpredictable delays (Haering & Kiesel, 2015; Haggard, Clark, et al., 2002); second, the temporal contiguity between action and effect — that is, the duration of the delay between the action and the following effect (Humphreys & Buehner, 2009; Nolden et al., 2012; Ruess, Thomaschke, Haering, Wenke, & Kiesel, 2017; Ruess, Thomaschke, & Kiesel, 2017).

To our knowledge, only one previous study investigated the influence of temporal predictability on an explicit measure of SoA (Haering & Kiesel, 2015). Yet, this study employed a somehow special design where participants adapted to one specific effect delay (depending on group either 0 ms or 250 ms) in learning phases of the experiment. In consecutive test blocks participants were asked to rate their perceived control over an effect occurring in half of the trials after the adapted delay (depending on group either again 0 ms or 250 ms) and in the other half of the trials after different, not adapted delays (depending on group either > 0 ms or < 250 ms). Haering and Kiesel (2015) observed higher control ratings for effects occurring after the adapted delay in comparison to effects occurring after not adapted delays. Yet, in that study the participants' effect was never 100 % predictable in test blocks, and besides, the study was rather framed in the sense of an adaptation to a specific delay instead of temporal predictability. Nevertheless, the results somehow indicate that explicit SoA might be stronger for temporally predictable effects compared to temporally unpredictable effects. This conclusion is in line with results of implicit measures of SoA (Haggard, Clark, et al., 2002). Haggard and colleagues (2002) showed stronger IB, and, thus, stronger implicit SoA for temporally predictable effects compared to temporally unpredictable effects and this influence of temporal predictability on implicit SoA depended on the amount of the unpredictability of the temporally unpredictable effect (varying +/– 50 ms vs. +/– 150 ms around the delay of the temporally predictable effect; Ruess, Thomaschke, & Kiesel, 2017). Thus, overall, previous results indicate stronger explicit and implicit SoA for temporally predictable effects in comparison to temporally unpredictable effects. However, they also clearly point out the necessary of a more direct investigation of how temporal predictability influences SoA, especially explicit SoA.

Results on the influence of temporal contiguity are somewhat ambiguous. Explicit measures of SoA showed stronger SoA for early compared to late effects (Dewey & Carr, 2013; Wen et al., 2015). For implicit SoA, however, contrasting results have been found depending on the employed method. On the one hand, IB has been shown to decrease for longer delays if it was measured as point estimates of the effect (i.e.; for delays > 250 ms early effects were more temporally biased toward the action compared to late effects; Haggard, Clark, et al., 2002; Ruess, Thomaschke, Haering, et al., 2017). On the other hand, studies measuring IB as estimates of the duration of the delay between action and effect showed the reverse pattern of results. These studies compared duration estimates for delays between own actions and effects and for equally long delays between an external stimulus and an effect. With different ranges of delays (ranging from 0 ms up to 4000 ms), Humphreys and Buehner (2009) observed IB to increase with increasing action-effect delay (for a similar conclusion see Nolden et al., 2012). Consequently, results concerning the influence of temporal contiguity on explicit and implicit SoA may diverge (Wen et al., 2015) depending on how implicit SoA is measured. Taken together, it seems that the influence of temporal contiguity depends substantially on the specific method used to assess SoA (Ruess, Thomaschke, & Kiesel, 2017).

Previous studies investigating explicit SoA employed a scale (e.g., scale) on which participants had to rate their perceived control over an effect stimulus (e.g., Haering & Kiesel, 2015). In the current study, we employed a more direct measure of explicit SoA by using a novel dichotomous, forced-choice paradigm. Participants had to decide which of two possible effects they had caused by their actions. We assessed this measure either block-wise (in the first part of the experiments) or trial-wise (in the second part of the experiments). Employing this novel measure of explicit SoA, we intended to further clarify the influence of temporal predictability on explicit SoA. Above that, we intended to compare which of both factors, the temporal predictability and the temporal contiguity of an effect, is more important for the experience of explicit SoA.

To this end, we slightly modify the paradigm of a recent study that employed a somehow similar design to elaborate time perception of own effects in comparison to effects caused by others (Haering & Kiesel, 2012). In that study, two participants were asked to cause an effect (i.e., the appearance of a lifebuoy) by pressing the response key as fast as possible when they saw an imperative stimulus (i.e., a man overboard) on the screen. They were told that their own effect, represented by a red color (or yellow, counterbalanced across participants), and the effect of the other participant, represented by a yellow color (or red, counterbalanced across participants), would appear on the screen in the order of their reactions. However, in fact, both effects occurred on the screen after programmed delays that only depended on the reaction of each single participant. In each trial, one of the two effects (the own effect or the effect of the other participant) occurred first, or both effects occurred at the same time after the participant's reaction. At the end of each trial, participants were asked to report whether their assumed own effect or the assumed effect of the other participant occurred first. In line with earlier studies on IB, the own effect was perceived earlier compared to the effect of the other participant. Thus, this study investigated time perception of an assumed own effect and effect of another person, thereby assessing implicit SoA (Haering & Kiesel, 2012).

