Was it me when it happened too early?
Experience of delayed effects shapes sense of agency

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Sense of agency, the feeling of causing a certain event, depends largely on the delay between an action and its ensuing effect: The feeling to control an effect that is caused by our preceding action is stronger the closer the effect follows the action in time. Yet, repeatedly experiencing an effect after a constant delay might alter this general rule. Here, we assessed sense of agency for effects that occurred 0 to 250 ms after an action in conditions in which the effect either mostly occurred immediately or mostly delayed after 250 ms after the action. Participants who experienced mostly delayed effects rated their influence over the effect’s occurrence to be larger the longer the action-effect interval was. Thus, sense of agency is not always stronger at shorter action-effect intervals, but rather depends on the match between the agent's expectations and the actual timing of events.

Keywords: sense of agency, causality, action effect delay, temporal deviation

1. Introduction

How do we know which of our actions causes which effects in the environment? When we interact with our environment, we often do not deliberately think about action-effect relations, but simply act – for instance pressing a light switch – and have the immediate feeling that the effect – light – was caused by our action.

One key factor for perceived causality is temporal contiguity. The longer the delay between two events, the less likely it is that the second event will be judged to be caused by the first event (Choi & Scholl, 2006; Greville & Buehner, 2010; Michotte, 1963; Shanks & Dickinson, 1987).

Sense of agency, that is, the immediate feeling of causing an effect, is a special case of perceived causality. While we can perceive causality between any two entities in the environment, for instance between two billiard balls (Michotte, 1963), agency only refers to effects caused by actions. Nevertheless, the same factors that determine perceived causality are assumed to affect agency judgments (Eagleman & Holcombe, 2002; Haggard, 2005; Moore, Lagnado, Deal & Haggard, 2009). Accordingly, temporal contiguity between an action and its effect is assumed to determine sense of agency.

Although perceived causality generally decreases the larger the delay between action and effect, we occasionally face situations with considerable delays between our actions and their effects. For instance, when we press a switch, it can take seconds until the energy saving light bulb brightens up (Buehner & May, 2002). Nevertheless, we have no doubt that our action caused the light to turn on. Yet, the question remains whether in such situations, we directly sense agency to have caused the effect. Furthermore, it is an open question whether we sense less agency for effects that occur earlier than usual. For instance, if we start a computer program from the server which usually it takes 1 second to start, do we sense less agency if the program starts earlier than usual?

There is some evidence that the effect of temporal contiguity on causal perception is modulated by expectations (Einhorn & Hogarth, 1986; see also Buehner & May, 2002, 2003, 2004). When the experimental design and/or instructions suggest that a delay between action and effect is probable, the detrimental effect of delays on causality judgments was alleviated (Buehner & May, 2002, 2003) or even abolished (Buehner & May, 2004). A study by Buehner and McGregor (2006) revealed that knowledge can even reverse the detrimental effect of temporal delays on causality judgments. Participants first watched a marble traveling through a Bernoulli board and causing a light onset when reaching the bottom. Participants were instructed and perceived that the marble travelled slower when the tilt of the board was low rather than high. Then the board was covered and participants judged if the marble caused the light that occurred after a short or a long delay. When the tilt of the board was low, causality judgments were larger after the long than the short delay, i.e. the opposite result that would be expected if temporal contiguity determined causality judgments.

Interestingly, there is no need to explicitly inform participants about the delay of an effect, but they can acquire knowledge about expected delays based on repeated experience. Participants learn when an effect usually occurs after an action and consequently they expect effects at the typical time of their occurrence and respond slower when an effect occurs earlier than expected (Haering & Kiesel, 2012). Similarly, causality judgments for delayed effects depend on whether participants experienced the same effect to occur immediately in a preceding block or not (Buehner & May, 2004).

