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Supplemental Information

Negative Emotional Outcomes

Attenuate Sense of Agency

over Voluntary Actions

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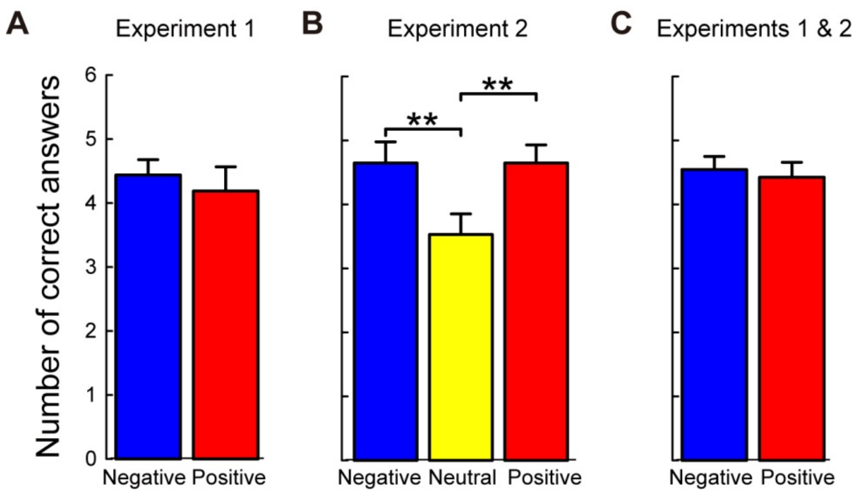

Figure S1. Task Performance, Related to Figure 1

(A) In experiment 1 ($n = 16$), the number of correct answers (out of 6) to questions about the frequency of different sounds at the end of every sub-block did not differ between the negative and positive conditions.

(B) In experiment 2 ($n = 17$), the number of correct answers was slightly reduced in the neutral condition compared to the negative and positive conditions, possibly reflecting higher vigilance associated with valenced stimuli.

(C) The statistical comparison on the whole sample ($n = 33$) revealed no significant difference in task performance between the negative and positive conditions.

Data are represented as mean ± SEM. ** $p < 0.01$.

Table S1. Physical Properties of Auditory Stimuli, Related to Figure 1

Sound	Pitch (Hz)	Duration (ms)	Mean duration (ms)
Negative			
Male - Fear	730	700	1050
Male - Disgust	378	1400	
Female - Fear	779	700	1050
Female - Disgust	398	1400	
Neutral			
Low - Short	409	700	1050
Low - Long	409	1400	
High - Short	722	700	1050
High - Long	722	1400	
Positive			
Male - Achievement	520	700	1050
Male - Amusement	596	1400	
Female - Achievement	782	700	1050
Female - Amusement	338	1400	

Note: The second column (pitch) indicates the peak frequency of each sound. The pitch of the low-pitch neutral sound (409 Hz) was determined by averaging the pitches of four low-pitch vocalizations (male - disgust, female - disgust, male - achievement, female - amusement), and the pitch of the high-pitch neutral sound (722 Hz) was determined by averaging the pitches of four high-pitch vocalizations (male - fear, female - fear, male - amusement, female - achievement). The sounds used here are substantially longer than those used in previous intentional binding experiments, which were typically 100 ms long [S1]. Informal pilot testing suggested that a sound duration of 700 ms was the minimum necessary for successful recognition of emotion.

