Current Psychology (2021) 40:1795–1806
https://doi.org/10.1007/s12144-018-0121-3

Sense of agency is modulated by interactions between action choice, outcome valence, and predictability

Takumi Tanaka[1] · Hideaki Kawabata[2]

Published online: 5 January 2019

Abstract

Sense of agency is a feeling of control over one's actions to cause sensory events in one's environment. While previous studies investigated the role of action choice and emotional valence of action outcome in forming implicit agency, the results were not consistent and the relationship between these factors remains unclear. We manipulated both action alternatives available and emotional valences of sounds (either positive or negative) as action outcomes and measured the resultant intentional binding effects in two experiments that differed in predictability of outcome valence. When participants could not predict the valence of action outcomes, they showed stronger sense of agency for negative outcomes determined by their free choice (Experiment 1). Conversely, when participants' actions caused only outcomes with specific valence, this interaction was not observed (Experiment 2). These findings imply that the implicit processes of agency reflect an integrative context-dependent cognition of consequence of action choice, prior to explicit attribution judgments.

Keywords Sense of agency · Intentional binding · Action choice · Emotional valence · Action-outcome predictability

Introduction

Based on environmental perception, humans consistently choose their actions and then perceive sensory outcomes as potential cues for the next action choice. This cycle is mediated by "sense of agency," which is the feeling that one's intentional actions cause specific events in the outside world (Gallagher 2000). This experience of agency makes a person realize the causal relationship between one's actions and outcomes associated with reward or punishment and evokes cognitive, emotional reactions to one's *own* action outcomes. In particular, agency over a negative outcome is linked to feelings of guilt, regret, or responsibility and plays a critical role in the modification of inappropriate behavior (Gentsch and Synofzik 2014). However, like the case of learned helplessness (Seligman 1968), a perception of the close causal relationship between actions and negative outcomes might only foment negative emotional reaction, and cannot improve future behavior unless one realizes a possibility to avoid them by their action choice. Especially, when someone only obeys another's orders or has no other action choices, people find it difficult to attribute the negative outcome to themselves and to feel agency or any negative emotion, even for one's voluntary actions (Mezulis et al. 2004). Milgram's (1963) famous study implied that this tendency could distort emotional reactions to negative action outcomes and allow one to behave highly immorally in specific situations. It is important to mention that agency is subject to the process of action choice as well as the actual cause of action outcome (Frith 2014); thus, this process can contribute to the arousal of regret and changing the choice of behavior (Bossuyt et al. 2014).

In previous studies, participants reported they had a keen sense of agency over actions chosen by themselves, where agency was measured by self-report (e.g., Lepron et al. 2015). However, since a sense of agency is naturally a vague experience that is not consciously accessed in the usual situation, participants can have difficulty in quantifying the degree of agency (Haggard and Chambon 2012). Moreover, participants' reports can be distorted to meet the demand characteristics (Woolfolk et al. 2006). To avoid these problems, many

✉ Takumi Tanaka
kino31513@gmail.com

Hideaki Kawabata
kawabata@flet.keio.ac.jp

1 Department of Psychology, Graduate School of Human Relations, Keio University, Mita, Minato-ku, Tokyo, Japan

2 Department of Psychology, Keio University, Mita, Minato-ku, Tokyo, Japan

experimental studies have quantified sense of agency with implicit measurements, such as “intentional binding” (Haggard et al. 2002). Intentional binding is a subjective compression of the temporal interval between a voluntary action and its external sensory consequence, which is composed of two illusions in time perception called “action shift” and “outcome shift.” While action shift refers to a phenomenon in which actions that cause an event are experienced later, outcome shift refers to one where an outcome is experienced earlier when it is triggered by a voluntary action, compared to when there is no sequence composed of voluntary actions and an event as their outcome (see Moore and Obhi 2012, for a review). Intentional binding is not caused by an involuntary movement induced by transcranial magnetic stimulation (Haggard et al. 2002) and requires knowledge about the causal relationship between actions and outcomes (Cravo et al. 2009). Conversely, since this compression has been observed in the interval between observation of another’s action and its outcome, some studies claimed that it reflects mere perceived causality, but not agency (e.g., Buehner 2012).

Some researchers believe that these explicit and implicit measures reflect different aspects of agency. The representative theory of agency (e.g., Synofzik et al. 2008) assumes a distinction of two levels of processing: the *feeling* of agency and the *judgment* of agency. Feeling of agency is a non-conceptual sense, unconsciously formed based on a multifactorial weighting process of different agency cues, including sensorimotor factors such as prediction of action outcome. Meanwhile, judgment of agency arises because of an explicit attribution of agency, based on inferential cognitive processes involved in social or contextual cues, and even the feeling of agency. In this framework, the implicit measure of sense of agency, such as intentional binding, is believed to depend more on the feeling of agency, while the explicit measure, such as self-report, is believed to depend more on the judgment of agency. The process of action choice should be linked largely to the action planning and formation of implicit agency based on sensorimotor processing. Moreover, Gentsch and Synofzik (2014) claimed that emotional factors could modulate the sense of agency in each of these stages. Therefore, these factors might form the sense of agency in advance of one’s conscious cognition of a situation, including attributional inference. This means that agency measured implicitly can dissociate from the explicit agency that one finally experiences.

Even so, we can use binding to measure the relative degree of psychological involvement in an event, independently of qualitative attribution judgment. For example, in a situation where one participant initiated a movement and a second person passively moved subsequently toward him, both participants experienced intentional binding, but only the initiator reported an explicit sense of agency (Obhi and Hall 2011). This indicated that the binding did not depend only on actual causality and thus enables us to compare sense of agency between conditions, with no ambiguity of actual causality. As Frith (2014) mentioned, agency reflects not only actual causality but also the possibility of action choice. Intentional binding revealed that more action choices enhanced implicit agency (Barlas and Obhi 2013), while following another’s actions or orders attenuated it (Caspar et al. 2016; Pfister et al. 2014).

While the nature of this intentional binding offers a great advantage of investigating sense of agency for negative events in a situation without attributional ambiguity, it remains unknown how negative outcomes modulate implicit agency. Some studies clarify that outcomes associated with monetary loss (Takahata et al. 2012), emotionally negative valence (Gentsch et al. 2015; Yoshie and Haggard 2013), or painful somatosensory stimuli (Borhani et al. 2017) attenuate the intentional binding. Conversely, Moreton et al. (2017) failed to find any effect of emotionally negative outcomes with a procedure identical to Yoshie and Haggard (2013). Moreover, negative outcomes could even enhance intentional binding in specific situations, including the opportunity of action choice. Moretto et al. (2011) confirmed it with a scenario of dilemma situations, in which participants’ action choice of whether to intervene (“change”) or not (“stay”) had unpredictable consequences that were either moral or economic only. Indicating that moral compared to non-moral contexts, and severely negative compared to moderately negative outcomes, elicited a stronger outcome shift, they interpreted implicit sense of agency as a pre-reflective source of responsibility. While their results showed no effect of action choice nor interaction with outcome valence, their experiments did not include a condition of absence of any action choice and, thus, the effect of opportunity to choose remained unclear.

