Supplementary Materials for:

How Action Selection Influences the Sense of Agency: an ERP study

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Supplementary Data

*Note: * Degrees of freedom and p-values are based on the Satterthwaite approximation for degrees of freedom (Kuznetsova, Brockhoff, & Christensen, 2015).*

Target N2

Table S1. Target N2 model: parameter estimates, with bootstrapped 95% confidence intervals.

						95% CI	
	Estimate	SE	*t*	df *	*p**	Lower	Upper
Intercept	6.77	0.86	7.88	23	< 0.001	5.14	8.64
Choice	-0.02	0.17	-0.11	23	0.91	-0.35	0.36
Priming	0.34	0.14	2.41	34	0.022	0.08	0.61
RTs (Z)	-1.98	0.12	-17.04	8325	< 0.001	-2.20	-1.75
Choice x Priming	-0.11	0.13	-0.84	37	0.41	-0.36	0.12
Choice x RTs	-0.07	0.12	-0.61	8494	0.54	-0.30	0.18
Priming x RTs	-0.25	0.12	-2.13	8449	0.033	-0.45	-0.02
Choice x Priming x RTs	-0.10	0.12	-0.85	8353	0.39	-0.33	0.12

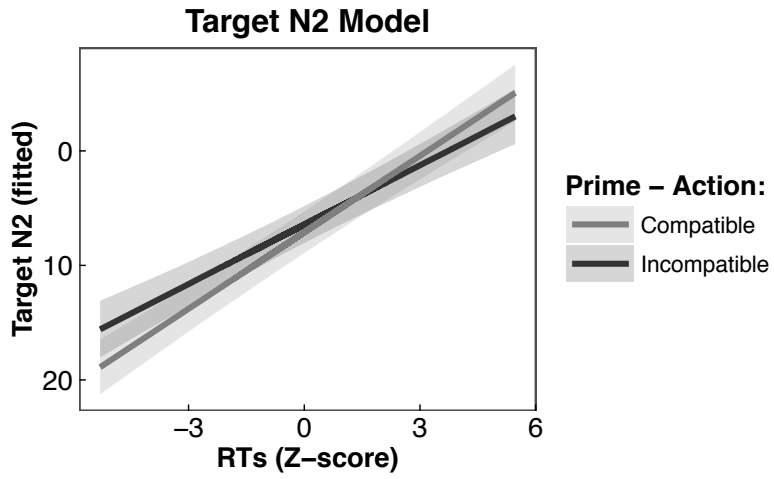

Figure S1. Target N2 model predictions for the priming by RTs interaction (with 95% prediction intervals shaded around regression lines). For fast RTs, incompatible priming led to larger Target N2 than compatible priming, but this effect reduces for slow RTs.

Action CRN

Table S2. Action CRN model: parameter estimates, with bootstrapped 95% confidence intervals.

						95% CI	
	Estimate	SE	*t*	df *	*p**	Lower	Upper
Intercept	3.23	0.53	6.05	23	< 0.001	2.25	4.26
Choice	0.13	0.15	0.86	21	0.40	-0.17	0.43
Priming	-0.27	0.13	-2.12	24	0.044	-0.52	-0.01
RTs (Z)	-0.54	0.10	-5.55	8485	< 0.001	-0.73	-0.33
Choice x Priming	0.12	0.10	1.16	58	0.25	-0.09	0.32
Choice x RTs	0.17	0.10	1.73	8696	0.084	-0.02	0.35
Priming x RTs	0.37	0.10	3.85	8667	< 0.001	0.19	0.56
Choice x Priming x RTs	0.05	0.10	0.50	8458	0.62	-0.14	0.21

