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Intention insertion: Activating an action's perceptual consequences is sufficient to induce non-willed motor behavior

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Supplementary Experiment

This experiment was part of a series of prior pilot studies conducted to refine the design for the main study and to determine an appropriate sample size. This iteration differed from the main experiment only in that participants were presented with pairs of lateralised auditory tones (which matched the onscreen movement) together with the surprising action cues and both yellow and blue coloured backgrounds. As in the main experiment, we expected participants to make action slips more frequently when the onscreen movement matched their concurrently imagined movement than when it did not, and that the executed actions would be these imagined movements.

Method

Participants

32 participants took part in the experiment (25 female; 5 Left-handed; Age in years: *M*=23.2, *SD*=4.9), recruited from the Plymouth University's paid participation pool (remunerated £4). The study was approved by Plymouth University's ethics committee, in according with the declaration of Helsinki.

Materials and Apparatus

The design employed a slightly different set of stimuli to those of the main experiment. The stimulus set consisted, first, of three auditory stimuli created with the tone generator in Audacity: a 200ms 440Hz tone, which served as a metronome beat, a 200ms 'chirp', a sine wave tone which ascended from 200Hz to 800Hz over 200ms as well as a 200ms 'buzz', a square wave tone which descended from 200Hz to 800Hz over 200ms.

Visual stimuli were largely identical to the main experiment. They consisted of two images of egocentric left and right hands with artificial 'shadows' as if viewed from above (each with visual angle of approximately 16° vertically and 14° horizontally). The hands were presented either with the fingers in a neutral position, with the left index finger depressed, or the right index finger depressed, giving an impression of apparent motion (a downward finger press) when displayed after the neutral stimulus without stimulus onset asynchrony. They differed from the main experiment in that when either finger was depressed, the background colour was altered from white to either blue or yellow and was fully counterbalanced within-participants. The yellow background was always presented with the 'buzz' tone and the blue background was always presented with the 'chirp' tone. Furthermore, the tones were panned either hard left or right and were always compatible with the onscreen movement (i.e. a left panned tone with a left index finger movement). The observed movement, imagined movement (and thus Cue Compatibility) and Colour-Tone Pair were fully counterbalanced within-participants.

Procedure

The experiment progressed exactly as in the main experiment and cue presentation was identical with the exception that Colour-Tone Pairs varied across the course of the experiment.

Results

The percentage of correct responses at the end of each trial (when the "Go!" stimulus was presented, and participants were required to respond) was used to assess whether participants were correctly imagining the instructed movements at each point in the sequence. Because all further analyses depend on tasks compliance, and as in the main experiment we set conservative criteria and only considered participants with accuracy rates within one standard deviation of the group mean (*M*=87.9.1%; *SD*=10.5%; *M-SD*=77.5%), leading to the removal of 6 participants (leaving $N = 26$ participants).

The remaining data were analysed using generalised linear mixed-effects regression, GLMER, using the glmer() function of the lme4 package (Bates, Mächler, Bolker, & Walker, 2015) in R Version 3.4.2 environment (R Core team, 2017). As in the main experiment, the analysis proceeded in three steps. We first tested whether the surprising visual stimuli would induce unintended key presses (i.e. action slips) in the imagination period. To do this, each 800ms inter-beat period (hereafter, simply 'Beat') was treated as a discrete event in which an action slip could have occurred or not (coded *one* or *zero* respectively). The model included a fixed effect for Cue Presence (2 levels: Yes/No) and Trial (1-96, logged and mean centred) and a random intercept for each Participant and each Beat. In addition, we allowed the effect of Cue Presence, Trial and their interaction to vary within Participant by including a random slope for these terms. Indeed, the unexpected cues increased the probability of action slips, LRT: χ^2 (1) = 30.1, $p < .001$; GLMER estimate: β = 3.15, 95% CI = [2.28, 3.87]. Predicted probabilities derived from repeated simulation of our model suggest that there was a 6.92% [2.85, 14.7] chance of an action slip when a cue was present, but only .1% [.07, .46] when no cue was present. We found evidence of a significant main effect of Cue Order, LRT: χ^2 (1) = 20.5, $p < .001$; GLMER estimate: β = -.25, 95% CI = [-.5, .27], and a significant interaction with Cue Presence, LRT: χ^2 (1) = 12.5, $p < .001$; GLMER estimate: β = -1.03, 95% CI = [-1.67, -.66], suggesting participants became less likely to make any responses (i.e. whether following cued or non-cued Beats) as the experiment progressed, but that there was a pronounced decline in responsiveness to the unexpected cues.

