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Report

Negative Emotional Outcomes Attenuate Sense of Agency over Voluntary Actions

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Summary

Sense of agency (SoA) refers to the feeling that one's voluntary actions produce external sensory events [1, 2]. Several psychological theories hypothesized links between SoA and affective evaluation [3–6]. For example, people tend to attribute positive outcomes to their own actions, perhaps reflecting high-level narrative processes that enhance self-esteem [3]. Here we provide the first evidence that such emotional modulations also involve changes in the low-level sensorimotor basis of agency. The intentional binding paradigm [1] was used to quantify the subjective temporal compression between a voluntary action and its sensory consequences, providing an implicit measure of SoA. Emotional valence of action outcomes was manipulated by following participants' key-press actions with negative or positive emotional vocalizations [7], or neutral sounds. We found that intentional binding was reduced for negative compared to positive or neutral outcomes. Discriminant analyses identified a change in time perception of both actions and their negative outcomes, demonstrating that the experience of action itself is subject to affective modulation. A small binding benefit was also found for positive action outcomes. Emotional modulation of SoA may contribute to regulating social behavior. Correctly tracking the valenced effects of one's voluntary actions on other people could underlie successful social interactions.

Results and Discussion

Humans are constantly interacting with the surrounding environment through voluntary, instrumental actions. The brain processes the causal relationship between actions and their sensory outcomes, which produces a subjective sense of agency (SoA) over these external events [1, 2]. SoA is assumed to underlie the ability to learn and execute goal-oriented behaviors, but this link has rarely been tested directly. Since our actions normally aim at positive rather than negative outcomes, we speculated that SoA should vary with the emotional valence of action outcomes. Several accounts of cognitive mechanisms of self-presentation suggest this should be so: people claim more responsibility for positive events than negative ones (self-serving biases), which seems to be a mechanism for enhancing self-esteem [3, 4]. Conversely, when people perform a morally unacceptable action, they may reduce their SoA through cognitive restructuring of the causal relationship between their action and its harmful effects (moral disengagement) [5, 6]. These theories are normally based on explicit self-reports of responsibility, which may be influenced by postperceptual effects, such as social desirability and cognitive dissonance. It remains unclear whether the low-level sensorimotor experience of agency is altered by valence. Therefore, we have investigated, apparently for the first time, whether the affective value of action outcomes also alters low-level implicit measures of SoA.

We used the intentional binding paradigm [1] as an implicit, quantitative proxy measure of SoA (Figure 1A). While viewing a continuously rotating clock, participants pressed a key at a time of their choosing, which produced a sound after a fixed delay of 250 ms (agency condition). Participants then judged where the clock hand was at the onset of their key press or, in a separate block, at the onset of the sound. We first measured a judgment error (i.e., difference between the judged and actual time of a corresponding event) for each trial in each condition. A positive judgment error indicated a delayed judgment, while negative error indicated anticipatory judgment. Next, we compared mean judgment errors in single-event baseline conditions, where participants pressed the key without producing the sound (baseline action), or heard the sound at random intervals without pressing the key (baseline sound), to mean judgment errors for the same event in the agency condition. Finally, to provide a single composite binding measure, quantifying the overall subjective temporal association between actions and outcomes, we combined the shift in action judgment and that in sound judgment, inverting the sign of the latter [8, 9].

We used this paradigm to investigate whether SoA is altered by the emotional content of action outcomes. The voluntary action could produce an emotionally negative outcome, an emotionally positive outcome, or a neutral outcome. Each of these three affective conditions was tested in a separate block of trials. Each key press was thus followed by one of four negative emotional vocalizations (two fear sounds, two disgust sounds, randomized) or by one of four positive emotional vocalizations (two achievement sounds, two amusement sounds, randomized). These sounds were independently validated by a separate group of participants [7]. A subset of participants also performed a neutral condition in which actions were followed by one of four pure tones, matched for average pitch and duration with the vocalization stimuli (Table S1 available online). To ensure vigilance and attention to the auditory stimuli, we asked a question about the frequency of sounds (i.e., which of the four sounds they heard most frequently during an ~3 min subblock) at the end of every subblock. The experimental procedures were approved by the University College London Ethics Committee for Human Research.