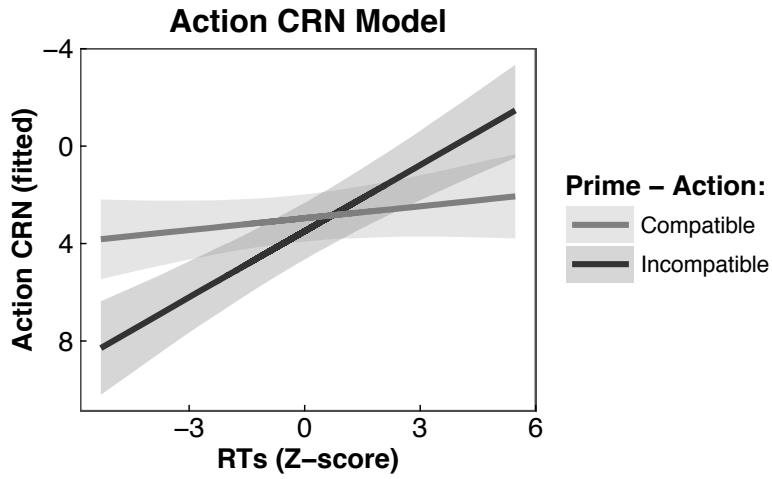

Figure S2. Action CRN model predictions for the priming by RTs interaction (with 95% prediction intervals shaded around regression lines). For incompatible priming, Action CRN varied across RTs, with an enhancement of the Action CRNs for very slow RTs, but a suppression for fast RTs.

Table S3. Action CRN model with Target N2: parameter estimates, with bootstrapped 95% confidence intervals.

						95% CI	
	Estimate	SE	*t*	df *	*p**	Lower	Upper
Intercept	3.23	0.53	6.05	23	< 0.001	2.13	4.40
Choice	0.13	0.15	0.88	21	0.39	-0.17	0.43
Priming	-0.24	0.13	-1.91	24	0.069	-0.52	0.02
RTs (Z)	-0.71	0.10	-7.27	8495	< 0.001	-0.89	-0.53
Target N2 (Z)	-0.94	0.09	-10.02	8775	< 0.001	-1.14	-0.74
Choice x Priming	0.11	0.10	1.08	55	0.28	-0.10	0.31
Choice x RTs	0.16	0.10	1.68	8693	0.093	-0.03	0.33
Priming x RTs	0.35	0.10	3.62	8663	< 0.001	0.15	0.53
Choice x Priming x RTs	0.04	0.10	0.42	8451	0.68	-0.15	0.24

Outcome FRN

Table S4. Outcome FRN model: parameter estimates, with bootstrapped 95% confidence intervals.

						95 % CI	
	Estimate	SE	*t*	df *	*p**	Lower	Upper
Intercept	-0.22	0.97	-0.23	23	0.82	-2.42	1.54
Choice	-0.015	0.17	-0.09	23	0.93	-0.36	0.31
Priming	-0.09	0.13	-0.75	42	0.46	-0.33	0.15
Choice x Priming	0.13	0.13	1.00	29	0.33	-0.12	0.39

Table S5. Outcome FRN model with Action CRN: parameter estimates, with bootstrapped 95% confidence intervals.

						95 % CI	
	Estimate	SE	*t*	df *	*p**	Lower	Upper
Intercept	-0.22	0.97	-0.23	23	0.82	-2.04	1.62
Choice	-0.02	0.17	-0.09	23	0.93	-0.35	0.30
Priming	-0.10	0.13	-0.75	42	0.46	-0.38	0.12
Action CRN (Z)	-0.09	0.11	-0.76	8778	0.45	-0.32	0.15
Choice x Priming	0.13	0.13	1.00	29	0.32	-0.14	0.38

Agency Ratings

Model parameters

Table S6. Agency ratings model: parameter estimates, with bootstrapped 95% confidence intervals.

						95% CI	
	Estimate	SE	*t*	df *	*p**	Lower	Upper
Intercept	5.18	0.17	30.33	23	< 0.001	4.84	5.52
Choice	0.15	0.08	2.06	23	0.051	0.00	0.30
Priming	0.10	0.04	2.45	23	0.022	0.03	0.20
RTs (Z)	-0.15	0.03	-5.94	8726	< 0.001	-0.20	-0.10
Target N2 (Z)	-0.02	0.03	-0.92	8754	0.36	-0.07	0.02
Action CRN (Z)	0.08	0.02	3.22	8760	0.001	0.03	0.13
Outcome FRN (Z)	0.13	0.02	5.52	8760	< 0.001	0.08	0.18
Choice x Priming	0.02	0.04	0.56	23	0.58	-0.06	0.11