Thus, the described studies observed that the effect of temporal contiguity on causal perception is modulated by expectations. However, in these studies causality judgments were only assessed at the end of a block and participants were asked to judge the estimated mean causality in the preceding block. The aim of the current study was to examine the effect of temporal contiguity and expectations on sense of agency judgments that were assessed after each trial. We conjecture that prediction processing detailed in predictive forward models, assumed to underlie sense of agency judgments (e.g., Haggard, 2005), have more impact on immediate, trial-by-trial judgments than on judgments given after one block of observations. Consequently, it is an open question whether sense of agency depends on temporal contiguity or is modulated by experience that effects usually occur delayed rather than immediately. To address this question, we split participants into two groups. The experimental group, the *delay group*, was adapted to an action-effect delay of 250 ms. The control group, the *immediate group*, was adapted to an immediate effect. In both groups, we assessed sense of agency in test blocks in which effects occurred after different delays ranging between 0 ms and 250 ms. We chose a virtual instead of a physical environment with a new computer-game like task so that participants' a priori expectations were minimal. Additionally, we did not inform participants about the delays between actions and effects.

In this setup, two opposing hypotheses can be tested (see Figure 1). According to the contiguity hypothesis (our null hypothesis), participants are expected to sense less control the longer the delay and this pattern of results should be independent of experimental group. Thus, despite prior experience that usually effects occurred either after a constant delay of 250 ms or immediately after the action, sense of agency should not differ between both conditions, but decrease with temporal delay. In contrast, the experience hypothesis suggests that participants' sense of agency judgments should depend on prior experience and expectations. Participants should sense less control the more their previously built temporal expectations are violated (e.g., Sato, 2009), that is, the more the current delay deviates from the usually experienced delay. Please note that this hypothesis predicts the same pattern of results for the immediate group as the contiguity hypothesis. Yet, for the delay group, the experience hypothesis predicts control judgments to be smallest when effects occur immediately after the action and increase up to a maximum after 250 ms.

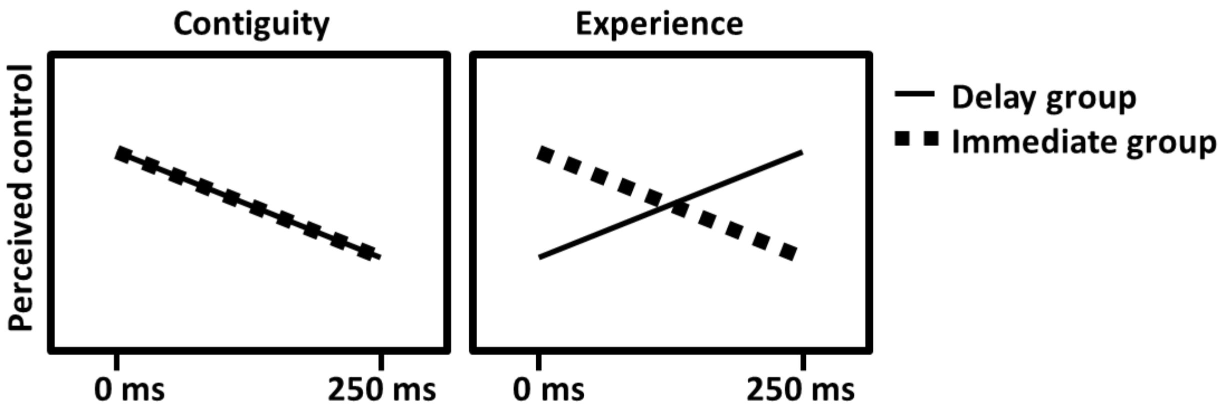

Figure 1. Hypothetical result pattern after adaptation to delayed (solid line) compared to immediate (dashed line) action effects. If contiguity determines sense of agency, perceived control for both groups decreases with the delay between action and effect. If experience of usual delay shapes perceived control, sense of agency decreases the larger the temporal deviation from the usual delay.

2. Method

Participants. 36 participants (9 male, mean age 25 years) took part for 3 Euros or course credit. Two participants were left-handed, but all indicated to use the mouse with the right hand.

Apparatus and stimuli. The experiment was run with E-Prime (Schneider, Eschman, & Zuccolotto, 2002) on a PC with a 17” CRT monitor. Acoustic stimuli were presented with VicFirth SIH-1 isolation headphones. Responses were collected with an optical computer mouse used with the right hand. On the screen “Edgar the moose” was presented with a red circle (3.7 cm) as its nose at the center of the screen. Clicking Edgar’s nose resulted in a 50 ms tone that sounded like a moose bellowing. For control judgments in test blocks the moose disappeared and a rating scale (see Figure 2) was presented.