We then tested the prediction that action slips would primarily elicited by cues that matched the currently imagined finger key press, not by those that mismatched. We constructed a smaller dataset consisting only of intervals in which cues were present (i.e. each participant contributed 32 observations). The model included fixed effects for Perception-Imagery Compatibility (2 levels: Compatible/Incompatible), Cue Order (1^{st} to 32^{nd}, logged and mean centred), Colour-Tone Pair (2 levels: Blue/Yellow) and all interactions between these three variables. In addition, we fitted a random intercept for each Participant with random slopes for Perception-Imagery Compatibility, Cue Order, Colour-Tone Pair and all interactions, which allowed each effect to vary within-participants. As predicted, there was a main effect of Perception-Imagery Compatibility, LRT: χ^2 (1) = 4.91, p = .027; GLMER estimate: β = -.83, 95% CI = [.21, 3.99], action slips were most likely in the compatible condition where the observed finger press and the imagined finger press were identical (Figure S1, middle panel). There was also a main effect of Cue Order, LRT: χ^2 (1) = 7.6, p = .006; GLMER estimate: β = -1.53, 95% CI = [-2.99, -.67]. We found no evidence of a main effect of Colour-Tone Pair or any significant higher order interaction between any of the three fixed effects.

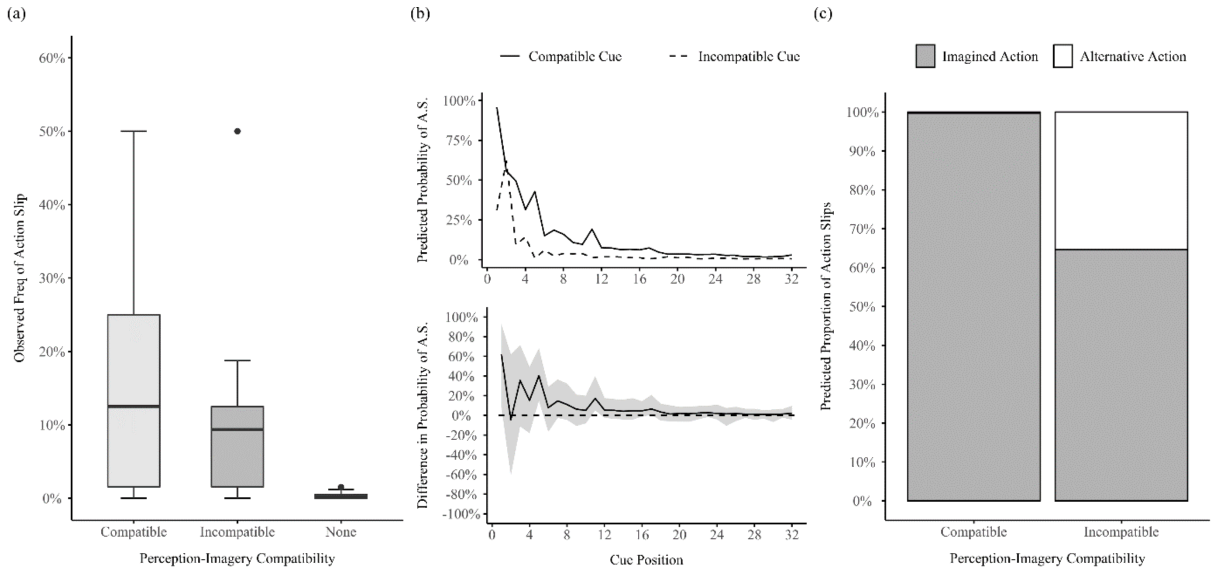

Figure S1. Observed frequencies and predicted probabilities of general and specific action slips by condition**.** Four plots showing, from left to right; (a) a box plot of the observed frequency of action slips produced by each participant, broken down by Perception-Imagery Compatibility with a thick black bar to represent the median, a box showing the interquartile range and whiskers to indicate maxima and minima, (b) a combination plot indicating the predicted probability of action slips across the experiment according to Perception-Imagery Compatibility and the associated difference plot (i.e. Compatible - Incompatible) in which the shaded area shows a 95% confidence interval derived by simulation, and (c) a stacked bar plot indicating the predicted proportion of specific action slips (i.e. either the imagined action or alternative action) made according to Perception-Imagery Compatibility, derived by simulation.

Finally, we explored the hypothesis that participants should be more likely to execute the alternative (i.e. non-imagined) action when faced with an incompatible cue. We created a new dataset consisting of only observations in which an action slip occurred and added a new outcome variable indicating whether the participant had executed the imagined or alternative action (coded one and zero respectively). The model included a fixed effect of Perception-Imagery Compatibility and Cue Order. In addition, we fitted a random intercept for each Participant and a random slope for Perception-Imagery Compatibility. The Colour-Tone Pair term was omitted from the model because of convergence issues with GLMER due to over parameterisation. The test revealed a significant main effect of Perception-Imagery Compatibility, LRT: χ^2 (1) = 9.52, p = .002; GLMER estimate: β = 2.64, 95% CI = [1.62, 22.2] (Figure S1, right panel), and a significant interaction with Cue Order, LRT: χ^2 (1) = 5.14, p = .023; GLMER estimate: β = 1.12, 95% CI = [-.13, 11.3].