In the current study we adapted this design in order to investigate explicit SoA. Two participants performed the experiment simultaneously and each participant was instructed to press a response key to cause an effect (i.e., the appearance of a lifebuoy). After the keypress, a red and yellow effect appeared. Similar to the study by Haering and Kiesel (2012), in fact, both effects occurred after delays that only depended on the reaction of each single participant. Yet, participants were told that they would only cause one of both effects (while the other would be caused by the other participant). In contrast to the study by Haering and Kiesel (2012), however, participants were not told which of both effects (i.e., the red or yellow effect) would be caused by them and which of both effects would be caused by the other participant. Further, we manipulated the temporal predictability of both effects in a block-wise manner. One effect (e.g., the red effect) occurred in a whole block temporally predictably; that is, in each trial 500 ms after the participants' keypress. The other effect (e.g., the yellow effect) occurred in a whole block temporally unpredictably; that is, sometimes slightly earlier than 500 ms, exactly after 500 ms, or slightly later than 500 ms after the participants' keypress. Consequently, in some trials the temporally unpredictable effect occurred earlier than the temporally predictable effect (in trials where it occurred earlier than 500 ms after action execution), whereas in other trials the temporally unpredictable effect occurred later than the temporally predictable effect (in trials where it occurred later than 500 ms after action execution).

In the initial blocks, we asked participants only after the last trial of a block to indicate the color of the effect they assumed that they had caused in the previous block. Additionally, in the last blocks we asked participants after each single trial to indicate the color of the assumed own effect. We included block-wise judgements to allow participants to develop an impression of causality in a more continuous fashion, without constant disturbances by reports. We reasoned that the temporal predictability of an effect might need the experience of a few trials in order to be established. And we included trial-wise judgements, because contiguity evaluation is not possible with block-wise judgements.

Thus, with the block-wise measure we were able to investigate whether the color of the temporally predictable effect would be indicated more often as own effect (in more than 50 % of all block-wise responses). Such a finding would be in line with the before mentioned study by Haering and Kiesel (2015). However, it would extend their results as they investigated temporal predictability in a quite untypical manner, which was rather framed in terms of adapted effect delays. Additionally, the trial-wise measure of explicit SoA was conducted in order to investigate whether participants would indicate the color of the temporally predictable effect or the color of the earlier effect more often as own effect. Comparable to the block-wise measure, also in the trial-wise measure the percentage of own effect ratings for the predictable effect should be higher than 50 %. Yet, if temporal contiguity would determine SoA (Dewey & Carr, 2013; Wen et al., 2015), participants were to indicate the color of the earlier effect as own effect, independently of whether this was the temporally predictable effect or the temporally unpredictable effect. The two predictions for the trial-wise measure are not mutually independent and we were, thus, not able to derive the overall result pattern based on previous studies.

2. Experiment 1

In Experiment 1, we presented a predictable effect stimulus always 500 ms after the action. The unpredictable effect stimulus was presented either simultaneously with the predictable effect or 30 ms or 60 ms before or after the predictable effect. Thus, the range in which we varied unpredictable effect occurrence was +/– 60 ms (overall +/– 120 ms).

2.1. Method

2.1.1. Participants

Based on effect sizes in previous studies (Haering & Kiesel, 2012), 48 participants (31 females; mean age = 25, *SD* = 3.89, range 19 – 39 years; 46 right-handed) were included as part of a course requirement or in exchange for 8 euros.

2.1.2. Apparatus and stimuli

The experiment was run using the E-Prime 2.0 software (Schneider, Eschmann, & Zuccolotto, 2012) on two standard PCs with 24” LCD monitors (1920 pixels x 1080 pixels, 59 Hz refresh rate). The PCs were situated in two adjacent laboratory rooms and connected via serial ports to synchronize the beginning of each trial. This setting was used to prevent participants from hearing each other’s keypresses.

The background color of the screen was navy blue, and all messages and the fixation cross (0.5 cm) were presented in white. The imperative stimulus consisted of a centrally presented passenger who fell overboard (head of a person with a swim cap; width * height: 2.5 cm * 1.9 cm; see Figure 1 and uploaded pictures in Open Science). A red and yellow lifebuoy (width * height: 5.0 cm * 3.6 cm) served as the action effects (appearing 5.2 cm on the left or right of the center of the screen; the left/right location of the red and yellow lifebuoy was counterbalanced across trials). Participants had to react to the imperative stimulus using the left button of the mouse. Later, they reported the color of their own effect using the ‘d’ key (‘Der Gelbe’; i.e., the yellow one, choice option presented on the left side of the screen) and the ‘k’ key (‘Der Rote’; i.e., the red one, choice option presented on the right side of the screen — see Figure 1) of the keyboard.

2.1.3. Procedure

Two subjects were tested per session (one hour duration). To ensure that the participants believed that the PCs were connected, the experiment started with a two-step training phase: initially participants were instructed to imagine that they were a security officer of a ship who would have to save a passenger that often fell overboard. After the passenger appeared on the screen, participants had to press the left mouse button as fast as possible to throw a lifebuoy (in this initial training phase this appeared in the center in a randomly red or yellow color). In this initial training phase (6 trials for each participant, 3 yellow and 3 red lifebuoys in random order), the lifebuoy appeared on the screen 500 ms after the keypress. During this initial training phase, one of the participants stood behind the other participant and watched him/her reacting to the passenger overboard (his/her PC was blocked). After the first participant had finished these initial training trials, it was his/her turn to watch the second participant accomplishing this initial training trials in his/her room.

During the rest of the experiment, participants were placed separately in the two adjacent rooms. Four further training blocks followed (2 blocks of yellow and 2 blocks of red as the temporally predictable effect, each block with 6 trials). Participants were told that the PCs would be connected and the overboard passenger would emerge at the same time on the screens in both laboratories. Again, their task was to throw the lifebuoy as fast as possible after the appearance of the passenger. Participants were told that each of them would control one of the two lifebuoys and that the lifebuoys would appear on the screens as soon as they fell into the water in the order of the participants’ reactions. Furthermore, they were told that the assignment of lifebuoy color to each participant would change for each block in a random manner. In fact, only the starting time of each trial was synchronized. The occurrence of both lifebuoys, however, was determined only by the reaction of each individual participant (one after a temporally predictable delay, the other one after a temporally unpredictable delay), independent of the reaction of the participant in the other room. After each block, participants were required to spontaneously report the color of the lifebuoy they assumed was triggered by themselves (‘Welcher Rettungsring war von Dir?’; i.e., which lifebuoy was yours?).