Design and Procedure. Participants completed adaptation blocks and test blocks. Each trial started with a fixation cross (1.6 cm) presented centrally for 500 ms within the target area, Edgar's nose. Then the mouse cursor appeared 9.7 cm left of the center of the screen. Participants were instructed to move the cursor to the target area and then to press the left mouse key as fast as possible.

In adaptation blocks, Edgar bellowed after each click on the target either immediately (immediate group) or with a delay of 250 ms (delayed group). After 1000 ms the next trial started. Target missed clicks resulted in an error sound and a written error message („Daneben! Bitte klicke nur auf die Nase!", German for "Missed! Please only click on the nose!"). When no click was recorded within 1000 ms, participants were asked to respond faster ("Bitte schneller!", German for "Faster, please!"). In both cases, the cursor disappeared and the trial restarted with the fixation cross.

In test blocks, trials differed with respects to the delays between action and effect. Whereas action-effect delay were stable in the adaptation blocks, in test blocks effects were presented at variable delays either shortly before the mouse click (as will be explained below) or 0 ms, 50 ms, 100 ms, 150 ms, 200 ms, 250 ms or 1250 ms after the mouse click. Effects occurred in 21 trials with their usual delay (either 0 ms or 250 ms depending on group) and with any of the other delays in 3 trials per test block, resulting in 42 trials per test block. Whenever the effect was presented before the mouse click, the sound occurred as soon as the distance between mouse cursor and target was less than 5 mm[1]. We introduced effects preceding the mouse click and effects with a delay of 1250 ms to increase the variability of participants' control judgments. In the following

[1] Please note that it is not possible to present an effect with a fixed interval before the action. Yet, this procedure assured that effects were presented before the action. On average, the interval between effect and action was 411 ms (range 150 ms to 984 ms).

we only report descriptive data for these conditions, but not include these trials in statistical analyses. After the effect occurred participants rated whether they had caused the effect with their action on a scale ranging from 0% to 100% (see Figure 2). Participants clicked on the scale and the respective position was marked with a red "X" for 500 ms. Then the moose reappeared with the fixation cross.

Each participant performed 10 adaptation trials as practice, followed by two initial adaptation blocks of 42 trials each. Then there were three test blocks of 42 trials, each separated by an adaptation block. After each block participants could take a short break.

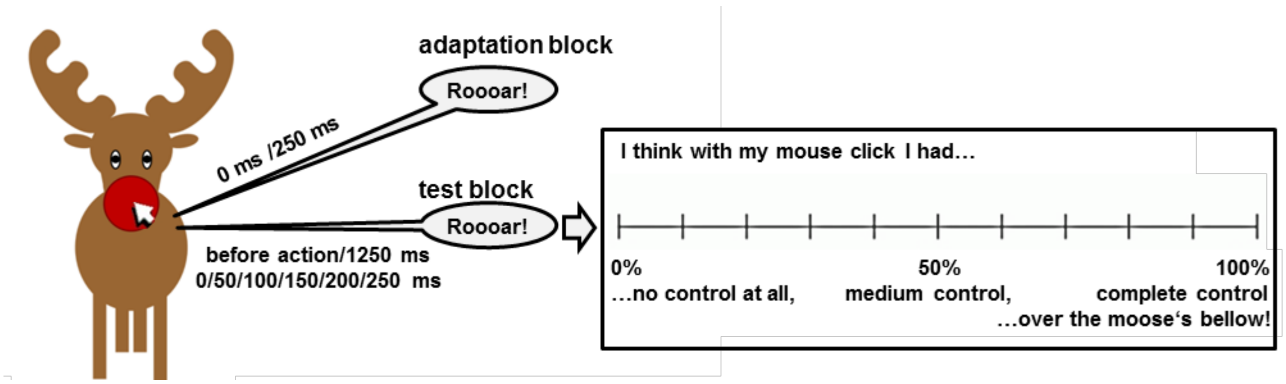

Figure 2. Schematic layout of trials in adaptation blocks and test blocks. The times indicate the delay between action (mouse click on the target) and the effect (bellowing sound). The wording for judgments in test blocks was originally presented in German.