Beck et al. (2017) and Di Costa et al. (2017) also showed enhancement of outcome shift for negative outcomes. Moreover, they suggested another potential moderator of the effect of outcome valence: controllability of outcome or the possibility of learning an action-outcome association. For instance, Beck et al. (2017) showed stronger outcome shifts when participants experienced a negative outcome as a result of choosing between two alternatives with different probabilities for two levels of outcome intensity, compared to choices with the same probabilities. This indicated that not only the presence of choice, but also the degree of variability of outcome obtained by diverse options (instrumental divergence; Mistry and Liljeholm 2016), might contribute to implicit agency regarding negative outcomes.

This may help to explain the inconsistency in results regarding the interaction between action choice and outcome valence on implicit agency. In experiments by Caspar et al. (2016) and Caspar et al. (2017), participants executed actions that either gave others pain or not, according to free-choice or coercive instruction by an experimenter. They showed a significant effect of the manner of action choice, with a larger binding in the free-choice condition, but no significant effect of outcome valence nor a significant interaction. Borhani et al. (2017) reported similar effects of the intensity of either painful heat stimuli or nonpainful electrotactile stimuli as results of participants' action, and of participants' choices of this intensity in advance of execution of action or not. In their study, the outcome modality types were manipulated as a between-subjects factor. Participants who received painful stimuli experienced a smaller outcome binding than those who received nonpainful stimuli. Further, high-intensity heat-pain stimuli decreased and the free choice over outcome intensity, but not forced choice, increased outcome shift; however, no interaction was observed between them. Similar to how Borhani et al. (2017) called this *outcome choice*, the studies by Caspar et al. (2016, 2017) indicated the absence of the interaction effect between the choice over which outcome to cause, but not over which action alternative to exercise, and the outcome valence. Since each option always caused a specific outcome throughout the experiments, participants knew the outcomes of their choices beforehand, regardless of the way the actions were chosen. In this sense, they could always cause desired events in the free-choice condition. Such a situation might be inadequate to investigate an aspect of agency linked to regret and responsibility.

This problem was partly shared by Beck et al. (2017) and Di Costa et al. (2017), because the participants in their experiments could predict outcome valence relatively well in the condition with the possibility to control the outcome. Therefore, they did not separate the expectation of receiving a desirable outcome and the opportunity of action choice. Recent studies indicated that the predictability of outcome modulated the effect of outcome valence on implicit agency, even without action choice (Christensen et al. 2016). As one interprets that both predictability and action choice should contribute to cognition of the consequences in the specific context, they might elicit interaction effects on agency on negative outcome. To investigate this possibility, binding in the free-choice and no-choice conditions, which have the same action-outcome contingency (that is predictability), should be compared. Studies investigating a phenomenon called the "illusion of control" have revealed that even choices that did not affect outcomes at all enhanced perceived control and induced the overestimation of the expectation of a personal success probability (e.g., Langer 1975). This indicates that the apparent presence of action choice can distort participants' cognition of causal context. Barlas et al. (2017, 2018) manipulated the number of action alternatives and outcome valence, such that there was unpredictable contingency between action alternatives, and failed to find an interaction between the two factors. However, they measured the binding with direct estimation of the action-outcome interval, instead of a clock paradigm. Given that the effect of negative outcome has been observed specifically in outcome shift but not action shift, this procedure, which could not discriminate each phenomenon, seems inadequate to identify subtle situational differences.

Assuming the context-dependency of sense of agency, the nature of an outcome, such as whether it is ecological and socially relevant (such as real pain), emotional (such as vocalization), or economical, might interact with effects of choice and valence on outcome shift. However, some studies have indicated that the difference of the kinds of stimuli could not simply account for the inconsistent results of negative effects on intentional binding. While Beck et al. (2017) showed the significant interaction effect between choice and valence, Caspar et al. (2016, 2017) did not find such effect with similar stimuli of pain. Likewise, Di Costa et al. (2017) and Barlas et al. (2017 and 2018) provided different results using financial loss as negative outcomes.

Therefore, in the present study, we investigated how the manner of action choice and outcome valence influence implicit sense of agency interactively in two experiments, which differ in the predictability of outcome valence. We used a modified intentional binding task based on studies manipulating action choice (Barlas and Obhi 2013) and outcome valence (Yoshie and Haggard 2013). We first randomized outcome valences within each experimental block so that participants could not predict which alternatives would correspond to the specific outcomes, and they could receive negative consequences unintentionally, in Experiment 1. Then, to be sure that the interaction of those factors was context-dependent, we executed the same procedure, except for manipulating outcome valence as a between-block factor, in Experiment 2. In both experiments, we used only positive and negative, not neutral, emotional stimuli to uniform the salience of stimuli.

Experiment 1

Methods

Participants Twenty-four right-handed adults (10 females; mean age = 21.8 ± 1.88 years) participated. We determined the sample size based on the those in a previous study investigating the effects of valence and counterbalance. Moreton et al. (2017) recruited 24 participants "to achieve 95% power to detect Yoshie and Haggard's reported effect size for their Experiment 1 (dz = 0.77)," and this size allowed us to use each one of 12 execution orders for counterbalance across participants in Experiment 1. All experiments in this study were approved by the local ethical committee of the Keio University, Japan (approval ID: 15020). Participants individually provided informed consent, signed a written consent form, and received 1500 Japanese yen for each participation.

Apparatus The visual stimuli were presented on a 22-in. LED monitor (2233RZ, Samsung) with a 1920 × 1080 pixel spatial and 60 Hz temporal resolutions. The auditory stimuli were presented via headphones (HDA200, Sennheiser). The experiment was controlled using MATLAB (The Math Works, Natick, MA) with Psychotoolbox (Brainard 1997; Kleiner et al. 2007; Pelli 1997) using a MacBook Pro (MacBook Pro, Apple).

Stimuli To select auditory emotional stimuli, a preliminary pre-rating experiment was conducted with 12 participants (six females; mean age = 21.67 ± 1.67 years) who were independent to the main experiment. They rated emotional valence and arousal of 42 non-verbal vocalization stimuli from "The International Affective Digitized Sounds" (Bradley and Lang 2007) on a scale from 1 (*unpleasant*) to 9 (*pleasant*) for valence and 1 (*calm*) to 9 (*excited*) for arousal. Sounds were trimmed to 700 ms duration from onset and their maximum amplitude was uniformed. Based on pre-rating scores, we selected four positive and four negative sounds so that the difference of the mean of valence rating between positive and negative sounds became as large as possible (positive: mean = 6.42, $SD = 1.25$; negative: mean = 2.47, $SD = 0.72$) and the arousal rating became equal (positive: mean = 6.51, $SD =$ 1.13; negative: mean = 6.13, $SD = 1.17$).

Procedure This experiment comprised an intentional binding task and a post-rating task. The intentional binding task included three between-block conditions (i.e., operant or baseline, action choice (free choice or no choice), and critical event (action or outcome)) and one within-block condition (i.e., outcome valence (positive or negative)). The requirements of key press, presence of outcome feedback, critical events, and trial numbers of each block are shown in Table 1.