After both training phases had finished, the first part of the main experiment started. In this first part (20 blocks * 20 trials each = overall 400 trials in block-wise response blocks), we asked participants only after the last trial of a block to indicate the color of the effect they assumed that they had caused in the previous block (i.e., one single own effect rating per block, i.e., after the 20th trial of a block). Additionally, in the second part of the experiment (2 blocks * 20 trials each = overall 40 trials in trial-wise response blocks), the participants had to indicate the color of their assumed own effect after each single trial (i.e., after both effects had disappeared). That is, overall 20 answers of block-wise response blocks and overall 40 answers of trial-wise response blocks were analyzed separately.

Each trial began with the centrally presented fixation cross (1000 ms). The imperative stimulus (passenger) followed after an additional blank screen of 1000 ms (see Figure 1).

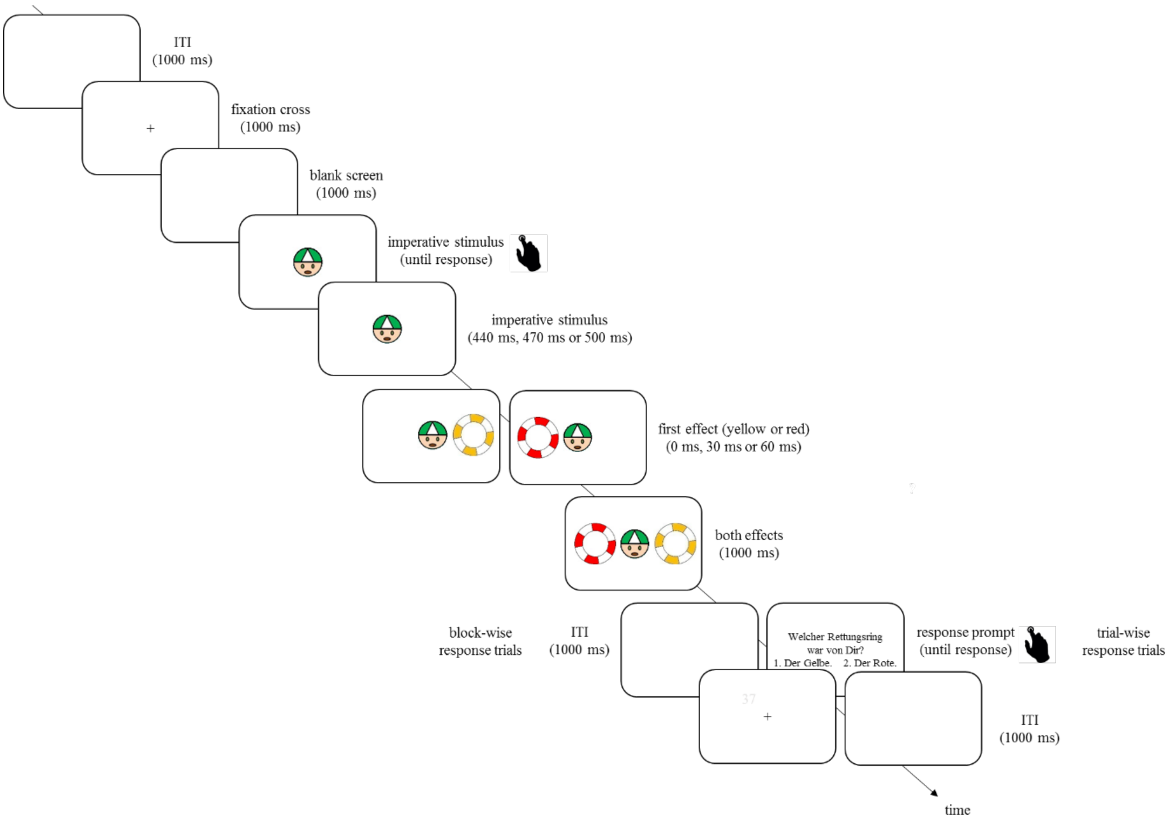

Figure 1. Schematic trial procedure starting with a fixation cross (1000 ms) and an blank screen (1000 ms) which was followed by the appearance of the overboard passenger. After participants had responded to the imperative stimulus (i.e., passenger overboard) one effect (i.e., lifebuoy) was presented temporally predictably after 500 ms while the other effect was presented temporally unpredictably (but on average also after 500 ms). Thus, the two effects occurred either simultaneously (i.e., separated by a delay of 0 ms), the temporally unpredictable effect occurred 60 ms or 30 ms before the predictable effect (i.e., negative delay in comparison to the temporally predictable effect, – 60 ms or – 30 ms), or 30 ms or 60 ms after the predictable effect (i.e., positive delay in comparison to the temporally predictable effect, + 30 ms or + 60 ms). Assignment of color to the temporally predictable and unpredictable effects varied between blocks. The side of the predictable and unpredictable effect was randomized (see Procedure). Participants had to judge block-wise (in block-wise response blocks, after 20 trials; depicted on the left side of the trial scheme) or trial-wise (in trial-wise response blocks; depicted on the right side of the trial scheme) which effect had been theirs by indicating the color of the respective effect (‘Welcher Rettungsring war von Dir?’; i.e., which lifebuoy was yours?; ‘1. Der Gelbe’; i.e., the yellow one; ‘2. Der Rote’; i.e., the red one). For better readability, the background in the figure is white and the text black, instead of a navy blue background and white text as used in the experiment.