Histograms of Agency Ratings

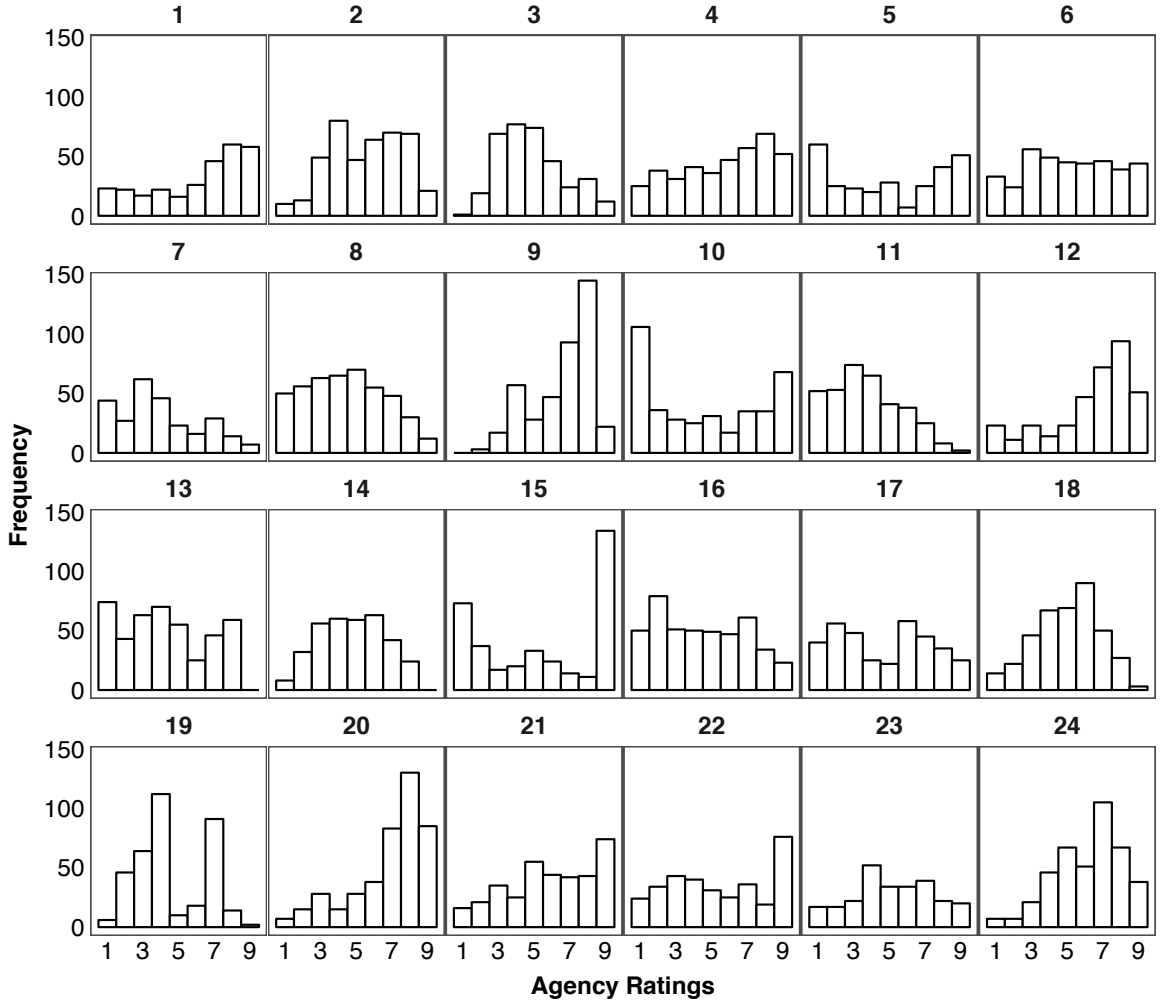

Figure S3. Histograms of agency ratings across participants.