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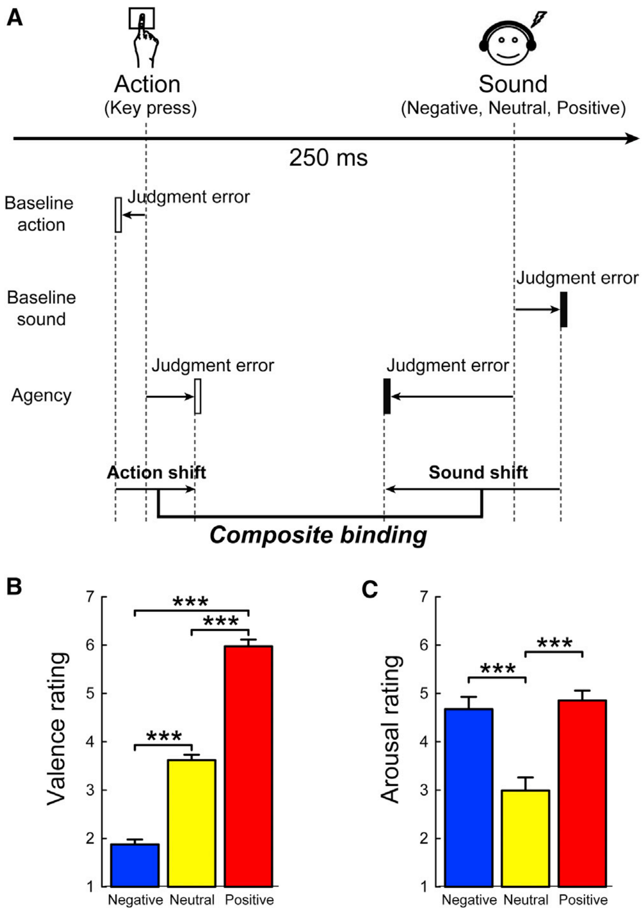

Figure 1. Experimental Paradigm and Auditory Stimuli

(A) Intentional binding paradigm. In the agency condition participants' voluntary action (key press) produced negative, neutral, or positive sounds. Using a continuously rotating clock, participants reported the perceived onset time of their action or the sound. The mean judgment error (i.e., difference between the judged and actual time of a corresponding event) in agency conditions was compared with that in single-event baseline conditions to calculate the shift in action or sound judgment. We also calculated a measure of composite binding by combining the shifts in action and sound judgments.

(B) Perceived emotional valence of auditory stimuli. Participants rated negative sounds to be more negative and positive sounds to be more positive than neutral sounds.

(C) Perceived emotional arousal of auditory stimuli. Participants rated both negative and positive sounds to be more emotionally arousing than neutral sounds. There was no difference in arousal rating between negative and positive sounds, indicating that we could effectively manipulate emotional valence of action outcomes while controlling for emotional arousal.

Data are presented as mean ± SEM. ***$p < 0.001$. See also Figure S1 and Table S1.

Postexperiment subjective ratings of valence (Figure 1B) confirmed the perceived valence of the sounds ($F [2, 64] = 247.8$, $p < 0.0001$). Negative sounds were rated as more negative than neutral sounds ($p < 0.0001$) and positive sounds as more positive than neutral sounds ($p < 0.0001$). In contrast, the reported level of arousal (Figure 1C) did not significantly differ between negative and positive sounds ($p = 0.56$), suggesting that we successfully controlled for effects of emotional arousal. As expected, perceived arousal was lower for neutral sounds than negative ($p < 0.0001$) or positive ($p < 0.0001$) vocalizations. In keeping with the arousal ratings, the mean number of correct answers to questions about the frequency of sounds did not differ between the negative and positive conditions (Figure S1).

In experiment 1, we tested a sample of 16 native English speakers (eight males and eight females) using negative and positive emotional vocalizations (Figure 2A; Table S2). The composite binding measure clearly demonstrated that intentional binding was smaller in the negative than positive condition ($T_{15} = -3.11$, $p = 0.0072$). That is, the subjective temporal compression between actions and positive sounds was stronger than that between actions and negative sounds. Thus, SoA can be modulated by emotional valence of action outcomes.