If the participant did not respond within 750 ms, an error message reminded him/her to respond as quickly as possible (except in the initial training phases). Participants had to acknowledge reading this message by pressing the right mouse button and the next trial started. The time limit was used following the procedure of Haering and Kiesel (2012). If participants responded within the 750 ms time window, the red and yellow effects (i.e., lifebuoys) appeared after an average delay of 500 ms (the man overboard stayed on the screen during this delay) and both lifebuoys together stayed on the screen for an additional 1000 ms (order and delay duration, see below). In the block-wise response blocks the disappearance of both lifebuoys and man overboard was followed by the next trial after a navy blue blank screen which lasted 1000 ms. In the trial-wise response blocks the prompt to estimate one's own effect appeared before the next trial started. After each block there was a break of at least 30 s.

In each block, one of the two lifebuoys appeared after a temporally predictable delay (500 ms after the reaction), whereas the other one appeared after a temporally unpredictable delay (5 different delays: 500 ms +/– 0 ms, 30 ms, or 60 ms delay, but on average also 500 ms after the reaction). The unpredictable effect either occurred at the same time as the predictable effect (i.e., separated by a delay of 0 ms), 60 ms or 30 ms before the predictable effect (i.e., negative delay in comparison to the temporally predictable effect, – 60 ms or – 30 ms), or 30 ms or 60 ms after the predictable effect (i.e., positive delay in comparison to the temporally predictable effect, + 30 ms or + 60 ms). Consequently, the first of the two effects was either the temporally unpredictable effect (in the – 60 ms and – 30 ms condition), the predictable effect (in the + 30 ms and + 60 ms condition), or none of these appeared before the other one (in the 0 ms condition).

Each of the five possible delays of the temporally unpredictable effect was presented equally often (500 ms +/– 0 ms, 30 ms, or 60 ms, in random order). Thus, each delay occurred 4 times per block (4 trials * 20 blocks = overall 80 trials per delay in block-wise response blocks; 4 trials * 2 blocks = overall 8 trials per delay in trial-wise response blocks). Overall, in the block-wise response blocks the temporally unpredictable effect occurred in 160 trials before (– 60 ms or – 30 ms delay) and in 160 trials after the temporally predictable effect (+ 30 ms or + 60 ms delay). In the trial-wise response blocks the temporally unpredictable effect occurred 16 times before (– 60 ms or – 30 ms delay) and 16 times after the temporally predictable effect (+ 30 ms or + 60 ms delay). The colors red and yellow were equally often assigned to the temporally unpredictable and temporally predictable effect. This assignment varied block-wise in a random manner. In each block the temporally unpredictable and predictable effect appeared equally often on the left and on the right side of the screen (10 times on each side, in random order).

2.1.4. Data analysis

Block-wise and trial-wise responses were analyzed separately. For the block-wise responses, we calculated the percentage that the predictable effect was rated as own effect. With this block-wise measure of explicit SoA we investigated, whether the color of the temporally predictable effect would be indicated more often as own effect (in more than 50 % of all block-wise responses).

For the trial-wise analyses, we assessed two measures: First, we calculated for each participant the percentage of responses in which the temporally predictable effect was reported as own effect to calculate the influence of temporal predictability on perceived own effect in trial-wise responses. If temporal predictability would determine SoA, participants were to indicate the color of the temporally predictable effect more often as own effect independently of whether this temporally predictable effect was the earlier or the later effect. In order to investigate this, we analyzed whether the percentage of trials in which participants rated the temporally predictable effect as own effect would be higher than 50 %. Second, we computed the percentage of responses in which the early effect was rated as own effect to calculate the influence of temporal contiguity on perceived own effect in trial-wise responses. For this, we excluded all trials in which both effects occurred after the same delay (500 ms after the reaction, i.e., delay of 0 ms; thus, 8 trials were excluded per participant). In the remaining trials, we analyzed the influence of temporal contiguity by calculating for each participant the percentage of responses where the first effect was reported as own effect. If temporal contiguity would determine SoA, participants were to indicate the color of the earlier effect as own effect, independently of whether this was the temporally predictable effect or the temporally unpredictable effect. In order to investigate this, we analyzed whether the percentage of trials in which participants rated the earlier effect as own effect would be higher than 50 %. Please note that the two predictions concerning an influence of temporal predictability and temporal contiguity in trial-wise responses are not mutually independent because for early effects, participants cannot always choose predictable effects or alternatively, for predictable effects, participants cannot always choose early effects.

Finally, *t*-tests against the chance level of 50 % were calculated (*p*-level of 5 %) for all three measures (i.e., block-wise predictability, trial-wise predictability, and trial-wise contiguity) in order to detect systematic tendencies due to these factors.

2.2. Results

2.2.1. Block-wise responses

The temporally predictable effect was not perceived more often as own effect compared to the temporally unpredictable effect, as the rating did not differ significantly from the chance level of 50 %, $M = 47.50$, $SE = 1.56$, $M_{Diff} = 2.50$, $t(47) = 1.60$, $p = .116$ (see Figure 2).