Participants were informed at the beginning of the experiment and at the beginning of each test block that the mouse click usually causes the moose to bellow but that in some trials the moose might bellow independent of the click. At the beginning of each adaptation block participants were informed that during the following block each click would cause the effect. Importantly, we never mentioned different delays between action and effect.

Data Analysis. We calculated mean control judgments per participant separately for each delay. For each participant a regression analysis was computed predicting the mean control judgments for the delays between 0 ms and 250 ms. The resulting correlation coefficients and the slopes of each participant's regression function were then averaged separately for each group.

3. Results

Raw data of the participants' average perceived control over the effect for the delays of 0 ms to 250 ms are shown in Figure 3. For effects preceding the action participants indicated to 8 % (delay group) and 11 % (immediate group) of perceived control and for 1250 ms delayed effects they indicated 29 % and 22 % of perceived control respectively.

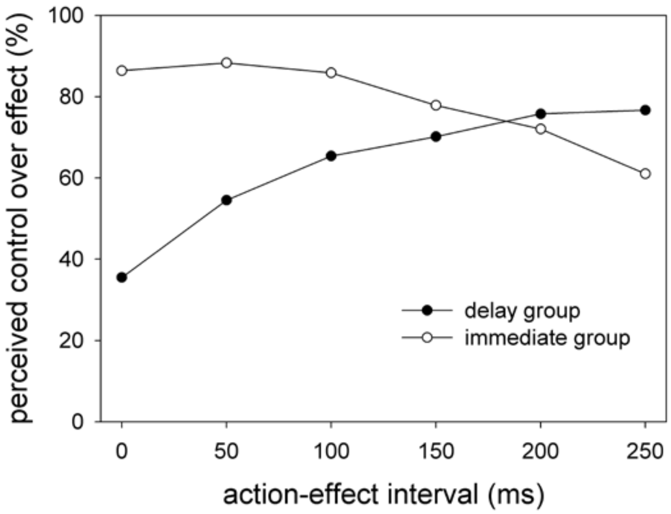

Figure 3. Raw average ratings of perceived control over the effect for the delays of 0 ms to 250 ms.

In the immediate group, the average correlation coefficient was r = -.68 with a slope of -0.09, indicating that control judgments on average decreased 9% per 100 ms delay. In the delay group the average correlation coefficient was r = .72 with a positive slope of 0.14, that is for each 100 ms delay, the control judgments on average increased by 14%. Thus, as predicted by the experience hypothesis the relation between action-effect delay and perceived control reversed in the delay group.

To check whether deviation from the usually experienced delay of an effect similarly affected perceived control judgments in both groups, we inverted the correlation coefficient r and the slope in the delay group by multiplying them with -1 and computed a t-test for independent samples. Neither the size of the correlation coefficients, $t(34) = -0.49$, $p = .63$, nor the slopes of the functions, $t(34) = -1.64$, $p = .11$, differed between groups.

4. Discussion

In this study, we assessed the impact of temporal delays between action and effect on sense of agency judgments depending on whether participants frequently experienced that actions caused effects either immediately or delayed by 250 ms. Participants who were adapted to immediate effects, sensed less agency the longer the delay between action an effect. In contrast, participants who were adapted to 250 ms delayed effects, showed the reversed result pattern and sensed less agency the shorter the delay between action and effect.

To further examine whether sense of agency judgments depended on deviations from the usual delay of the effect or were at least partly influenced by temporal contiguity of action and effect, we computed regression analysis predicting control judgments from the action-effect delays. The comparison of regression coefficients and slopes (reversed in sign in the delay group) indicated that deviations from the usual time of the effect predicted control judgments equally well in both, the immediate and the delay group. Numerically, the correlation coefficient r and the slope of the regression function were even larger in the delay group. These data rule out that sense of agency judgments were determined by temporal contiguity alone or by both temporal contiguity and proximity to the adapted delay, because in this case slope and regression coefficient should be smaller in the delay group than in the immediate group. Instead our data unequivocally indicate that deviation from the usual time of an effect and not temporal contiguity between action and effect determines sense of agency judgments.

