

1 **How social contexts affect cognition: mentalizing interferes with sense of agency during**  
2 **voluntary action**

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26 **Abstract**

27 Living in complex social structures, humans have evolved a unique aptitude for mentalizing:  
28 trying to understand and predict the behaviour of others. To date, little is known about how  
29 mentalizing interacts with other cognitive processes. “Sense of agency” refers to the feeling of  
30 control over the outcomes of one’s actions, providing a precursor of responsibility. Here, we test  
31 a model of how social context influences this key feature of human action, even when action  
32 outcomes are not specifically social. We propose that in social contexts, sense of agency is  
33 affected by the requirement to mentalize, increasing the complexity of individual decision-  
34 making. We test this hypothesis by comparing two situations, in which participants could either  
35 consider potential actions of another person (another participant acting to influence the task), or  
36 potential failures of a causal mechanism (a mechanical device breaking down and thereby  
37 influencing the task). For relatively good outcomes, we find an agency-reducing effect of external  
38 influence only in the social condition, suggesting that the presence of another intentional agent  
39 has a unique influence on the cognitive processes underlying one’s own voluntary action. In a  
40 second experiment, we show that the presence of another potential agent reduces sense of agency  
41 both in a context of varying financial gains or of losses. This clearly dissociates social  
42 modulation of sense of agency from classical self-serving bias. Previous work primarily focused  
43 on social facilitation of human cognition. However, when people must incorporate potential  
44 actions of others into their decision-making, we show that the resulting socio-cognitive processes  
45 reduce the individuals’ feelings of control.

46

47 sense of agency; social context; mentalizing; outcome processing

48

49 **Introduction**

50 Humans live in highly complex cooperative social structures, a fact that is linked to the  
51 development of sophisticated mentalizing skills during recent evolution (Hare, 2011).  
52 Mentalizing can be defined as the cognitive processes associated with trying to understand and  
53 predict the behaviour of another agent in a social interaction. The evolution of the human brain  
54 appears directly driven by the need for such complex social cognition, with a wide-ranging  
55 network of neural structures (medial prefrontal cortex; temporo-parietal junction; temporal poles;  
56 precuneus) supporting mentalizing processes (Schurz et al., 2014). This would suggest that the  
57 mentalizing processes underlying social interaction have shaped other, non-social cognitive  
58 processes (Mercier & Sperber, 2011). In that case, consistent and characteristic interactions  
59 between mentalizing and non-social cognition should exist. However, the tasks used in much  
60 previous research on this topic often *assumed* this interaction, rather than directly test it – often  
61 requiring social cognition as an explicit element of the task. For example, when participants need  
62 to learn to predict another agent’s behaviour, mentalizing is indeed related to better performance  
63 (Devaine et al., 2014).

64

65 Despite its generally adaptive value, we suggest that, in some contexts, mentalizing may have a  
66 deleterious effect on cognition and behaviour. A troubling example of how social context can  
67 impact individuals’ behaviour is the “bystander effect” (Darley and Latane, 1968), in which the  
68 presence of other people reduces the likelihood that any one individual will act in an emergency  
69 situation, like someone needing help. This effect has been linked to the phenomenon of diffusion  
70 of responsibility (Bandura, 1991), whereby people feel less responsible for their own actions in

71 social contexts. We recently proposed that these effects are due to mentalizing processes  
72 interfering with decision-making and sense of agency (Beyer et al., 2017).