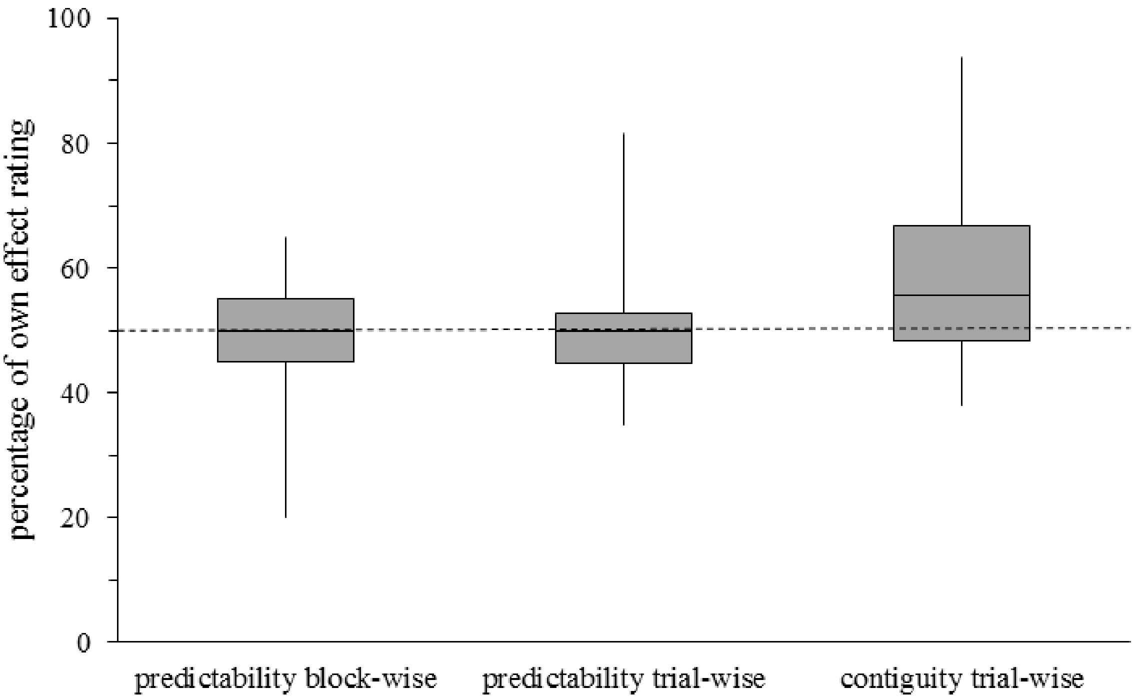

Figure 2. Boxplots of percentage (i.e., minimum, 25 %, median, 75 %, and maximum) of own effect (i.e., lifebuoy) rating for temporally predictable or early effects, separately for block-wise temporal predictability, trial-wise temporal predictability, and trial-wise temporal contiguity responses. The employed delay range of Experiment 1 was +/– 0 ms, 30 ms, or 60 ms (see Method). Just the trial-wise contiguity measure resulted in a percentage that exceeded 50 %, indicating that earlier effects were more often perceived as own effects.

2.2.2. Trial-wise responses

The temporally predictable effect was not perceived more often as own effect compared to the temporally unpredictable effect, as the rating did not differ significantly from the chance level of 50 %, $M = 49.92$, $SE = 1.24$, $M_{Diff} = 0.08$, $t(47) = 0.06$, $p = .949$. However, the earlier effect was significantly more often perceived as own effect, as expected by the chance level of 50 %, $M = 58.37$, $SE = 1.93$, $M_{Diff} = 8.37$, $t(47) = 4.35$, $p < .001$ (see Figure 2). To illustrate the influence of temporal contiguity on own ratings more detailed, Figure 3 depicts the percentage of the temporally predictable effect indicated as own effect in the trial-wise response blocks depending on the five different delays between predictable and unpredictable effects (i.e., – 60 ms, – 30 ms, 0 ms, + 30 ms, or + 60 ms).

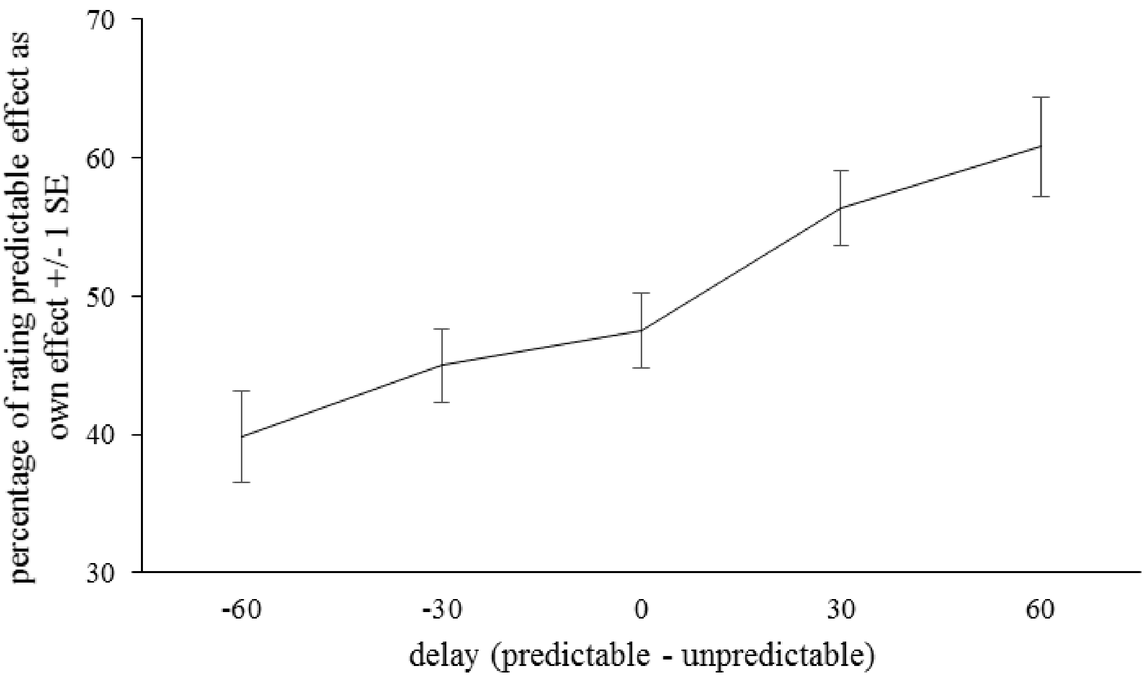

Figure 3. Percentage of rating the temporally predictable effect as own effect for trial-wise responses depending on the delay between the unpredictable and the predictable effect. – 60 ms and – 30 ms indicate that the unpredictable effect is presented before the predictable effect (that is, the predictable effect is the second effect), 0 ms indicates that both effects occur simultaneously, and 30 ms and 60 ms indicate that the predictable effect is presented before the unpredictable effect (this means the predictable effect is the first effect). Error bars represent standard errors.