To investigate whether this reflects a cost of SoA for negative outcomes or a benefit for positive outcomes, experiment 2 tested a new sample of 18 native English speakers (nine males and nine females) using neutral sounds in addition to negative and positive vocalizations (Figure 2B; Table S2). One participant was excluded because of highly erratic temporal judgments (mean SD of judgment errors across trials > 300 ms; rejected by Smirnov-Grubbs tests for outliers, $p < 0.05$) [10, 11]. The composite binding again varied across different sound conditions ($F [2, 32] = 4.90$, $p = 0.014$). Post hoc comparisons replicated the significant difference in the size of intentional binding between the negative and positive conditions ($p = 0.0073$). Importantly, composite binding was significantly reduced in the negative condition compared to the neutral condition ($p = 0.025$), while no difference was found between the neutral and positive conditions ($p = 0.50$). The results from experiment 2 suggested that negative outcomes attenuate SoA, while enhancement of SoA due to positive outcomes was less reliable. Finally, a pooled analysis of experiment 1 and the negative and positive conditions of experiment 2 confirmed a highly significant effect of valence on intentional binding ($T_{32} = -4.40$, $p = 0.00011$; Figure 2C; Figure 2D; Table S2).

Intentional binding involves a perceptual shift in the time of action toward outcome, and also a shift in the opposite direction, of the outcome toward the action that caused it. These shifts may dissociate and could reflect separate mechanisms [12, 13]. We therefore used linear discriminant analysis to quantify the contributions of action shift and sound shift to the effects of emotional valence on SoA.

For experiment 1, inspection of standardized discriminant coefficients showed that the difference between positive and negative valence depended on both action shift (standardized coefficient = −1.24) and on sound shift (standardized coefficient = 1.87; the sign reversal is explained by the different direction of action and sound shifts). For experiment 2, the first canonical discriminant extracts the main variation between the three conditions. It accounted for 60% of the between-condition variance and effectively separated the negative condition from the neutral and positive conditions (Figure 3A). Inspection of standardized coefficients again showed that both action shift (1.28) and sound shift (−0.91) contributed strongly to altered perception when generating emotionally negative outcomes. Supporting this finding, univariate tests showed that the decrease in action shift from the neutral to negative condition did not significantly differ from the decrease in sound shift ($T_{16} = -1.04$, $p = 0.31$; Figure 3B). The second discriminant, accounting for 40% of the variance between conditions, primarily separated the positive condition from the neutral and negative conditions. It loaded much less on action shift (0.45) than on sound shift (2.44). Again, univariate tests were consistent with this result: the change in sound shift from the neutral

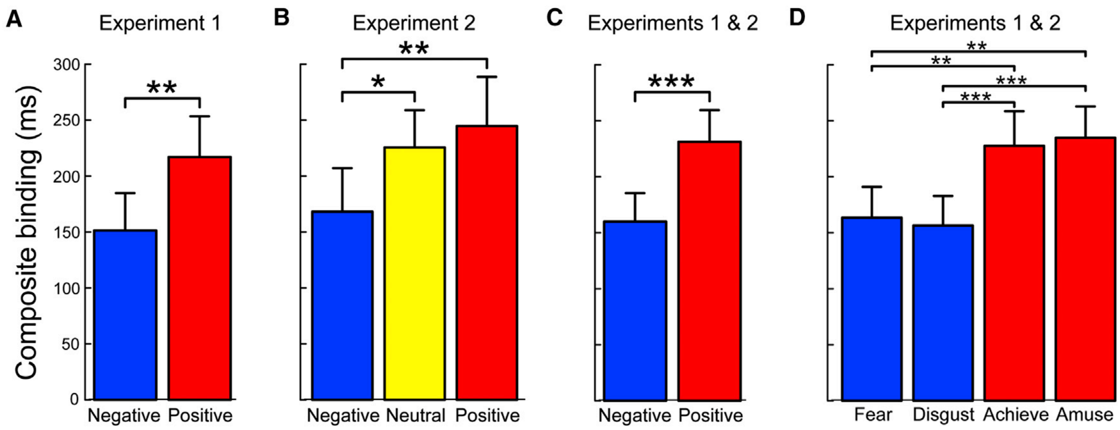

Figure 2. Intentional Binding for Sounds with Different Emotional Valence

(A) In experiment 1 (n = 16), composite binding was significantly smaller for the negative than positive sounds.

(B) In experiment 2 (n = 17), the emotional modulation of intentional binding was replicated. In addition, the size of binding effect for positive sounds was similar to that for neutral sounds.

(C) The statistical comparison on the whole sample (n = 33) revealed a strong effect of emotional valence on intentional binding.

(D) The differences in composite binding between negative and positive sounds were all significant (ps < 0.01). No significant difference was found between sounds with the same emotional valence (fear versus disgust, or achievement versus amusement).