Supplementary Analyses

A. Action-locked ERPs with a pre-target baseline

In order to exclude possible confounds linked to using a baseline immediately prior to action, we obtained Action-locked ERPs using the same neutral baseline as the one used for the Target-locked ERPs (-155 to -55 ms before target onset): we refer to these as $Action_{target}$ ERPs. As before, CRN amplitudes at FCz, between 0 and 100 ms, were obtained, for trials with correspondingly valid Target and Outcome ERPs (average trial N = 92, min = 48, across choice x priming conditions).

To clarify that the observed association between Action CRN and agency ratings did not result from baseline confounds, we computed a hierarchical linear model to predict agency ratings similar to the one used before. Due to the high collinearity between Target N2 and $Action_{target}$ CRN introduced by the common baseline, and since we had observed no relation between Target N2 and agency ratings, this predictor was excluded from the model. Thus, agency ratings were modelled by the experimental factors of choice and priming, entered as fixed and participant random effects, as well as $Action_{target}$ CRN, Outcome FRN, and RTs (log-transformed), entered as fixed covariates (standardised within-subjects).

Table S7. Agency ratings model, with a pre-target baseline for the Action CRN: parameter estimates, with bootstrapped 95% confidence intervals.

						95% CI	
	Estimate	SE	*t*	df *	*p**	Lower	Upper
Intercept	5.18	0.17	30.60	23	< 0.001	4.85	5.53
Choice	0.17	0.08	2.21	23	0.037	0.02	0.35
Priming	0.10	0.04	2.42	25	0.023	0.02	0.18
RTs (Z)	-0.16	0.02	-6.40	8673	< 0.001	-0.21	-0.11
$Action_{target}$ CRN (Z)	0.06	0.02	2.58	8735	0.010	0.01	0.11
Outcome FRN (Z)	0.12	0.02	4.99	8736	< 0.001	0.08	0.18
Choice x Priming	0.02	0.04	0.37	24	0.714	-0.06	0.10

Results show similar effects to those observed with the original Action CRN baseline prior to action. $Action_{target}$ CRN remained a significant predictor of agency ratings, as did Outcome FRN, RTs, and priming. Notably, these results show a significant effect of choice on agency ratings, which was only marginal in the previous model (displayed on Table S6). The effect of choice on agency ratings was also significant

in the ANOVA on average agency ratings, and thus before ERP artefact rejection. Given the different baselines for Action-locked ERPs in this and the previous analyses, different trials may have been excluded during artefact rejection. Therefore, this shows that the effect of choice on agency ratings was not highly reliable, as it was sensitive to differences in trial rejection, unlike other predictors.

B. Effects of trial number on agency ratings and ERPs

The effects of trial number on agency ratings were assessed by extending our previous agency ratings model (Table S6), with the original Action CRN (pre-action baseline). For this analysis, the number of trials per block was capped at 64, since all blocks contained at least this many trials (some contained more trials due to error replacement). Trial was added as both linear and quadratic predictor (computed using orthogonal polynomials, range of linear trial predictor = [-0.21, 0.21]), entered as fixed covariates. This served to test the hypothesis that: a) agency ratings could increase across the block; and b) this change could, in turn, alter the relation between ERPs and agency ratings. We additionally included interactions between a linear effect of trial and each of the 3 ERP components, in order to test hypothesis c) that the relation between ERPs and agency ratings might itself change across the trials.

Table S8. Agency ratings model, considering the effect of trial: parameter estimates, with bootstrapped 95% confidence intervals.

						95% CI	
	Estimate	SE	*t*	df *	*p**	Lower	Upper
Intercept	5.16	0.17	29.81	23	< 0.001	4.80	5.48
Choice	0.20	0.07	2.74	23	0.012	0.05	0.33
Priming	0.12	0.05	2.47	24	0.021	0.02	0.20
RTs (Z)	-0.11	0.02	-4.56	8357	< 0.001	-0.16	-0.06
Target N2 (Z)	0.00	0.02	-0.01	8367	0.99	-0.05	0.05
Action CRN (Z)	0.07	0.02	2.77	8373	0.006	0.02	0.12
Outcome FRN (Z)	0.13	0.02	5.50	8373	< 0.001	0.08	0.17
Trial-Linear	5.72	0.19	30.18	8370	< 0.001	5.32	6.09
Trial-Quadratic	-1.75	0.19	-9.24	8367	< 0.001	-2.11	-1.39
Choice x Priming	0.02	0.04	0.51	24	0.61	-0.06	0.10
Trial-L x Target N2	-0.06	0.19	-0.31	8367	0.76	-0.45	0.38
Trial-L x Action CRN	-0.06	0.19	-0.31	8366	0.76	-0.42	0.33
Trial-L x Outcome FRN	-0.58	0.19	-3.07	8371	0.002	-0.96	-0.22