Table S2. Comparisons of Mean Judgment Errors and Shifts Relative to Baseline Conditions between Different Emotional Conditions, Related to Figure 2

Sound	Action judgments			Sound judgments		
	Baseline (ms)	Agency (ms)	Shift (ms)	Baseline (ms)	Agency (ms)	Shift (ms)
Experiment 1 (n = 16)						
Negative	-16.3 (19.1)	1.5 (16.2)	+17.8 (12.9)	220.6 (24.4)	87.1 (33.3)	-133.5 (28.9)
Positive	-18.0 (13.5)	16.1 (15.5)	+34.1 (10.9)	249.5 (20.4)	66.6 (35.7)	-182.9 (30.5)
Experiment 2 (n = 17)						
Negative	-12.6 (20.7)	14.8 (22.6)	+27.4 (14.1)	247.7 (20.8)	107.0 (43.9)	-140.7 (37.7)
Neutral	-12.6 (20.7)	59.2 (24.2)	+71.8 (11.6)	288.4 (24.5)	134.8 (43.3)	-153.7 (36.9)
Positive	-12.6 (20.7)	33.1 (21.3)	+45.8 (11.7)	273.1 (21.9)	74.1 (46.9)	-198.9 (45.8)
Experiments 1 & 2 (n = 33)						
Negative	-14.4 (13.9)	8.4 (13.9)	+22.8 (9.5)	234.6 (15.9)	97.3 (27.4)	-137.3 (23.6)
Positive	-15.2 (12.3)	24.9 (13.2)	+40.1 (8.0)	261.6 (14.9)	70.5 (29.2)	-191.2 (27.5)

Note: Baseline action judgment errors were obtained in the absence of sound (2nd column). Although there were two separate baseline action blocks for the two different emotional conditions in experiment 1, there was only one common baseline action block in experiment 2 (see also Supplemental Experimental Procedures). Baseline sound judgment errors were obtained for each sound in the absence of action (5th column). In agency conditions, the action was followed by the sound onset 250 ms later (3rd and 6th columns). The shifts in perceived onset times of actions (4th column) and of sounds (7th column) were measured for each action-sound combination. Note the significant positive judgment errors for all the sounds: the long duration of these sounds compared to those used previously in intentional binding experiments causes a strong perceptual-center effect [S2]. However, this bias is identical in both baseline and agency conditions, and does not affect estimates of sound shifts. The numbers in brackets indicate SEM.

Supplemental Experimental Procedures

Participants

This study was approved by the University College London Ethics Committee for Human Research. Participants were recruited via the University College London psychology subject pool, and screened for the following exclusion criteria: native language other than English, left handedness, recent use of illicit drugs, uncorrected visual or auditory impairment, and history of psychiatric or neurological illness. All participants gave written informed consent prior to the experiment.

In experiment 1, the sample size was determined in advance to fully counterbalance potentially confounding order effects: order of emotional conditions (negative first or positive first), order of judged events (action first or sound first), and order of task types (baseline first or agency first). We thus recruited 8 males and 8 females (mean age = 21.3 ± 1.4 years), one of each for the 8 (2 x 2 x 2) possible orders of conditions.

In experiment 2, we aimed to recruit an independent sample whose size was approximately equal to that of the first sample. Since the main effect of interest was emotional valence, it was necessary to fully control the order effect of three emotional conditions (negative, neutral, and positive; ${}_3P_3$ = 6 patterns). We thus chose to recruit 18 individuals (6 patterns x 3 repetitions).

One participant was excluded because of highly erratic temporal judgments (mean standard deviation of judgment errors across trials > 300 ms; rejected by Smirnov-Grubbs tests for outliers, $p < 0.05$) [S3] and the final sample consisted of 17 individuals (9 males and 8 females; mean age = 21.9 ± 2.5 years). Here, the order of judged events (action first or sound first) and the order of task types (baseline first or agency first) were randomly chosen for each participant and to avoid order effects (i.e., 9 participants performed action judgments first, and 8 performed sound judgments first; 8 participants performed baseline conditions first, and 9 performed agency conditions first). All of the 33 participants were right-handed, with a mean (± SD) Edinburgh Handedness Inventory [S4] score of 84.9 ± 15.6.