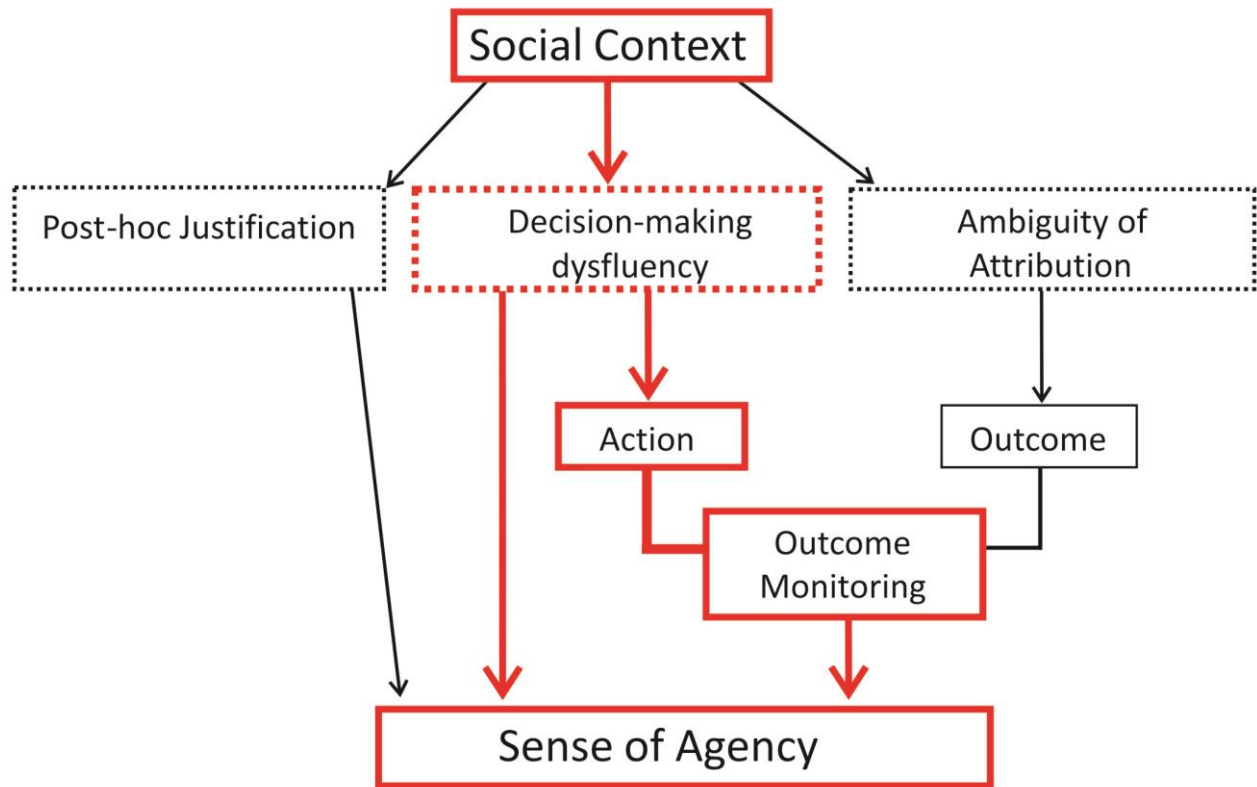
73  
74 Sense of agency refers to the feeling of being in control of our actions and their outcomes, and is  
75 essential for attribution of responsibility (Frith & Haggard, 2018). Sense of agency is an essential  
76 feature of normal human behaviour, and has wide structuring effects on cognitive processes, from  
77 perception (Tsakiris & Haggard, 2005) to outcome evaluation (Bednark & Franz, 2014). It is  
78 understood as arising from monitoring one's own volitional control over a physical event. Models  
79 of motor control (Blakemore et al., 2002) have highlighted a role for detecting mismatches in the  
80 comparison between internal predictions of sensory feedback, given efferent motor commands,  
81 with observed sensory feedback. Recent frameworks have emphasised an integration of such  
82 sensory-motor signals with other relevant cues, such as contextual information, or information  
83 about the decision-making process (Chambon et al., 2014; Synofzik et al., 2013). Traditionally,  
84 sense of agency is measured as a non-social aspect of cognition, which depends on action-  
85 outcome contingencies in interactions of the individual with their environment (Wen, 2019). Yet,  
86 navigating the social world raises particular opportunities and challenges for individual agency.

87  
88 Social contexts offer the opportunity of expanding one's agency by acting together with, or  
89 through, other agents. This can be supported by socio-cognitive processes, such as reflective  
90 mentalizing, or automatic mimicry. Interestingly, another view, akin to models of motor control,  
91 conceptualises social interaction as a feedback loop, between one's own actions and outcomes  
92 and that of other agents, which would serve to facilitate coordination, as well allow assessing  
93 one's control over the interaction partner (Wolpert et al., 2003). Yet, while this model addresses  
94 how one may come to feel a sense of control over the interaction partner's actions, it does not

95 address the question of how the interaction partner affects one's own sense of agency over non-  
96 social, environmental consequences of one's own behaviour. In fact, social interactions can also  
97 present challenges to monitoring one's own agency. Namely, they can introduce ambiguity as to  
98 which of two or more potential agents caused a given event. Several studies have tested the effect  
99 of social interaction on sense of agency, particularly in joint action (Bolt et al., 2016), or in  
100 situations in which control over events is objectively shared between participants (Li et al., 2011).  
101 Using experimental designs that prevent such ambiguity as to who caused a given outcome, our  
102 work has demonstrated a different challenge to sense of agency, as social contexts can also  
103 increase the complexity of individual decision-making (Beyer et al., 2017, 2018).

104  
105 Previously, we have shown that the mere presence of another potential agent alters decision-  
106 making, and reduces sense of agency and outcome monitoring (Beyer et al., 2017). Interestingly,  
107 this agency-reducing effect of social context was associated with increased activation of the  
108 precuneus (Beyer et al., 2018), a key node in the mentalizing network. This supports the  
109 hypothesis of strong interactions between mentalizing and wider cognition. Based on these  
110 findings, we developed a cognitive model (Figure 1) of how social context influences sense of  
111 agency (Beyer et al., 2017, 2018). This model states that in social contexts, mentalizing interferes  
112 with decision-making processes, as the potential actions of other agents must also be considered,  
113 thereby reducing sense of agency. This model draws on previous work showing that sense of  
114 agency is reduced by dysfluency in action selection (Sidarus et al., 2013, 2017a; Sidarus &  
115 Haggard, 2016) and increased cognitive load (Hon et al., 2013; Howard et al., 2016; Wen et al.,  
116 2016). Here, we further investigate this framework of how social settings may influence human  
117 action processing.