To better understand the observed interaction between the linear effect of trial and Outcome FRN, we obtained model predictions across trials and 3 levels of Outcome FRN amplitude: more negative potentials (-1 SD) reflected a large FRN; 0 SD reflected average FRN; and more positive potentials (1 SD) reflected a small FRN. To compare model fits to the observed data, we additionally averaged the Outcome FRN (Z) data across subjects around these 3 levels (-1.5 to -0.5; -0.5 to 0.5; 0.5 to 1.5; respectively). Figure S4 shows that Outcome FRN amplitude had a robust influence on agency ratings in the beginning of the block, but this effect gradually reduced across trials.

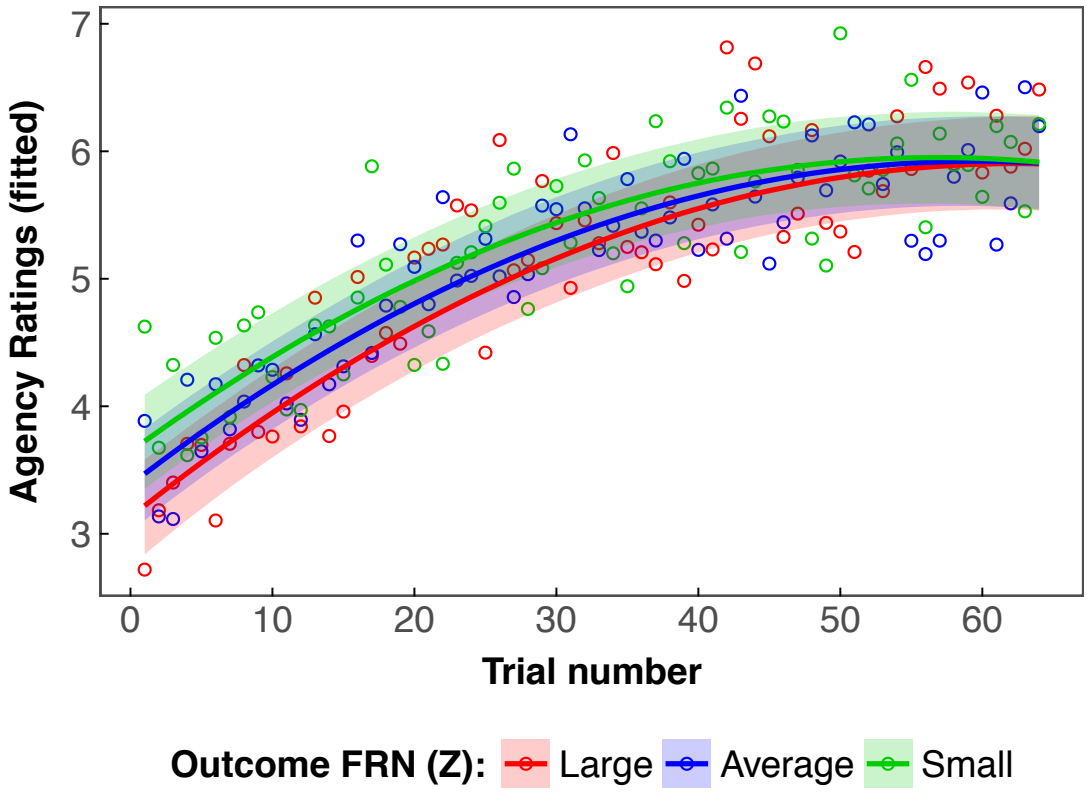

Figure S4. Model predictions for agency ratings across trials and 3 levels of Outcome FRN (lines, 95% CI shading), with average data around those levels (open circles). Here, large Outcome FRN denotes more negative potentials (-1 SD) than average (0 SD), whereas small FRN refers to more positive potentials (+1 SD) than average.