Data are presented as mean ± SEM. ***p < 0.001, **p < 0.01, *p < 0.05. See also Table S2.

to positive condition was significantly larger than that in action shift ($T_{16} = 2.70$, $p = 0.016$; Figure 3B). The order of the variates could be taken as indicating that the agency cost of negative outcomes exceeds the agency benefit of positive outcomes, but we would urge caution regarding this interpretation. First, some theories treat emotions as distinct categories, rather than as a continuous dimension extending from negative, through neutral, to positive. Second, we did not attempt to measure valence using an interval scale, so we cannot be certain that our negative and positive stimuli were matched for strength relative to neutral. In fact, the difference in valence ratings between negative and neutral was significantly less than the difference between neutral and positive ($T_{32} = -2.12$, $p = 0.042$). This suggests that the predominant effect of negative valence on binding, as captured by the first canonical variate, was not simply an artifactual consequence of choosing very strongly negative stimuli. However, we suggest caution in comparing the costs of negative valence to the benefits of positive valence, since the only quantification of valence is a rating scale that may not have interval properties.

Our results provide the first direct and objective evidence for the modulation of SoA by affective significance of action outcomes. In two experiments, we showed that intentional binding was attenuated for negative compared to positive or neutral outcomes. Linear discriminant analyses indicated that this emotional modulation was driven by shifts in the perceived time of both actions and outcomes. In addition, the effect primarily involved a reduced binding for negative outcomes rather than increased binding for positive outcomes.

Our experimental design allowed us to clearly link differences in intentional binding between conditions to differences in emotional valence. Importantly, the observed effects cannot be explained by emotional arousal, because there was no difference in perceived arousal between the negative and positive conditions (Figures 1C and S1). A recent study [9] combined intentional binding with various morally relevant visual stimuli. Severely negative moral outcomes led to stronger binding than less negative outcomes, which is opposite to the effect found here. However, that experiment differed from ours in two important ways. First, their outcomes were unpredictable, whereas valence of each trial was predictable in advance in our design. Second, they also found that increasing the magnitude of a nonmoral outcome produced a similar enhancement of binding. This suggests that the moral and nonmoral effects in that study may have been byproducts of a general influence of magnitude on arousal or salience, rather than an effect of valence. In our study, in contrast, valence is defined by sign (positive/negative), rather than magnitude. Furthermore, the effects observed in our study cannot be attributed to the differences in acoustic properties of the stimuli. We not only carefully minimized the differences in physical properties such as pitch and duration (Table S1), but also included a nonagency single-event baseline condition for each set of sounds. We then analyzed the *change* in judgment errors from the baseline to agency block for each emotional condition. Any effects of different acoustic properties on the perception of sound onsets, such as the perceptual-center effect [14] should be common to both agency and baseline blocks and should therefore be controlled for when these are subtracted to calculate perceptual shift. The observed effects also cannot be attributed to the individual identity of voices. To control this factor, in the negative and positive conditions, we randomly intermixed four emotional vocalizations produced by four different individuals varying in age and gender. Moreover, we confirmed that the observed modulation of intentional binding was consistent across different sounds with the same emotional valence (Figure 2D).

A recent study of SoA in *economic* contexts showed reduced intentional binding when participants lost money compared to when they gained or retained money [11]. Our study supports those authors' finding that negative outcomes can reduce SoA, but in relation to an affective rather than an economic neurocognitive system. We studied actions that produced sensory outcomes with inherently different emotional valences, while their study manipulated outcome value using neutral sounds that were associated with different monetary reward. Therefore, we believe that our study may be

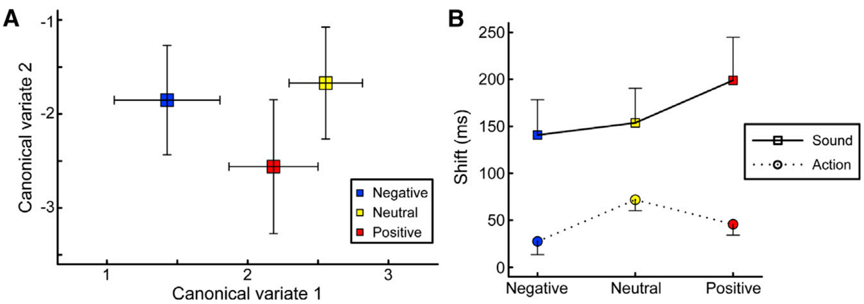

Figure 3. Results of Linear Discriminant Analysis of Experiment 2

(A) The action shifts and sound shifts from experiment 2 were compared between the negative, neutral, and positive conditions using linear discriminant analysis. The graph shows the mean of each condition on the first and second canonical variates. The axis scales have been adjusted according to the different proportions of between-condition variance explained by each variate (see the main text). The first canonical variate effectively separated the negative condition from the neutral and positive conditions, and the second canonical variate separated the positive condition from the negative and neutral conditions.