Auditory Stimuli

In order to manipulate the emotional valence in the perceptual consequences of participants' voluntary action, we used a selection of non-verbal emotional vocalization stimuli that have been validated in the native English population (Table S1) [S5]. In the negative condition, participants' keypress was followed by one of four negative vocalizations (screams expressing fear or retches expressing disgust). In the positive condition, these were replaced by positive vocalizations (cheers expressing achievement or laughs expressing amusement). The original validation study confirmed that these two sets of vocalization stimuli significantly vary in perceived valence, but not in perceived arousal. The participants of experiment 2 also underwent the neutral condition where four pure tones varying in pitch and duration were presented. The auditory stimuli in each condition were carefully matched for pitch (peak frequency) and duration. All the auditory stimuli were presented by a headphone (Sennheiser HD650; Sennheiser, Wedemark, Germany).

Experimental Task and Procedure

All participants were asked to refrain from drinking caffeinated or alcoholic beverages on the testing day. A customized program running in LabVIEW 2010 (National Instruments, Austin, TX, USA) presented participants with the intentional binding task [S1]. Participants viewed a clock hand (length: 12 mm) rotating about a clock face at a rate of 2,560 ms per cycle on a 17-inch flat screen (Dell Rev-A00; Dell, Round Rock, TX, USA). The clock face was marked with conventional intervals (5, 10, 15, …, and 60). On each trial the rotation of the clock hand started from a random position on the clock face. In *agency* conditions, a participant was instructed to press a key on a silent silicone computer keyboard with the right index finger at a time of his/her choosing, which caused a sound 250 ms later. After the sound's offset the clock hand continued rotating for a random time (1,100 – 2,800 ms), and then stopped. The participant was then prompted to verbally report where the clock hand was at the onset of their keypress or, in a separate block, at the onset of the sound. In the single-event *baseline action* condition, the participant pressed a key at a time of his/her choosing. This keypress did not cause a sound, and the participant was asked to judge the time of his/her keypress. In the single-event *baseline sound* condition, the participant heard sounds at random intervals, which mimicked time intervals of his/her voluntary keypress, and judged the times of sound onsets. To make sure that participants understood the task, we asked participants to perform 5 practice trials before each condition.

In experiment 1, participants underwent four task blocks of 32 trials each (baseline action, baseline sound, agency action, and agency sound) for both the negative and positive conditions, or 256 (32 trials x 8 blocks) trials in total. In each block four different sounds of an emotional condition were presented in a randomized order (4 sounds x 8 repetitions). Each block was further divided into two sub-blocks of 16 trials each and the repetitions of the four sounds were manipulated to be unevenly distributed across the sub-blocks. To ensure attention to the auditory stimuli, at the end of every sub-block we asked participants which of the four sounds they heard most frequently during that sub-block. Participants gained a reward of 25 pence for each correct answer to this question. The whole experiment was divided into two sessions of four blocks each. Each session was devoted to action judgments (baseline action and agency action) or sound judgments (baseline sound and agency sound) only. Half of participants (n = 8) judged the times of action in the first session and of sound in the second session, while in the other half (n = 8) the order was reversed. A 10-min break was inserted between the two sessions. To maximize the effects of emotional valence, within each session the baseline and agency blocks of one emotional condition (e.g., negative) were presented successively, and after a 5-min break the blocks of another emotional condition (e.g., positive). Both the order of emotional conditions (negative first or positive first) and the order of task types (baseline first or agency first) were consistent within a participant, and completely counterbalanced between participants (see also Participants section).

Experiment 2 generally adopted the same protocol as experiment 1. Although in experiment 1 there were two baseline action blocks corresponding to two emotional conditions, the comparison of judgment error data between the two revealed no difference. We thus included only one common baseline action block (32 trials) in experiment 2, just like previous studies of intentional binding with multiple conditions [S6, 7]. In addition, there were two agency blocks (agency action and agency sound) and one baseline sound block for each of the three emotional conditions (negative, neutral, and positive). Therefore, experiment 2 involved 10 blocks of 32 trials each or 320 trials in total.

In both experiments, after completing the intentional binding task, participants were asked to rate each of the 12 sounds on two scales used in the previous validation study [S5].