In each block, participants started each experimental trial by pressing the "enter" key on the keyboard. Then, like the general Libet clock procedure, there was a clock face with a 12 mm-long clock hand at a random position (Libet et al. 1983). After 500 ms, the clock hand started rotating at a rate of 2.5 s per cycle. There was a fixed interval scale from 0 (at the top position of the clock face) to 59 (clockwise around the clock face). In the operant condition, participants pressed a key on the keyboard at a freely chosen time, followed by auditory feedback of eight sounds (four positive and four negative non-verbal vocalization stimuli) 250 ms later. These sounds were selected from "The International Affective Digitized Sounds" (Bradley and Lang 2007) based on a preliminary pre-rating experiment. In the free-choice condition (A, B, and C in Table 1), participants chose one of eight keys; however, in the no-choice condition (D, E, and F in Table 1), the key pressed by each participant was limited to a specific one instructed on the display at the beginning of the trial. In both the choice conditions, participants were informed that their choice determined the kind of outcome, as well as its emotional valence, received in each trial. Once an outcome (i.e., auditory feedback) was presented, the clock hand kept rotating for a random time from 1 to 2 s and then disappeared. Participants were required to report the position where the clock hand pointed when the critical event of each block occurred, inputting any number between 0 and 59 on the keyboard. In the baseline action condition (C and F in Table 1), the auditory feedback on the key press was not presented. At a random time from 1250 to 2250 ms after the key press, the clock disappeared, and participants reported the timing of their actions. In the baseline outcome condition (G in Table 1), participants did not press any key and the auditory stimulus was presented automatically at a random timing between 1250 ms and 5 s after the clock hand started rotation. The typical sequence of a trial in the intentional binding task (i.e., operant action block) is shown in Fig. 1.

Table 1 The composition of each experimental block

Block	Action	Outcome	Critical event	Trial
A	Free choice	Present	Key press	64
B	Free choice	Present	Sound	64
C	Free choice	- [a]	Key press	32
D	No choice	Present	Key press	64
E	No choice	Present	Sound	64
F	No choice	–	Key press	32
G	–	Present	Sound	64

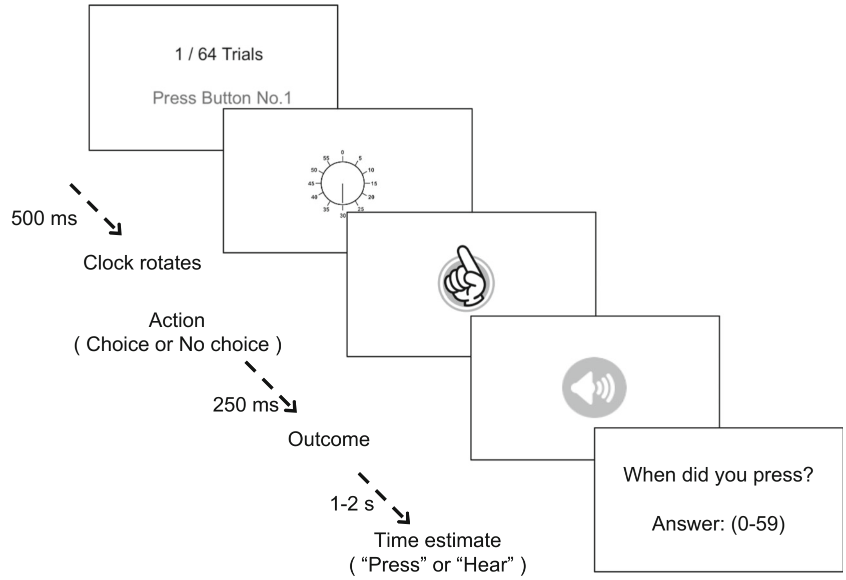
[a] Hyphens represent absence of action or outcome in the baseline condition

Participants were orally provided with five pieces of advice about their actions: (1) do not intend to press the key when the clock hand is pointed at the position they previously decided, (2) do not press the key before the clock hand has rotated around half of the clock face, (3) press the key with your right index finger, (4) do not choose the key in a stereotyped manner in the free-choice condition, and (5) press the key while keeping an eye on the clock after deciding which key to press.

In each experimental block, excluding the baseline action condition, each of the eight auditory stimuli were presented eight times in a randomized order. Since the execution order of the blocks was counterbalanced regarding each of three between-block conditions independently, one of 8 (2 × 2 × 2) patterns of sequence was assigned to each participant. The baseline action block comprised 32 trials; therefore, each condition included the same trial number. The specified key used in the no-choice condition was selected randomly in each trial. After the binding task, participants performed a post-rating task, requiring them to rate the emotional valence and arousal for each of the eight stimuli, the same as during the pre-rating task.

Data Analyses The trials with errors in time judgment two standard deviations away from participants' average errors

Fig. 1 Procedure of a typical (operant) trial in the intentional binding task. Instructions displayed on the screen are examples of those in the operant, no-choice condition requiring report on key press



in each specific situation (i.e., operant or baseline, free choice or no choice, the kind of stimuli, and the critical event) were excluded from the analyses. The mean number of removed trials was 4.36% (range among all participants = 0–6.77%).

To calculate the perceptual shifts of action and outcome, we first quantified judgment errors as the difference between the estimation of specific critical events and its actual onset times in each condition. Regarding action shift, we subtracted the mean of those errors in the baseline action condition from that in the operant action condition in the corresponding action choice condition (free choice or no choice) and corresponding outcome stimuli by participants. Regarding outcome shift, on the contrary, the mean errors in the operant outcome condition were subtracted from those in the baseline outcome condition in the corresponding action choice and outcome stimuli condition by participants. Thereby, in the case of both action and outcome shifts, a positive value indicated a perceptual shift in the compressional direction, which was consistent with the general intentional binding effect, and a negative value indicated a reverse shift.

All statistical analyses in this study were conducted with R statistical software. Compute.es package was used for analysis of Cohen's d (http://CRAN.R-project.org/package=compute.es). Anovakun package was used for the analyses of variance (ANOVAs) and partial η^2 ("http://riseki.php.xdomain.jp/index.php?ANOVA%E5%90%9B").

Results and Discussion

Stimuli Rating A two-tailed paired t-test of valance rating in the post-rating task revealed that stimuli labeled positive were rated as significantly more positive (pleasant) than stimuli labeled negative ($t(23) = 13.20$, $p < .001$, $d = 3.81$). Conversely, the arousal rating of both kinds of stimuli did not significantly differ ($t(23) = 1.16$, $p = .255$, $d = 0.336$) (Fig. 2).

Intentional Binding A 2 (action choice: free choice or no choice) × 2 (outcome valence: positive or negative) repeated-measures ANOVA of action shift revealed a significant main effect by valence ($F(1,23) = 5.57$, $p = .027$, partial $\eta^2 = .195$). Like Yoshie and Haggard (2013), outcomes with negative valence caused less action shift than positive outcomes. A main effect by action ($F(1,23) = 1.67$, $p = .209$, $d = 068$) and interaction effect were not significant ($F(1,23) = 1.46$, $p = .239$, $d = 056$).