2.3. Discussion

In the first experiment participants perceived earlier rather than later effects more often as own effects (in trial-wise responses). The temporal predictability of the effects did not influence the participants' perception of effects as being caused by them. More precisely, temporally predictable effects were not perceived more often as own effects in comparison to temporally unpredictable effects. This was the case for the block-wise and trial-wise responses of presumed own effect.

3. Experiment 2

In Experiment 1, the temporal predictability of the effects did not significantly influence the perception of own effect. Recently we showed, however, that the influence of temporal predictability on SoA might differ depending on the exact range of the delays (Ruess, Thomaschke, & Kiesel, 2017). In that study, no effect of temporal predictability was found for a delay range of +/– 50 ms, whereas for an extended delay range of +/– 150 ms temporal predictability did influence implicitly assessed SoA. The delay range of Experiment 1 in the present study was very similar to the insignificant delay range in Ruess, Thomaschke, and Kiesel's (2017) study (+/– 0 ms, 30 ms, or 60 ms). Therefore, in order to further investigate whether temporal predictability influences SoA or not, we conducted a second experiment with an extended delay range (+/– 0 ms, 60 ms, or 120 ms) of overall 240 ms.

3.1. Method

3.1.1. Participants

Forty-eight participants (38 females; mean age = 24, *SD* = 4.32, range 18 – 41 years; 46 right-handed) were included as part of a course requirement or in exchange for 8 euros.

3.1.2. Apparatus, stimuli, procedure, and data analysis

Apparatus, stimuli, procedure, and data analysis were similar to those in Experiment 1, except for the extended delay range of the temporally unpredictable effect (500 ms +/– 0 ms, 60 ms, or 120 ms). Additionally, instead of two final blocks asking for a trial-wise report of the own effect, this time four final trial-wise response blocks were included in the experiment (consequently, 4 blocks * 20 trials = overall 80 trials in trial-wise response blocks, i.e., 4 trials per delay * 4 blocks = overall 16 trials per delay in trial-wise response blocks; thus, 16 trials with the delay of 0 ms were excluded for the analysis of temporal contiguity). Therefore, in order to keep the overall duration of the experiment similar to Experiment 1, the break between each block was shortened to at least 20 s instead of 30 s.

3.2. Results

3.2.1. Block-wise responses

The temporally predictable effect was not perceived more often as own effect compared to the temporally unpredictable effect, as the rating did not differ significantly from the chance level of 50 %, M = 48.23, SE = 1.85, M_{Diff} = 1.77, $t(47)$ = 0.96, p = .343 (see Figure 4).

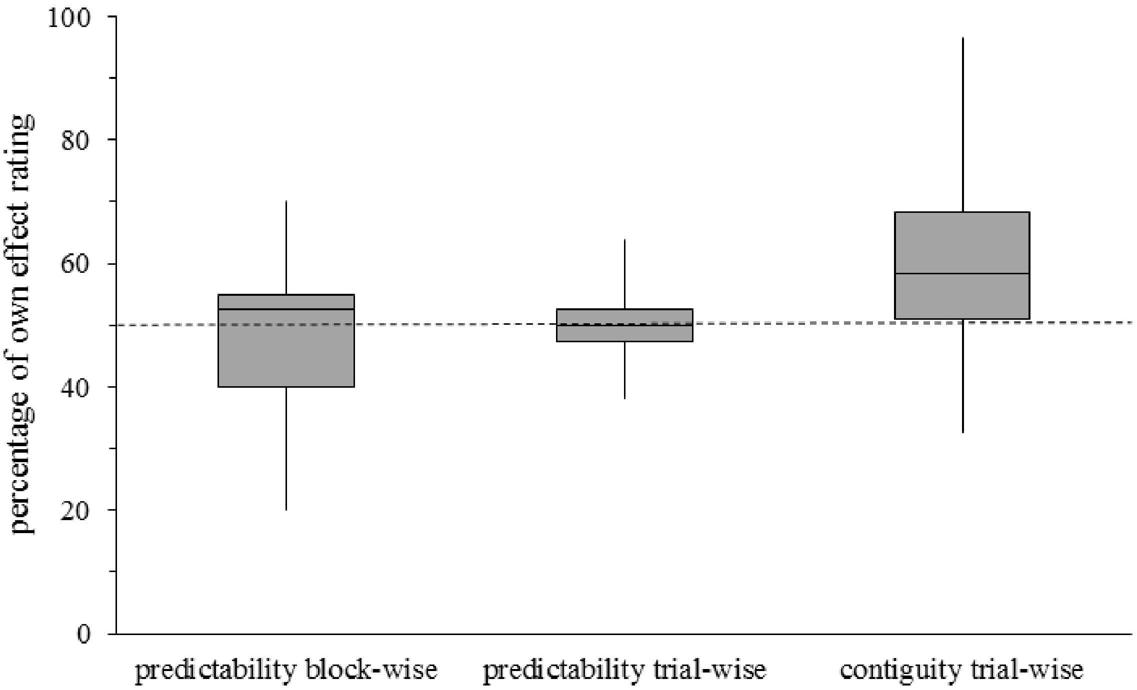

Figure 4. Boxplots of percentage (i.e., minimum, 25 %, median, 75 %, and maximum) of own effect (i.e., lifebuoy) rating for temporally predictable or early effects, separately for block-wise temporal predictability, trial-wise temporal predictability, and trial-wise temporal contiguity responses. The employed delay range of Experiment 2 was +/– 0 ms, 60 ms, or 120 ms (see Method). Just the trial-wise contiguity measure resulted in a percentage that exceeded 50 %, indicating that earlier effects were more often perceived as own effects.