Participants heard each sound three times through the headphone. The order of presentation was completely randomized between participants. As for emotional valence, participants were asked to judge the extent to which each stimulus sounds positive/negative, on a 7-point scale ranging from 1 (*highly negative*) to 7 (*highly positive*). As for emotional arousal, participants were asked to judge the extent to which each stimulus sounds emotionally arousing, on a 7-point scale ranging from 1 (*not arousing at all*) to 7 (*highly arousing*).

Data Analysis

All behavioral data were analyzed in Matlab 7.8 (MathWorks, Natick, MA, USA) using purpose-written routines. We first computed a judgment error for each trial in each block by subtracting the actual onset time of action or sound from the perceived onset time of the corresponding event. A positive judgment error indicated a delayed judgment, while negative error indicated anticipatory judgment. Next, we averaged judgment errors for each block for each participant. We then computed the mean shift in perceived time of actions by subtracting the mean judgment error in the baseline action condition from that in the agency action condition (*action shift*). Similarly we computed the mean shift in perceived time of sounds in the agency sound condition relative to the baseline sound condition (*sound shift*). Finally, to provide a single *composite binding* measure, quantifying the overall subjective temporal association between action and outcome, we combined the action shift and sound shift, inverting the sign of the latter. Paired t-tests (negative vs. positive) or one-way ANOVAs with a repeated factor (emotional valence; 3 levels; negative, neutral, and positive) were used to assess the effects of emotional valence on intentional binding. Linear discriminant analyses (experiment 2) were used to compare the combination of action shifts and sound shifts between the negative, neutral, and positive conditions. Standardized discriminant coefficients were used to assess the contribution of action shifts and of sound shifts to the between-condition variance.

As for the post-experiment subjective ratings of auditory stimuli, we first averaged rating scores of valence and arousal for each condition for each participant. We then used one-way ANOVAs with a repeated factor (emotional valence; 3 levels; negative, neutral, and positive) on these mean scores to examine whether we could effectively manipulate the perceived valence and arousal. In all statistical analyses, the p value < 0.05 was regarded as significant.

Table S2 shows the mean judgment errors and shifts relative to baseline conditions for different emotional conditions. In experiment 1, the composite binding measure clearly demonstrated that intentional binding was smaller in the negative than positive condition ($T_{15} = -3.11$, $p = 0.0072$; Figure 2B). Paired t-tests showed that sound shift tended to be smaller in the negative than the positive condition ($T_{15} = 1.96$, $p = 0.069$), while the difference in action shift between the two conditions did not reach statistical significance ($T_{15} = -1.22$, $p = 0.24$).

In experiment 2, the measure of composite binding again varied across different sound conditions ($F [2, 32] = 4.90$, $p = 0.014$; Figure 2B). 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 ($p = 0.50$). ANOVAs applied to each event separately showed that sound shift was significantly influenced by different emotional outcomes ($F [2, 32] = 3.96$, $p = 0.029$). Post-hoc comparisons indicated that sound shift was significantly smaller in the negative than the positive condition ($p = 0.0054$). There was also a tendency of smaller sound shift in the neutral than the positive condition ($p = 0.087$), though no difference was found between the negative and neutral conditions ($p = 0.56$). A second ANOVA on action shift revealed a significant effect of emotional valence ($F [2, 32] = 5.38$, $p = 0.0097$). Interestingly, we found that action shift was significantly increased in the neutral condition compared to both the negative ($p = 0.013$) and positive ($p = 0.033$) conditions. The difference between the negative and positive conditions did not reach statistical significance ($p = 0.19$).

We also analyzed the data from the combined sample of experiments 1 and 2, which revealed a highly robust effect of emotional valence on composite binding ($T_{32} = -4.40$, $p = 0.00011$; Figure 2C). With the whole sample of 33 participants, the difference in sound shift between the negative and positive conditions was highly significant ($T_{32} = 3.56$, $p = 0.0012$). Furthermore, action shift tended to be smaller in the negative than the positive condition ($T_{32} = -1.87$, $p = 0.071$).

Supplemental References

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