Conversely, the same 2 × 2 repeated-measures ANOVA of outcome shift revealed a significant interaction between choice and valence ($F(1,23) = 5.05$, $p = .035$, partial $\eta^2 = .180$). Although a simple-effect analysis revealed no significant effect, our results indicated the tendency that negative outcome caused a larger shift than positive outcome, but only in the free-choice condition ($F(1,23) =$

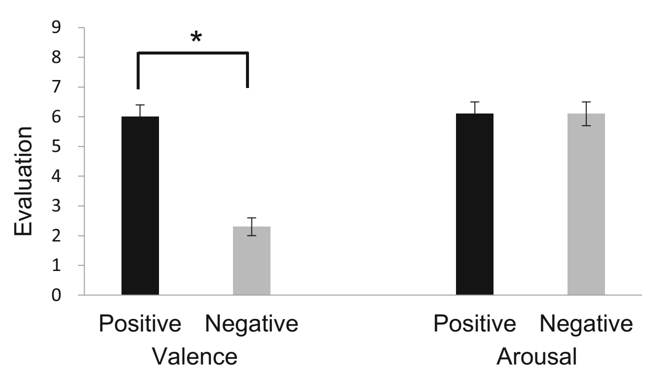


Fig. 2 Mean rating scores for valence and arousal of positive and negative stimuli in Experiment 1. Error bars represent standard errors. An asterisk indicates a significant difference at the .01 probability level

3.09, $p = .068$, partial $\eta^2 = .138$) (Fig. 3). There were no significant main effects of action ($F(1,23) = 0.67$, $p = .419$, partial $\eta^2 = .029$) nor outcome valence ($F(1,23) = 0.56$, $p = .460$, partial $\eta^2 = .024$). As predicted, only when participants had an opportunity to choose action alternatives, did our data show a larger outcome shift for the negative outcome, such as that observed by Moretto et al. (2011) and Di Costa et al. (2017). This result provided evidence of the potential role of action choice in forming agency in moral contexts without the ambiguity of actual causality.

To exclude the possibility that experimental manipulations influenced the precision of timing estimation itself, we conducted an analysis of the standard deviation of participants' judgments for actions and outcomes in operant conditions, respectively. Although the same 2 × 2 repeated-measures ANOVA of variance in judgments for actions showed no significant effect, there was a trend that reaction to negative stimuli was less reliable ($F(1,23) = 3.55$, $p = .072$, partial $\eta^2 = .134$). This may contribute to the effect of valence on action shifts. There were no significant main effect of action ($F(1,23) = 0.43$, $p = .620$, partial $\eta^2 = .018$) nor interaction effect ($F(1,23) = 0.02$, $p = .899$, partial $\eta^2 = .001$). The same analysis of variance in judgments for outcomes revealed no significant difference in the precision of estimation between each condition. Additionally, in Experiment 1, participants' actions always caused one of eight sounds. The acoustic characteristics of the sounds could systematically influence the time estimation for them. To investigate the potential difference in judgment error by outcome stimuli, we conducted a one-way ANOVA with the kind of sounds for judgments in the outcome baseline condition in Experiment 1. The result showed no significant difference in baseline estimation by stimuli ($F(7,161) = 1.43$, $p = .199$, partial $\eta^2 = .058$).

Experiment 2

In Experiment 1, we demonstrated that the manner of choosing and emotional valence interactively influenced agency, even when there was no other agent who could execute the action. Further, although participants were told that the valence of an action outcome depended on their choice, they could not predict it. However, when one can know an outcome valence in advance and regardless of one's choice, the value of opportunity to choose should largely change. To investigate the role of predictability, we tested whether manipulation of outcome valence as a between-block factor, by having participants' actions consistently cause outcomes with specific emotional valences throughout each experimental block, would diminish the enhancement of agency over the negative outcomes caused by one's own choice observed in Experiment 1.

Moreover, in Experiment 1, there were some variability of rating pattern within kinds of stimuli and participants, despite the significant difference in rating score between prefixed positive and negative stimuli on average. For example, a stimulus labeled positive was not always evaluated more positively than all stimuli labeled negative. To minimize such differences in cognition of outcome valence between participants, in Experiment 2, participants individually worked on the valence and arousal rating of 20 emotional vocalization stimuli on a visual analog scale at the beginning of the experiment and were presented eight of them in the binding task, which differed for every individual.

Methods

Participants We added another between-block condition in Experiment 2. Therefore, 32 right-handed adults (14 females; mean age = 20.9 ± 1.22 years) participated, independently of Experiment 1, due to counterbalancing. In Experiment 2, our

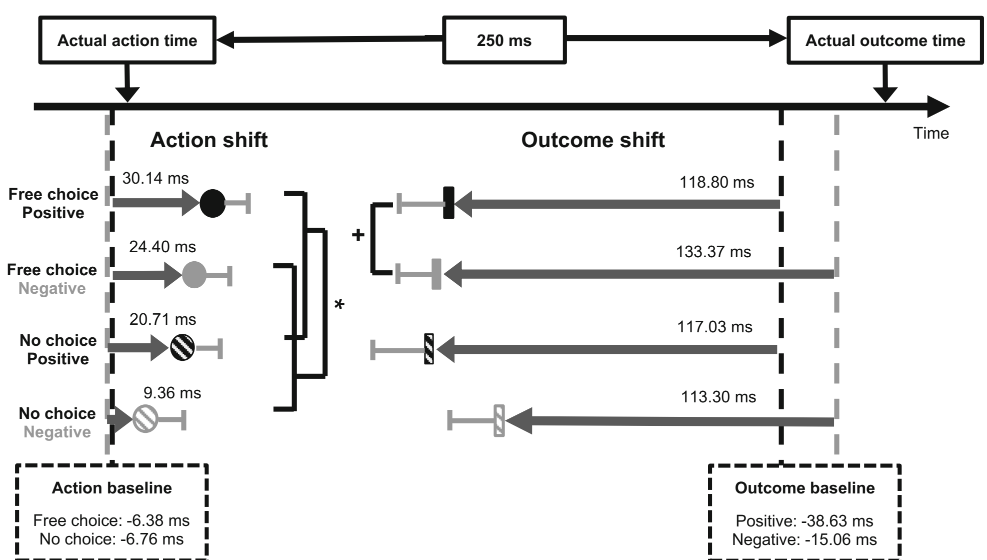


Fig. 3 Mean perceptual shifts of action and outcome in Experiment 1. Break lines indicate baselines. Upper two markers represent estimation in the free-choice and lower two represent those in the no-choice condition. Black markers refer to the positive and gray ones refer to the negative condition. Error bars represent standard errors. An asterisk indicates a significant difference at the .05 probability level

goal was to investigate whether the interaction effect between action selection and outcome valence, observed in Experiment 1, occurred or not in the condition where outcome valence was predictable. Thus, we recruited 32 participants to achieve 95% power to detect the effect size of interaction effect observed in Experiment 1 (partial $\eta = 0.18$) and to carry out 16 execution orders for counterbalance twice. Four participants were excluded from the analyses because it was impossible to select eight independent stimuli along with the criterion to minimize the difference of arousal between positive and negative stimuli.

Apparatus All apparatus and experimental settings were identical to Experiment 1.

Stimuli Participants rated emotional valence and arousal for 20 kinds of non-verbal emotional vocalization stimuli from "The International Affective Digitized Sounds" (Bradley and Lang 2007) on a visual analog scale from 1 (*unpleasant*) to 200 (*pleasant*) for valence and 1 (*calm*) to 200 (*excited*) for arousal. All sounds were trimmed to 700 ms duration and uniformed regarding the maximum amplitude. Based on their individual rating score, we selected each four positive and four negative sounds, which were presented in the intentional binding task for each participant. To minimize the difference in arousal scores between the valence conditions of sound (positive/negative), we repeatedly calculated the averaged arousal scores between these conditions, then replaced the highest arousal stimulus with a stimulus that was the next highest (or lower) valence, if the difference between averaged arousal scores of two sound conditions had exceeded 20 in the visual analog scale. For example, when the averaged arousal score of the four most positive stimuli was 20 points higher than that of negative stimuli, the highest arousal stimulus in positive stimuli was excluded and the next most positive stimulus was reselected. Four participants were excluded from the analyses because it was impossible to select independent eight stimuli along with this criterion.