3.2.2. Trial-wise responses

The temporally predictable effect was not perceived more often as own effect compared to the temporally unpredictable effect, as the rating did not differ significantly from the chance level of 50 %, M = 49.89, SE = 0.82, M_{Diff} = 0.11, $t(47)$ = 0.13, p = .894. However, the earlier effect was significantly more often perceived as own effect compared to the second effect, as expected by the chance level of 50 %, M = 60.45, SE = 1.94, M_{Diff} = 10.45, $t(47)$ =

5.40, $p < .001$ (see Figure 4). To illustrate the influence of temporal contiguity on own ratings more detailed, Figure 5 depicts the percentage of the temporally predictable effect indicated as own effect in the trial-wise response blocks depending on the five different delays between predictable and unpredictable effect (i.e., – 120 ms, – 60 ms, 0 ms, + 60 ms, or + 120 ms).

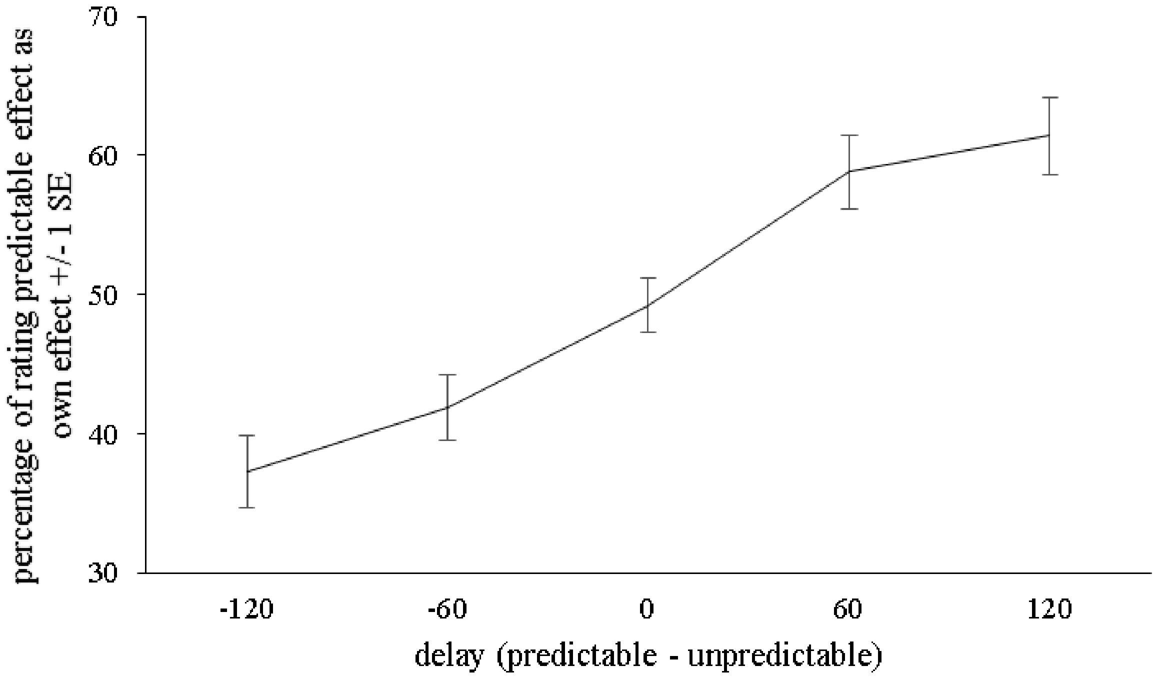

Figure 5. Percentage of rating the temporally predictable effect as own effect for trial-wise responses depending on the delay between the unpredictable and the predictable effect. – 120 ms and – 60 ms indicate that the unpredictable effect is presented before the predictable effect (that is, the predictable effect is the second effect), 0 ms indicates that both effects occur simultaneously, and 60 ms and 120 ms indicate that the predictable effect is presented before the unpredictable effect (this means the predictable effect is the first effect). Error bars represent standard errors.

3.3. Discussion

In this second experiment, the delay range of the temporally unpredictable effect (+/– 0 ms, 60 ms, or 120 ms) was extended in comparison to the delay range in Experiment 1 (+/– 0 ms, 30 ms, or 60 ms). Nevertheless, the results pattern of the second experiment was similar to Experiment 1. Again, earlier rather than later effects were perceived more often as own action effects (in trial-wise responses). Additionally, we found no influence of temporal predictability. Similar to Experiment 1, temporally predictable effects were not perceived more often as own effects in comparison to temporally unpredictable effects. This was the case for block-wise and trial-wise responses of the presumed own effect.

4. General Discussion

In this study we investigated the influence of temporal contiguity (duration of the delay between action and effect) and temporal predictability (fixed vs. variable delay of the action effect) with a new explicit measure of SoA; that is, the forced-choice decision which one of two effects is the own effect. Two independent experiments corroboratively showed that participants perceived the earlier one of two stimuli following their action more often as the effect caused by themselves. However, we did not find any influence of the temporal predictability of the effect on SoA, neither with the block-wise nor with the trial-wise measure of temporal predictability. This pattern of results was not affected by a change in the general delay range of the unpredictable effect (Experiment 1 to Experiment 2). Overall, in our trial-wise analysis the temporal contiguity of an effect influenced explicit SoA while temporal predictability of an effect did not impact on explicit SoA.