Interestingly, deviations from the usual time of the effect determined sense of agency although participants were not explicitly informed about the usual delay of the effect and although there was no physical mechanism that explained the action-effect delay (like in the study of Buehner & McGregor, 2006). Instead, participants adapted to the usual time of the effect because of repeated experience that the effect either occurred immediately or 250 ms delayed after the action. Thus, learning when an effect occurs impacts on sense of agency similarly as it impacts on responding to the effect (Haering & Kiesel, 2012). When action effects occur earlier than expected, participants not only respond slower, they also sense less agency.

To understand these findings, two phenomena of time perception in action contexts are interesting. First, actions and repeatedly delayed effects are perceived closer in time than they actually are (Haggard, Aschersleben, Gehrke, & Prinz, 2002; Haggard, Clark, & Kalogeras, 2002; Nolden, Haering, & Kiesel, 2011). This effect is termed intentional binding (IB) and is suggested to be linked to agency (Eagleman & Holcombe, 2002; Haggard, 2005; Moore & Obhi, 2012). Thus, participants in the delay group might have felt a strong sense of agency because they no longer perceived the delay as a violation of temporal contiguity due to temporal binding.

Second, repeated experience of delayed effects can even reverse the perceived order of action and effect when an effect occurs earlier than expected. In a study of Stetson, Cui, Montague, & Eagleman (2006), participants learned that a tone effect either occurred 35 ms or 135 ms delayed after a key press. Then the same tone occurred at variable delays shortly before or after the action. Participants who had experienced a 135 ms delay between key press and tone perceived the majority of tones up to 64 ms after the key press as having occurred before the key press. In contrast, participants who had experienced 35 ms delayed effects, judged only tones up to 20 ms after the action as occurring before the action. Stetson et al. hypothesized a recalibration process for usually delayed effects “to keep causality assessments appropriately calibrated” (p. 655/656).

Similarly to the IB effect, this recalibration process suggests that participants adapt to repeatedly delayed effects which may disable effects of temporal contiguity.

To account for our observation that sense of agency increased with action-effect delay in the delay group, a recent extension of ideomotor theory is relevant (Dignath, Pfister, Eder, Kiesel & Kunde, in press). Ideomotor theory proposes that a movement and contingently following effects become associated, and that, in turn, the effect can be used to select, initiate, and control an action (Herbart, 1825; James, 1890; for a modern version, see Hommel, Müsseler, Aschersleben, & Prinz, 2001). Dignath et al. reported evidence that the delay of an effect is integrated in the action-effect association and that the delay - similar to the effect - is automatically retrieved during action planning (see Kiesel & Hoffmann, 2004 for a similar finding). Consequently, if participants repeatedly experienced that an action produced an effect after a fixed delay, planning this action involves the expectation that a specific effect will occur after a specific delay. If this expectation is violated participants sense less control over the effect compared to conditions in which the effect occurs at its usual time.

Yet, our results contradict a recent study of Dewey & Carr (2013) which assessed sense of agency in test sessions in which two participants acted. In their Experiment 2, participants initially learned that a left / right key press resulted in a high / low frequency tone (with a contingency of 80%, in 20 % the action-effect mapping was reversed) after a delay of 600 ms. In the test phase, either the participant or another participant caused the effect tone and the participant either acted before or after the other participant (leader or follower). Irrespective of whether the effect was truly caused by the leader or the follower, participants sensed more agency as follower, thus for short delays between their action and effect.

Currently we can only speculate why results differ. In Dewey & Carr’s study, the context between learning and test session differed because participants initially acted alone and were tested in dyads. Additionally, the mapping between left / right key presses and high / low frequency tone changed from learning to test session - in the test session the mapping was random. Thus, participants' expectation that a specific action produces a specific effect was violated. We conjecture that the change in context and the random action-effect mapping may have prevented the retrieval of previously learned association between action, effect, and delay in the test phase. Yet, this speculation that learning and acquisition of associations between actions, effects, and delays depend on the context requires further testing.

Taken together, the present study shows that sense of agency is not determined by temporal contiguity between action and effect but that repeated experience of a delayed effect impacts on sense of agency judgments. Agency judgments diminish the larger the time point of an effect deviates from its usual time.

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