Procedure This experiment comprised a pre-rating task and an intentional binding task. Based on individual pre-rating score, we selected four positive and four negative sounds each, which were presented in the binding task for each participant. The binding task was almost the same as that of Experiment 1. The only difference was that the valence of feedback of participants' action was manipulated as a between-block factor in Experiment 2. Note that participants could predict the valence of outcomes, but not which outcome stimulus they would receive in each trial. To counterbalance the order of the four between-block conditions (i.e., operant or baseline; action choice; outcome valence (positive or negative); and critical event), one of 16 ($2 \times 2 \times 2 \times 2$) patterns of sequence was assigned to each participant. Four auditory stimuli, either positive or negative, were presented eight times in a randomized order within each block. Therefore, all experimental blocks consisted of 32 trials.

Data Analyses The trials with errors two standard deviations away from each participant's average errors in each specific situation were excluded from the analyses. The mean number of removed trials was 7.67% (range among all participants = 3.65–12.76%). We calculated the perceptual shifts of action and outcome in the same way as Experiment 1.

Results and Discussion

Stimuli Rating A two-tailed paired *t*-test of valance rating in the post-rating task revealed that stimuli labeled positive were rated as significantly more positive than stimuli labeled negative (positive: mean = 134.55, $SD = 5.36$; negative: mean = 48.01, $SD = 4.59$; $t(27) = 12.26$, $p < .001$, $d = 3.278$). Conversely, as shown in Fig. 4, the arousal rating of both kinds of stimuli did not significantly differ (positive: mean = 99.89, $SD = 6.28$; negative: mean = 100.71, $SD = 7.08$; $t(27) = .09$, $p = .931$, $d = 0.023$).

Intentional Binding A 2 (action choice) × 2 (outcome valence) repeated-measures ANOVA of action shift revealed a significant main effect by action choice ($F(1,27) = 4.61$, $p = .041$, partial $\eta^2 = .146$) (Fig. 5). A main effect by valence ($F(1,27) = 0.42$, $p = .526$, partial $\eta^2 = .015$) and interaction effect ($F(1,27) = 0.37$, $p = .544$, partial $\eta^2 = .014$) were not significant. Similar to Caspar et al. (2016) and Caspar et al. (2017), when there was no unpredictability of outcome valence, action choice induced a larger shift.

Conversely, the same 2 × 2 repeated-measures ANOVA of outcome shift did not reveal any significant main effects of action choice ($F(1,27) = 0.18$, $p = .677$, partial $\eta^2 = .007$) and outcome valence ($F(1,27) = 0.18$, $p = .480$, partial $\eta^2 = .019$),

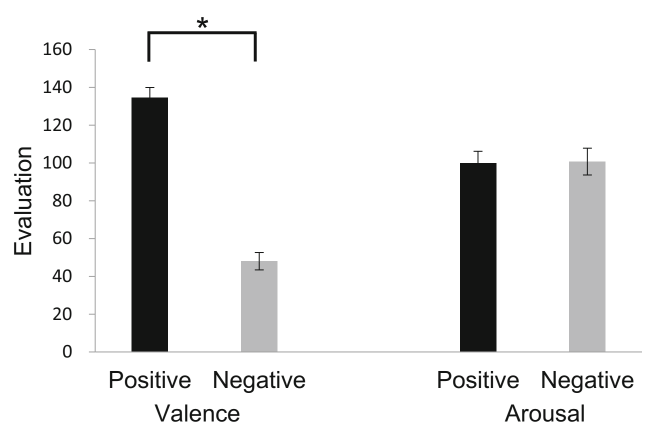


Fig. 4 Mean rating scores for valence and arousal of positive and negative stimuli in Experiment 2. Error bars represent standard errors. An asterisk indicates a significant difference at the .01 probability level

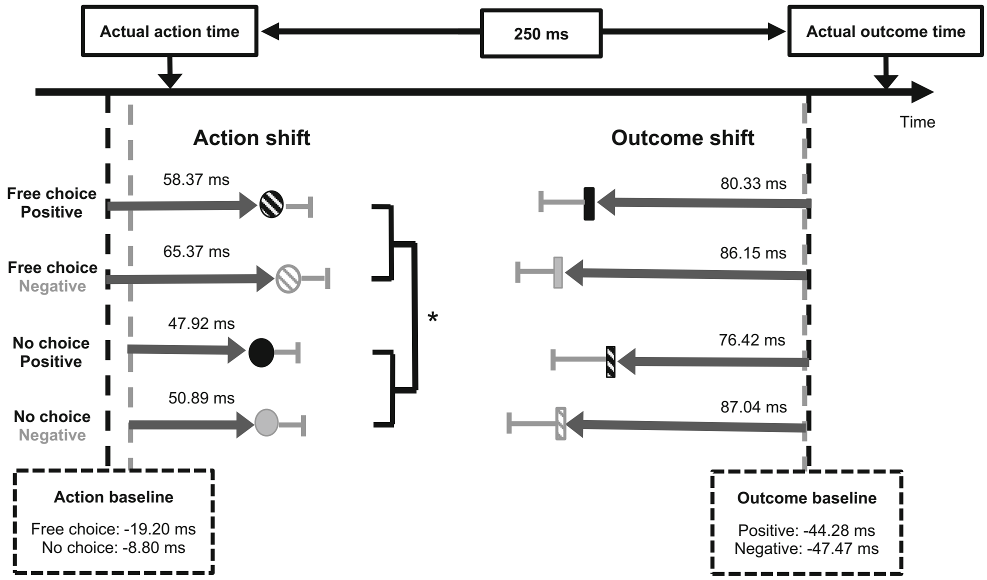


Fig. 5 Mean perceptual shifts of action and outcome in Experiment 2. Break lines indicate baselines. Upper two markers represent estimation in the free-choice and lower two represent those in the no-choice condition. Black markers refer to positive and gray ones refer to negative condition. Error bars represent standard errors. An asterisk indicates a significant difference at the .05 probability level

and their interaction ($F(1,27) = 0.63$, $p = .434$, partial $\eta^2 = .023$). As predicted, the results did not show any interaction effect between choice and valence without unpredictability of outcome. Even when one's action causes a negative outcome, it might not elicit a larger outcome shift unless one's action choice could influence the outcome valence.

We again conducted analysis of the standard deviation of participants' judgments in operant conditions. Neither the same 2 × 2 repeated-measures ANOVA of variance in judgments for actions (main effect of action choice: $F(1,27) = 0.001$, $p = .971$, partial $\eta^2 < .001$; main effect of action choice: $F(1,27) = 0.74$, $p = .397$, partial $\eta^2 = .027$; interaction effect: $F(1,27) = 1.61$, $p = .215$, partial $\eta^2 = .056$) nor outcomes (main effect of choice: $F(1,27) = 0.\ 81$, $p = .375$, partial $\eta^2 = .029$; main effect of valence: $F(1,27) = 0.01$, $p = .930$, partial $\eta^2 < .001$;interaction effect: $F(1,27) = 0.18$, $p = .678$, partial $\eta^2 = .007$) revealed significant differences in precision of estimation between each condition.