C. Outcome N1

To test whether sensory attenuation of outcome processing could be associated with influences of action selection on SoA, we additionally analysed the N1 component in the outcome-locked ERP (cf. Gentsch, Kathmann, & Schütz-Bosbach, 2012; Gentsch & Schütz-Bosbach, 2011). Average N1 amplitudes between 75-125 ms at Cz (Vogel & Luck, 2000) were modelled by the factors choice and priming, plus their interaction, as fixed and participant random effects. Results showed a significant negative relation between Outcome N1 and choice (b = -0.29, $t_{(25)}$ = -2.38, p = 0.025, 95% CI = [-0.54, -0.034], see Figure S5 below), with larger (more negative) N1 amplitudes for free choice, relative to forced choice, trials. There was no effects of priming (b = 0.061, $t_{(269)}$ = 0.65, p = 0.52, 95% CI = [-0.14, 0.25]), nor choice x priming interaction (b = -0.0042, $t_{(25)}$ = -0.039, p = 0.97, 95% CI = [-0.22, 0.20]). Therefore, we found no evidence of sensory attenuation for the effect of priming. In contrast, we found a sensory enhancement of N1 in free choice trials. Consistently, a recent study found larger N1 for the auditory outcomes of free choices, relative to a coercive condition (Caspar et al., 2016). The N1 is well known to be enhanced by attention (Vogel & Luck, 2000), suggesting that the sensory enhancement seen here may be related to greater attention to outcomes in free choice trials.

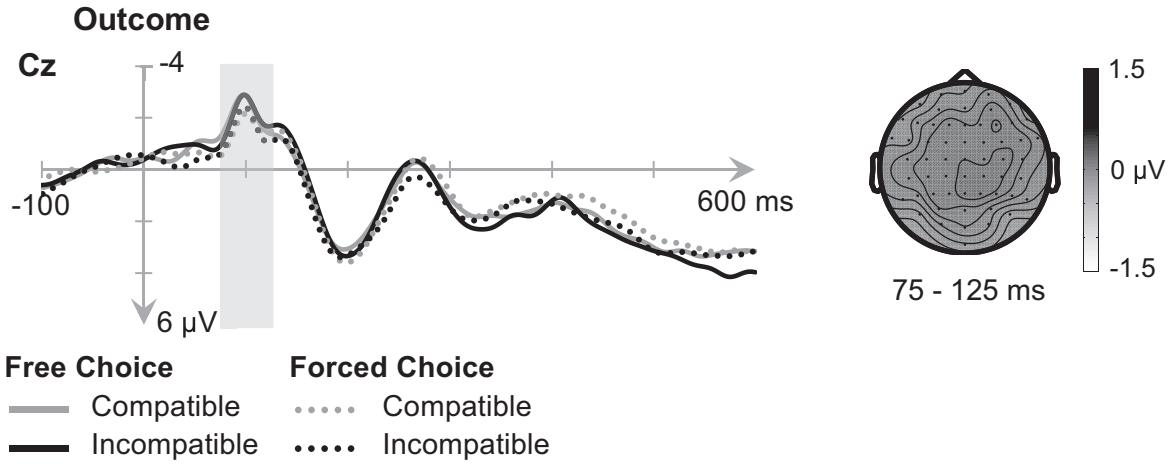

Figure S5. Outcome-locked ERPs across choice and priming conditions. The N1 component was larger in free choice, relative to forced choice, trials (window highlighted in grey). This component had a central scalp distribution (forced – free, 75-125 ms).

Note that choice had only a small effect on agency ratings, which became marginally significant after EEG artefact rejection, whereas priming had a more robust effect.

Thus, it seems unlikely that this sensory enhancement is related to how action selection influences SoA. Indeed, Outcome N1 was not related to agency ratings, as can be observed in Figure 4.e. of the main article. This was tested more directly by comparing BICs between a model predicting agency ratings by experimental factors (as above) only, with a model that additionally included Outcome N1 (standardised within-subjects). The resulting Bayes factor of 62.46 indicated strong evidence *for* the null hypothesis, that the Outcome N1 was not related to agency ratings.

References

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