(B) The graph shows the mean absolute values of action and sound shifts for each of the three emotional conditions. Inspection of standardized coefficients and additional paired t tests (see the main text) clearly demonstrated that the attenuation of intentional binding for negative outcomes was driven by both action shift and sound shift. Increased binding for positive outcomes, on the other hand, was explained largely by sound shift. See the main text for loadings of canonical variates on action and sound shifts and for further explanation.
Data are presented as mean ± SEM.

more relevant to SoA in social interactions. Moreover, in our study, the perception of emotion was completely irrelevant to participants' task: participants were asked to judge timing of action/sound onsets and to attend only to the number of times the different sounds were presented. Testing at the end of each subblock suggested that levels of vigilance could not account for our valence effects (Figure S1). Therefore, these specific effects of emotional valence on SoA are automatic and implicit. In contrast, in the previous study of reward [11], participants presumably intended to gain as much money as possible, which made outcome valence highly relevant to task success.

In principle, the binding effects we observed could involve either prediction of action outcomes or a postdictive reconstruction of experience occurring after the valence of the outcome is known. Previous research suggested that prediction dominates intentional binding when the action outcome probability is high, while reconstruction may be important when outcome probability is low [10]. In our study, different emotional valences were tested in separate blocks and were entirely predictable. In contrast, previous studies investigated changes in SoA for moral and economic outcomes that were completely unpredictable [9, 11]. Thus, in those studies, any modulation of binding effects must be purely reconstructive. Although we did not directly compare predictive and reconstructive contributions to SoA, our data suggest that the emotional modulation of SoA could also reflect predictions about the likely valence of outcomes. Future research should examine which of the two components (i.e., predictive or reconstructive) dominates in different social/emotional situations.

Psychological theories of self-serving biases highlight a general tendency to claim more responsibility for positive than negative events [3, 4]. Our results suggest that unwillingness to take responsibility for unpleasant outcomes may involve a low-level sensorimotor basis. Becoming inured to a predictable negative impact of our own actions may produce a kind of dissociative experience. The reduced SoA for negative outcomes may reflect a psychological mechanism to retain self-esteem [3]. Moreover, SoA is clearly linked to responsibility. Strong feelings of responsibility for all negative outcomes might discourage people from attempting any goal-directed actions in the future. Our finding of low binding for negative outcomes may be part of an optimistic bias that encourages future action and counteracts "depressive realism" [15]. Although here we focused on perceived emotional valence of action outcomes, participants' own vigilance or emotional state could also interact with the effects of perceived emotion. Previous studies suggest that self-serving biases are attenuated in individuals with depression or self-focusing cognitive style [4]. Future work could usefully investigate how participants' emotional state modulates the affective influence on SoA.

Although the social self-other dimension was not systematically manipulated in these experiments, our results are highly relevant to social interaction. Our experimental situation can be interpreted as one's own voluntary key-press action having either a positive or negative effect on another person's vocally expressed mental state. The ability to monitor and respond correctly to the effects of one's own action on others is a fundamental prerequisite of successful social behavior and is carefully trained and maintained by human cultures. It is compromised in several clinical conditions, notably autism spectrum disorders, psychopathy, and sociopathy. Our data show a reduced SoA for actions that might be treated as socially maleficent, as opposed to neutral or socially beneficial. We did not investigate empathy or social factors directly, but our data are consistent with the possibility that individuals with different degrees of emotional bias, or different responsivity to the emotions of others, may experience their social actions rather differently. We predict that prosocial and antisocial personality traits should interact with the valence effects on SoA shown here. Clinical disorders of social behavior may reflect extremes of this spectrum. Our methods may therefore be useful as assessments of, or interventions in, the primary experience of social behavior of such patients.

Supplemental Information

Supplemental Information includes Supplemental Experimental Procedures, one figure, and two tables and can be found with this article online at http://dx.doi.org/10.1016/j.cub.2013.08.034.

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