In Experiment 1, we did not record the key that participants pressed in each trial. However, the precision of time estimation might differ between the 8 keys due to the difference in the distance to the key from the finger's resting position. Therefore, we investigated whether the kind of key influenced the judgment error for time of action. A one-way ANOVA with 8 kinds of keys for the action baseline judgment revealed no significant effect ($F(7,189) = 1.91$, $p = .071$, partial $\eta^2 = .066$). The multiple comparison with the Bonferroni procedure also did not show any difference in judgment errors between any pair of keys ($ps > .10$).

Moreover, participants pressed each key for the same number of times in the no-choice condition, while the number of times each key was pressed depended on the participants' choice in the free-choice condition. This problem is shared with the previous studies manipulating action choice but such variability in key choice might contribute to the difference in action shifts between the free-choice and no-choice conditions. Although we instructed participants not to choose the key in a stereotyped manner, including an extremely unbalanced choice, the choice was partly biased so that the rightmost key ($t(27) = 4.04$, adjusted $p = .011$) and the third key from the right ($t(27) = 3.65$, adjusted $p = .023$) were significantly more pressed than the leftmost key. This seemed to be because all participants were right-handed. To investigate whether this bias in key choice was related to the effects of action choice on binding, we calculated the correlation coefficient between them. The degree of bias in key choice was calculated as the deviation from randomness for each participant, by subtracting the response proportion of each response key from .125 (chance level expected when each key was selected perfectly at random with the same probability) and averaging their absolute values (Karsh and Eitam 2015). The effects of action choice were calculated by subtracting mean action (outcome) shifts in the no-choice condition from those in the free-choice condition. They showed no systematic correlation in action shifts ($r = -.18$, $p = .32$) nor outcome shifts ($r = -.02$, $p = .92$).

Comparison Between Experiments 1 and 2

Proposing different results between the two experiments, we implied the potential contribution of action-outcome predictability to the interaction between choice and valence. To investigate the role of predictability more directly, we conducted a mixed design three-way ANOVA with two within-participant factors of action choice and outcome valence, and one between-experiment factor (Experiment 1 or 2). In terms of action shifts, this analysis showed a significant interaction between experiments and action choice ($F(1, 50) =$

5.26, $p = .026$, partial $\eta^2 = .095$). The choice modulated action shifts only in Experiment 2 ($F(1, 27) = 4.61$, $p = .041$, partial $\eta^2 = .146$). In contrast to Barlas and Obhi (2013), the free choice of action induced weaker action shifts. Including the effect of outcome valence observed in the two-factor analysis in Experiment 1, any other main effects or interaction effects were not observed (main effect of experiment: $F(1, 50) = 3.80$, $p = .057$, partial $\eta^2 = .001$; main effect of choice: $F(1, 50) = 0.01$, $p = .983$, partial $\eta^2 = .001$; main effect of valence: $F(1, 50) = 0.16$, $p = .694$, partial $\eta^2 = .003$; two-way interaction effect between experiment and valence: $F(1, 50) = 2.27$, $p = .138$, partial $\eta^2 = .044$; two-way interaction effect between choice and valence: $F(1, 50) = 0.04$, $p = .849$, partial $\eta^2 = .001$; three-way interaction effect: $F(1, 50) = 1.35$, $p = .251$, partial $\eta^2 = .026$).

In terms of outcome shifts, the results showed a significant three-way interaction effect on outcome shifts ($F(1, 50) = 5.36$, $p = .025$, partial $\eta^2 = .097$), supporting the significant interaction effect between choice and valence only in Experiment 1, where participants could not predict the outcome valence ($F(1, 50) = 6.72$, $p = .013$, partial $\eta^2 = .118$). The post-hoc analysis revealed the significant tendency that actions with free choice elicited larger outcome effects than those with no choice ($F(1, 200) = 4.22$, $p = .042$, partial $\eta^2 = .046$) but not a simple effect of outcome valence in the free-choice condition ($F(1, 200) = 1.90$, $p = .171$, partial $\eta^2 = .021$) in Experiment 1. No other main effects (main effect of experiment: $F(1, 50) = 3.84$, $p = .056$, partial $\eta^2 = .071$; main effect of choice: $F(1, 50) = 0.93$, $p = .339$, partial $\eta^2 = .018$; main effect of valence: $F(1, 50) = 0.94$, $p = .337$, partial $\eta^2 = .018$) and interaction (two-way interaction effect between experiment and choice: $F(1, 50) = 0.54$, $p = .468$, partial $\eta^2 = .011$; between experiment and valence: $F(1, 50) = 0.04$, $p = .843$, partial $\eta^2 < .001$; between choice and valence: $F(1, 50) = 1.82$, $p = .183$, partial $\eta^2 = .035$) were statistically significant.

General Discussion

Our goal was to investigate whether outcome valence influences implicit sense of agency, depending on the manner of action choice even when there is no ambiguity of attribution and whether this interaction depends on predictability. Experiments provided new evidence of an interaction between action choice and outcome valence and suggested the role of the predictability of outcome valence as a moderator of this interaction. In the first experiment, the perceptual shifts of unpredictable negative outcomes that were caused by participants' free choice were larger than those caused by forced choice. Conversely, the choice did not influence shifts of positive outcome. In Experiment 2, when the prediction of outcome valence was possible, the interaction diminished. We confirmed that participants felt enhanced agency over negative outcomes for actions that they chose, even if there was no ambiguity of attribution. Moreover, agency over negative outcomes seemed to be modulated by context, composed of action choice and predictability of outcome valence. The enhancement of agency by choice was observed only when participants' actions unexpectedly caused negative outcomes. In our experiments, the manipulation of action choice did not actually have any impact on the outcome that participants received. Thus, participants could not control the outcome valence in Experiment 1, even with free choice. Since we did not ask participants to report the subjective perception of causality, it was unclear how our manipulation of action choice influenced their explicit belief. Nevertheless, one of the important findings was the fact that even such meaningless choices could modulate the sense of agency implicitly measured, interacting with other situational factors such as predictability.

The obscurity of the interaction effect of action choice and outcome valence on implicit agency in previous studies may derive partly from the difference in the degree to which participants could predict the outcome valence. Since no previous study has investigated the interaction between the opportunity to choose action and outcome valence as a within-block factor, we cannot test this directly. Although Beck et al. (2017) and Di Costa et al. (2017) did not manipulate the opportunity to choose, they indicated the potential relationship between the predictability and interaction between choice and valence. Unlike our experiments, a more predictable condition in their study was accompanied with more control over outcome valence. Thus, the prediction in our study that an unpredictable situation should be linked to the significance of choice and induce the interaction with outcome could not be applied. However, if the tendency observed in our study is based on such an instrumental role of action choice, the results of our study and that of Beck et al. (2017) might be consistent in terms that the perceived significance of action choice in one situation modulated the sense of agency over negative events. The relationship between predictability, controllability, and perceived control and their influence on agency should be investigated independently. Moreover, we could not judge whether the effects observed in this research would work similarly in other contexts, for instance, in an economical task. Future research should also reveal the potential factors determining the influence of outcome valence, including the kinds of outcome stimuli.