Discussion

This pilot experiment captured the results of the main study. As in the main study, it showed that the combination of imagined and observed action effects is sufficient to induce a counter-intentional response. While both compatible and incompatible cues elicited action slips, compatible cues did so at a significantly higher rate. Further, participants were significantly more likely to execute the alternative (i.e. non-imagined) response following the onset of incompatible cues, during which time two sets of action effect codes are simultaneously active (i.e. one endogenously via imagery and one exogenously via perception).

References

Bates, D., Mächler, M., Bolker, B., & Walker, S. (2015). Fitting Linear Mixed-Effects Models Using lme4. *Journal of Statistical Software*, *67*(1), 1–48. https://doi.org/10.18637/jss.v067.i01

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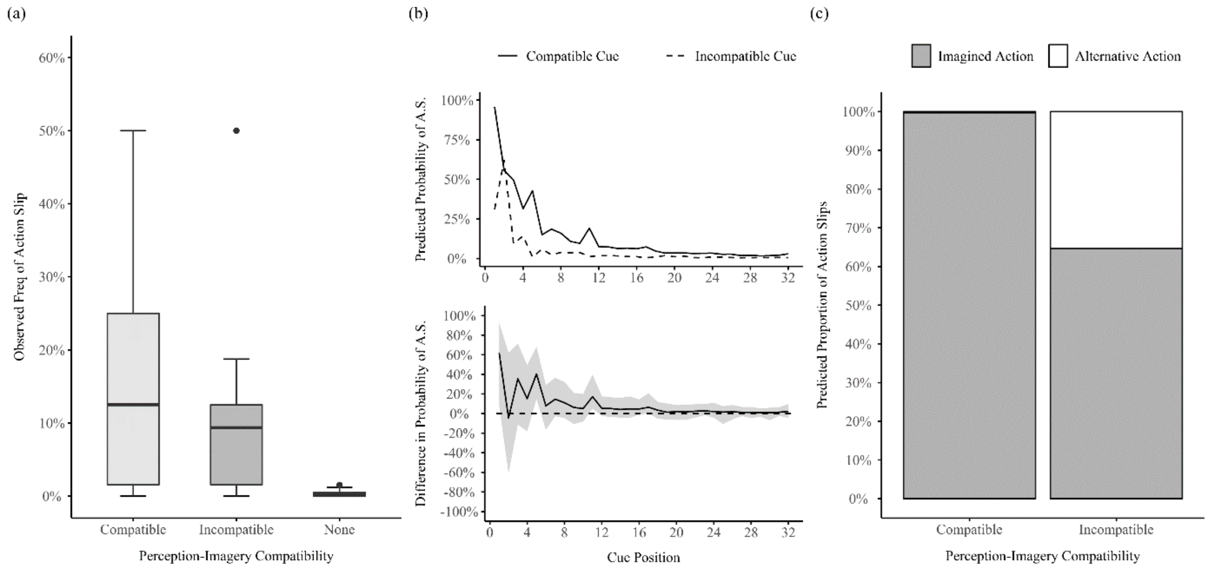
Figure Caption

Figure S2. Observed frequencies and predicted probabilities of general and specific action slips by condition**.** Four plots showing, from left to right; (a) a box plot of the observed frequency of action slips produced by each participant, broken down by Perception-Imagery Compatibility with a thick black bar to represent the median, a box showing the interquartile range and whiskers to indicate maxima and minima, (b) a combination plot indicating the predicted probability of action slips across the experiment according to Perception-Imagery Compatibility and the associated difference plot (i.e. Compatible - Incompatible) in which the shaded area shows a 95% confidence interval derived by simulation, and (c) a stacked bar plot indicating the predicted proportion of specific action slips (i.e. either the imagined action or alternative action) made according to Perception-Imagery Compatibility, derived by simulation.



(a)
(b)
(c)
60%
50%
40%
30%
20%
10%
0%
Observed Freq of Action Slip
Compatible
Incompatible
None
Perception-Imagery Compatibility
Compatible Cue
Incompatible Cue
Predicted Probability of A.S.
100%
75%
50%
25%
0%
Difference in Probability of A.S.
100%
80%
60%
40%
20%
0%
-20%
-40%
-60%
-80%
-100%
0
4
8
12
16
20
24
28
32
Cue Position
Imagined Action
Alternative Action
Predicted Proportion of Action Slips
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Compatible
Incompatible
Perception-Imagery Compatibility