The finding that participants rated earlier effects more often as own action effects than later effects is in line with some previous results on the influence of temporal contiguity measuring SoA either explicitly (Dewey & Carr, 2013; Wen et al., 2015) or implicitly (Haggard, Clark, et al., 2002; Ruess, Thomaschke, Haering, et al., 2017). These results showed higher explicit SoA ratings and a larger shift of the perceived point in time of the effect (i.e., stronger IB and, thus, stronger implicit SoA) for earlier in comparison to later effects. This indicates that SoA is higher for earlier in comparison to later action effects.

However, there are also some results that contrast with ours (Humphreys & Buehner, 2009; Nolden et al., 2012; Wen et al., 2015). Wen et al. (2015) assessed explicit SoA (i.e., Likert-scale rating of perceived agency in effect stimuli) and also implicit SoA (i.e., IB), but instead of measuring IB as perceived point in time of the effect, they measured the perceived duration of the delay between action and effect. Thereby they observed a reversed pattern for the influence of temporal contiguity on explicit SoA (i.e., stronger explicit SoA for earlier effects) in comparison to the influence of temporal contiguity on implicit SoA (i.e., stronger implicit SoA for later effects). While explicit SoA decreased for longer delays, implicit SoA showed to increase for longer delays. This raises the question, why do the results differ depending on the method used to investigate the influence of temporal contiguity on SoA? What overall conclusion can be drawn from these results?

Reflecting on the methodological perspective, a clear advantage of our study in comparison to most previous studies is that our explicit method can be unambiguously interpreted as a measure of SoA. We directly asked participants which of two stimuli they had caused. Concerning results of implicit measures, there is an ongoing debate on whether they totally correspond to results of explicit measures and what the differences might be due to (e.g., Wen et al., 2015). With regard to explicit measures, however, our results are well in line with previous related findings of different paradigms on the influence of temporal contiguity on SoA (Dewey & Carr, 2013; Wen et al., 2015). Thus, our results offer a further indication of a stronger explicit SoA for earlier in comparison to later effects. Yet, interpreting this in terms of implicit SoA has to be considered with caution. Results concerning the influence of temporal contiguity on implicit measures of SoA seem to differ depending on the employed method (Ruess, Thomaschke, & Kiesel, 2017).

The paradigm employed in our study was highly similar to the paradigm used in a previous study by Haering and Kiesel (2012); they asked participants to indicate whether their own effect or the other participant's effect was first. Thus, their study measured SoA implicitly by inferring it from the participant's time perception and showed own effects to be perceived earlier than effects of another participant. In our study, however, we investigated

SoA directly (i.e., explicit SoA), asking participants which of two differently colored effects they had caused by their action. As one of the effects occurred earlier than the other one, we, thus, directly measured whether the participants perceived the earlier or later effect as being caused by their action. We observed earlier effects to be perceived more often as own action effects compared to later effects. Thus, our results and the results of Haering and Kiesel (2012) correspond to each other, indicating a bidirectional relationship between temporal contiguity and SoA: own effects are perceived earlier, and earlier rather than later effects are more often perceived as own effects.

With regard to the influence of temporal predictability, we did not find any influence neither on our block-wise nor on our trial-wise measure of SoA. In a previous study, however, stronger implicit SoA (i.e., stronger IB) for temporally predictable effects in comparison to temporally unpredictable effects was found (Haggard, Clark, et al., 2002). Yet, this previous study measured SoA implicitly. To our knowledge only one study investigated the influence of temporal predictability on an explicit measure of SoA (Haering & Kiesel, 2015) and found stronger SoA if the effect occurred after the temporally predicted delay compared to if the effect occurred after a temporally unpredicted delay. However, the interpretation of these results in terms of temporal predictability is somehow limited, because in that study the temporal predictability was manipulated by adapting participants to a certain effect delay. Consequently, overall it is not fully clear so far, how temporal predictability influences explicit measures of SoA. Our results might be a cautious indication that it is not important for explicit SoA to know when exactly an effect occurs. Furthermore, our results, thus, might offer a first slight indication that the time of occurrence of an effect (i.e., early vs. late) is more important than whether the effect occurs temporally predictably or not. However, this is very speculative because the suggestions concerning an influence of temporal predictability on explicit SoA would be based on a null-finding.

Further, we did not just conduct blocks with trial-wise but also blocks with block-wise responses, in order to investigate a possible influence of temporal predictability on our newly developed explicit measure of SoA. The block-wise measure was conducted because it might be possible that an influence of temporal predictability explicitly shows up just after a few trials that have been experienced, and that need to be considered when responding after a whole block. Yet, for both measures we did not find any influence of temporal predictability. On the one hand this null finding might be due to the absence of an influence of temporal predictability on explicit SoA. On the other hand it might be due to an insensitivity of the newly developed paradigm for influences from temporal predictability. Future research is needed for investigating the importance of an effect to occur always at the same, predictable, point in time in order to be perceived as own effect (i.e., in the sense of explicit SoA).

Overall, our study was a novel direct investigation of whether and how temporal contiguity and temporal predictability influence explicit SoA. Stimuli that occurred earlier after action execution were more often perceived as own effects, whereas temporal predictability did not influence this explicit measure of SoA. This might be a slight indication that the point in time of effect occurrence is more important for explicit SoA than the temporal predictability of the effect.

5. References

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