Regarding action shift, we obtained distinct results from the outcome shift. Without the predictability of outcome valence, negative outcomes elicited less perceived shift than did positive outcomes. In this case, there was no effect on action choice. In contrast, when they knew the valence of outcome in advance, the action choice, not the outcome valence, impacted on action shift; action choice elicited a larger shift. In sum, action shift was modulated by both action choice and outcome valence, at least in the specific situation, but not at the same time. This suggests that the integration processing of plural factors might not be performed in forming action shifts, unlike outcome shifts. Our results conflict with those of Yoshie and Haggard (2017), who indicated that the effect of outcome valence on action shifts derived from predictive, prospective processing and thus appear only when participants can predict outcome valence. Even though this attenuation by predictable negative outcome is not always replicated (Moreton et al. 2017), the mechanism of intentional binding proposed by Moore and Haggard (2008) may help us to explain the variability of impacts of outcome valence on action shifts. They claimed that which factor determined the degree of binding effect depended on the reliability of each of the prospective and retrospective factors. That is, when a prospective cue such as predictability of the outcome was low, retrospective cues such as the actual occurrence of outcomes was significant for forming the binding, and vice versa. Such a trade-off of impact on binding may also occur between the predictability or the presence of action choice as a prospective cue and the valence as a retrospective cue in the action shifts observed in our experiments. Even though the manipulation of predictability in this study was limited to the valence of outcome, participants could use the predictive cue relatively more in Experiment 2 than in Experiment 1.

Considering smaller action shifts and larger outcome shifts in Experiment 1, relative to Experiment 2, the predictability of outcome valence may also influence the balance of the strength of each shift. The theory proposed by some studies (e.g., Desantis et al. 2011; Moore et al. 2010; Wolpe et al. 2013) claimed that outcome shifts depend more on predictive components than retrospective ones, compared to action shifts. As mentioned previously, the predictive cue of outcomes was less available in Experiment 1. Since action shifts did not depend on this cue, they might be subject to the outcome valence directly. Conversely, outcome shifts did not rely on perceptual information. This might make outcome shifts rely on more inferential processes based on contextual information. In contrast, the action shifts in Experiment 2 could not use the outcome valence as a significant retrospective cue, because the valence was always consistent throughout the experimental block. This might make action shifts rely on other contextual information, i.e., the opportunity of choice.

Constituted by these two independent shifts based on different mechanisms, intentional binding can be formed as a complex perceptual alteration depending on the contexts. It may reflect the co-occurrence of diverse processing of agency. Some previous studies measured the binding effect with an interval estimation method, which could not separate action and outcome shifts. To reveal the complex mechanism to form implicit agency in more detail, integrated evidence based on each perceptual shift observed with the clock method and other implicit measures of agency such as sensory attenuation (Blakemore et al. 1998) is necessary.

Particularly, the tendency observed in outcome shift in Experiment 1, that people felt a stronger sense of agency on negative outcomes determined by their free choice, unlike a fixed option, seemed to play a vital role in learning adaptive behaviors. When there are no other action alternatives, perception of a close causal relationship between actions and negative outcomes may only foster negative emotional experiences. Considering learned helplessness and a decreased self-serving tendency in depression (Rizley 1978), the prevention of such causal cognitions serves to maintain mental health. However, if people experience negative outcomes because of their choices, a correct comprehension of a causal relationship can increase the possibility of avoiding the same decision and its outcome next time. It has yet to be revealed how implicit and explicit sense of agency are integrated as subjective experiences. The contextual information about action choice and outcome predictability, of course, altered agency through the explicit inference of attribution as well as through implicit processing observed in intentional binding. Future research should attempt to reveal the mechanism of adaptive behavioral learning based on the cyclic relationship between action choice, the valence and predictability of outcome, and forming a sense of agency.

Funding This work was supported by JSPS KAKENHI [grant no. JP16H01515]. The funders had no role in study design, data collection and analyses, decision to publish, or preparation of the manuscript.

Data Availability The datasets analyzed during the current study are available in the Open Science Framework repository, https://osf.io/byv5c/.

Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

Ethical Approval All experiments in this study were approved by the local ethical committee of the Keio University, Japan.

Informed Consent Informed consent was obtained from all individual participants included in the study with a written consent form.

References

Barlas, Z., & Obhi, S. (2013). Freedom, choice, and the sense of agency. *Frontiers in Human Neuroscience, 7*, 514. https://doi.org/10.3389/fnhum.2013.00514.

Barlas, Z., Hockley, W. E., & Obhi, S. S. (2017). The effects of freedom of choice in action selection on perceived mental effort and the sense of agency. *Acta Psychologica, 180*, 122–129. https://doi.org/10.1016/j.actpsy.2017.09.004.

Barlas, Z., Hockley, W. E., & Obhi, S. S. (2018). Effects of free choice and outcome valence on the sense of agency: Evidence from measures of intentional binding and feelings of control. *Experimental Brain Research, 236*(1), 129–139. https://doi.org/10.1007/s00221-017-5112-3.

Beck, B., Di Costa, S., & Haggard, P. (2017). Having control over the external world increases the implicit sense of agency. *Cognition, 162*, 54–60. https://doi.org/10.1016/j.cognition.2017.02.002.

Blakemore, S. J., Wolpert, D. M., & Frith, C. D. (1998). Central cancellation of self-produced tickle sensation. *Nature Neuroscience, 1*, 635–640. https://doi.org/10.1038/2870.

Borhani, K., Beck, B., & Haggard, P. (2017). Choosing, doing, and controlling: Implicit sense of agency over somatosensory events. *Psychological Science, 28*(7), 882–893.

Bossuyt, E., Moors, A., & De Houwer, J. (2014). Exploring the relations between regret, self-agency, and the tendency to repair using experimental methods and structural equation modeling. *The Psychological Record, 64*(4), 841–857. https://doi.org/10.1007/s40732-014-0065-4.

Bradley, M. M., & Lang, P. J. (2007). *International Affective Digitized Sounds (2nd edn.): Affective ratings of Sounds and Instruction Manual* (Technical Report No. B-3). Gainesville, FL: University of Florida, NIMH Center for the Study of Emotion and Attention.

Brainard, D. H. (1997). The psychophysics toolbox. *Spatial Vision, 10*, 443–446. https://doi.org/10.1163/156856897x00357.

Buehner, M. J. (2012). Understanding the past, predicting the future. Causation, not intentional action, is the root of temporal binding. *Psychological Science, 23*(12), 1490–1497. https://doi.org/10.1177/0956797612444612.

Caspar, E. A., Christensen, J. F., Cleeremans, A., & Haggard, P. (2016). Coercion changes the sense of agency in the human brain. *Current Biology, 26*(5), 585–592. https://doi.org/10.1016/j.cub.2015.12.067.

Caspar, E. A., Vuillaume, L., Magalhães De Saldanha da Gama, P. A., & Cleeremans, A. (2017). The influence of (dis)belief in free will on immoral behavior. *Frontiers in Psychology, 8*, 20. https://doi.org/10.3389/fpsyg.2017.00020.

Christensen, J. F., Yoshie, M., Di Costa, S., & Haggard, P. (2016). Emotional valence, sense of agency and responsibility: A study using intentional binding. *Consciousness and Cognition, 43*, 1–10. https://doi.org/10.1016/j.concog.2016.02.016.

Cravo, A. M., Claessens, P. M., & Baldo, M. V. (2009). Voluntary action and causality in temporal binding. *Experimental Brain Research, 199*(1), 95–99. https://doi.org/10.1007/s00221-009-1969-0.

Desantis, A., Roussel, C., & Waszak, F. (2011). On the influence of causal beliefs on the feeling of agency. *Consciousness and Cognition, 20*(4), 1211–1220.

Di Costa, S., Théro, H., Chambon, V., & Haggard, P. (2017). Try and try again: Post-error boost of an implicit measure of agency. *The Quarterly Journal of Experimental Psychology, 71*, 1–28. https://doi.org/10.1080/17470218.2017.1350871.

Frith, C. D. (2014). Action, agency and responsibility. *Neuropsychologia, 55*, 137–142. https://doi.org/10.1016/j.neuropsychologia.2013.09.007.

Gallagher, I. (2000). Philosophical conceptions of the self: Implications for cognitive science. *Trends in Cognitive Sciences, 4*(1), 14–21. https://doi.org/10.1016/s1364-6613(99)01417-5.

Gentsch, A., & Synofzik, M. (2014). Affective coding: The emotional dimension of agency. *Frontiers in Human Neuroscience, 8*, 608. https://doi.org/10.3389/fnhum.2014.00608.

Gentsch, A., Weiss, C., Spengler, S., Synofzik, M., & Schütz-Bosbach, S. (2015). Doing good or bad: How interactions between action and emotion expectations shape the sense of agency. *Social Neuroscience, 10*(4), 418–430. https://doi.org/10.1080/17470919.2015.1006374.

Haggard, P., & Chambon, V. (2012). Sense of agency. *Current Biology, 22*(10), R390–R392. https://doi.org/10.1016/j.cub.2012.02.040.

Haggard, P., Clark, S., & Kalogeras, J. (2002). Voluntary action and conscious awareness. *Nature Neuroscience, 5*(4), 382–385. https://doi.org/10.1038/nn827.

Karsh, N., & Eitam, B. (2015). I control therefore I do: Judgments of agency influence action selection. *Cognition*, 138, 122–131. https://doi.org/10.1016/j.cognition.2015.02.002.

Kleiner, M., Brainard, D., Pelli, D., Ingling, A., Murray, R., & Broussard, C. (2007). What's new in Psychtoolbox-3. *Perception, 36*(14), 1.

Langer, E. J. (1975). The illusion of control. *Journal of Personality and Social Psychology*, 32, 311–328. https://doi.org/10.1037/0022-3514.32.2.311.

Lepron, E., Causse, M., & Farrer, C. (2015). Responsibility and the sense of agency enhance empathy for pain. *Proceedings of the Royal Society of London B: Biological Sciences, 282*(1799), 20142288. https://doi.org/10.1098/rspb.2014.2288.

Libet, B., Gleason, C. A., Wright, E. W., & Pearl, D. K. (1983). Time of conscious intention to act in relation to onset of cerebral activity (readi-ness-potential)—The unconscious initiation of a freely voluntary act. *Brain, 106*, 623–642. https://doi.org/10.1093/brain/106.3.623.

Mezulis, A. H., Abramson, L. Y., Hyde, J. S., & Hankin, B. L. (2004). Is there a universal positivity bias in attributions? A meta-analytic review of individual, developmental, and cultural differences in the self-serving attributional bias. *Psychological Bulletin, 130*(5), 711–747. https://doi.org/10.1037/0033-2909.130.5.711.

Milgram, S. (1963). Behavioral study of obedience. *The Journal of Abnormal and Social Psychology, 67*(4), 371–378. https://doi.org/10.1037/h0040525.

Mistry, P., & Liljeholm, M. (2016). Instrumental divergence and the value of control. *Scientific Reports, 6*, 36295. https://doi.org/10.1038/srep36295.

Moore, J., & Haggard, P. (2008). Awareness of action: Inference and prediction. *Consciousness and Cognition, 17*(1), 136–144. https://doi.org/10.1016/j.concog.2006.12.004.

Moore, J. W., & Obhi, S. S. (2012). Intentional binding and the sense of agency: A review. *Consciousness and Cognition, 21*(1), 546–561. https://doi.org/10.1016/j.concog.2011.12.002.

Moore, J. W., Ruge, D., Wenke, D., Rothwell, J., & Haggard, P. (2010). Disrupting the experience of control in the human brain: Presupplementary motor area contributes to the sense of agency. *Proceedings of the Royal Society, Series B: Biological Sciences*, 277, 2503–2509. https://doi.org/10.1098/rspb.2010.0404.

Moreton, J., Callan, M. J., & Hughes, G. (2017). How much does emotional valence of action outcomes affect temporal binding? *Consciousness and Cognition, 49*, 25–34. https://doi.org/10.1016/j.concog.2016.12.008.

Moretto, G., Walsh, E., & Haggard, P. (2011). Experience of agency and sense of responsibility. *Consciousness and Cognition, 20*(4), 1847–1854. https://doi.org/10.1016/j.concog.2011.08.014.

Obhi, S. S., & Hall, P. (2011). Sense of agency and intentional binding in joint action. *Experimental Brain Research, 211*(3–4), 655–662. https://doi.org/10.1007/s00221-011-2675-2.

Pelli, D. G. (1997). The VideoToolbox software for visual psychophysics: Transforming numbers into movies. *Spatial Vision, 10*(4), 437–442. https://doi.org/10.1163/156856897x00366.

Pfister, R., Obhi, S. S., Rieger, M., & Wenke, D. (2014). Action and perception in social contexts: Intentional binding for social action effects. *Frontiers in Human Neuroscience, 8*, 667. https://doi.org/10.3389/fnhum.2014.00667.

Rizley, R. (1978). Depression and distortion in the attribution of causality. *Journal of Abnormal Psychology, 87*(1), 32–48. https://doi.org/10.1037//0021-843x.87.1.32.

Seligman, M. E. P. (1968). Chronic fear produced by unpredictable electric shock. *Journal of Comparative and Physiological Psychology, 66*(2), 402–411. https://doi.org/10.1037/h0026355.

Synofzik, M., Vosgerau, G., & Newen, A. (2008). Beyond the comparator model: a multifactorial two-step account of agency. *Consciousness and Cognition*, 17(1), 219–239. https://doi.org/10.1016/j.concog.2007.03.010.

Takahata, K., Takahashi, H., Maeda, T., Umeda, S., Suhara, T., Mimura, M., & Kato, M. (2012). It's not my fault: Postdictive modulation of intentional binding by monetary gains and losses. *PLoS One, 7*(12), e53421. https://doi.org/10.1371/journal.pone.0053421.

Wolpe, N., Haggard, P., Siebner, H. R., & Rowe, J. B. (2013). Cue integration and the perception of action in intentional binding. *Experimental Brain Research, 229*(3), 467–474.

Woolfolk, R. L., Doris, J. M., & Darley, J. M. (2006). Identification, situational constraint, and social cognition: Studies in the attribution of moral responsibility. *Cognition, 100*(2), 283–301. https://doi.org/10.1016/j.cognition.2005.05.002.

Yoshie, M., & Haggard, P. (2013). Negative emotional outcomes attenuate sense of agency over voluntary actions. *Current Biology, 23*(20), 2028–2032. https://doi.org/10.1016/j.cub.2013.08.034.

Yoshie, M., & Haggard, P. (2017). Effects of emotional valence on sense of agency require a predictive model. *Scientific Reports, 7*(1), 8733. https://doi.org/10.1038/s41598-017-08803-3.