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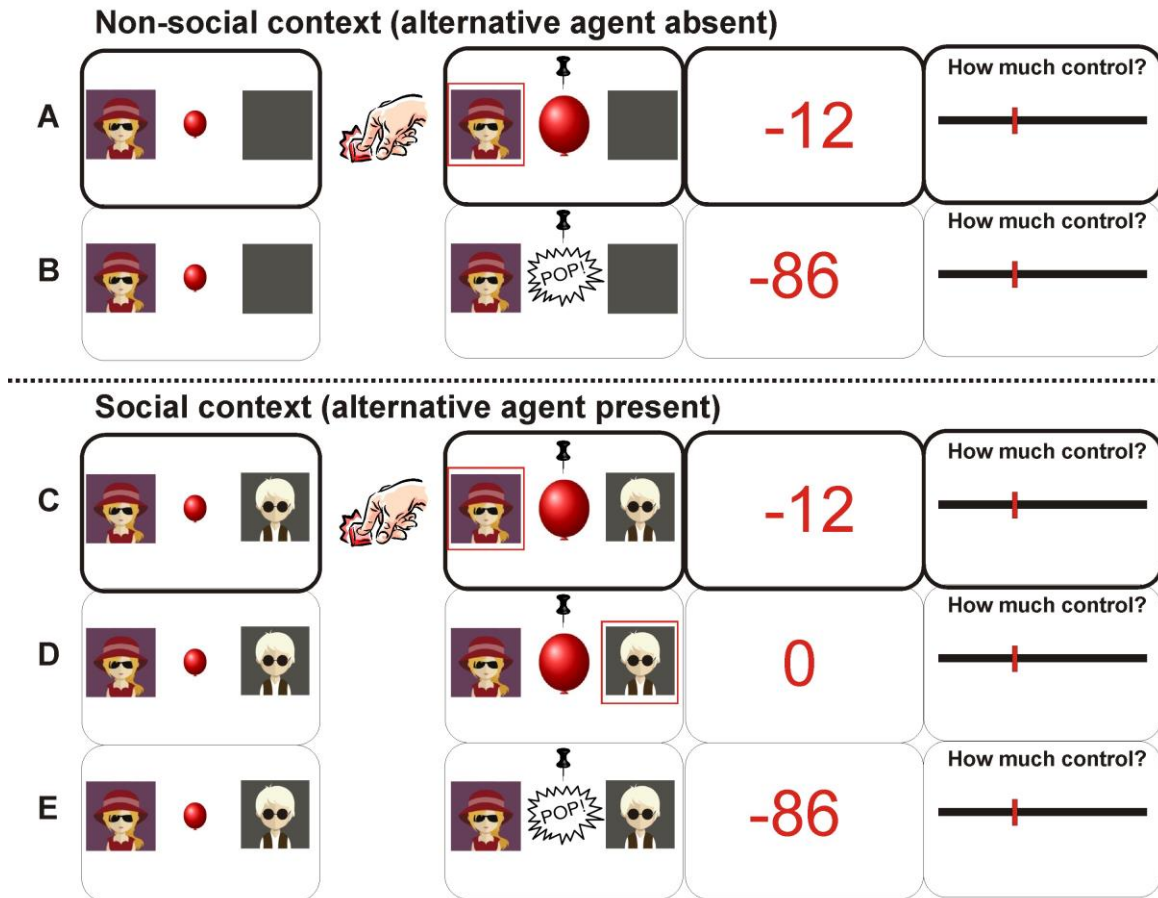
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121 **Figure 1: model of social context influences on sense of agency.** (from Beyer, Sidarus et al.,  
 122 2017) The model shows the proposed mechanism behind how the presence of other people can  
 123 reduce outcome monitoring and sense of agency (shown in red). We propose that in social  
 124 contexts, mentalizing processes increase dysfluency in the individual's decision-making and  
 125 action planning process. This dysfluency leads to a subjective loss of control over the outcomes  
 126 of the individual's own actions. Importantly, we have previously shown that this process is  
 127 independent of post-hoc reinterpretation or justification of action and outcomes, and of ambiguity  
 128 about the author of a given event (shown in dashed black lines).

129

130 To test the modulation of sense of agency in social and non-social contexts, we designed a task in  
 131 which participants allegedly interacted with another person, while preserving their objective  
 132 control over the outcomes of their own actions. In this task, participants made costly actions to  
 133 avoid a negative event, such as an inflating balloon bursting, as shown in figure 2. In order to  
 134 mimic the payoff structure of classical bystander scenarios, in which actions such as helping are  
 135 effortful but necessary, we designed actions to be costly (result in the loss of monetary points),

136 but not acting – and letting the balloon burst – was even more costly. Importantly, participants  
 137 had some control over the outcomes of their actions, as they lost fewer points, on average, the  
 138 later they stopped the balloon. Yet, there was also risk involved in the decision, as the balloon  
 139 could inflate at different rates across the trials, and could suddenly speed up during the trial.  
 140



141  
 142 **Figure 2: task outline to study social context effects on sense of agency in Experiment 1.**  
 143 Figure shows the different conditions for the task, similarly to previous studies Co-player absent  
 144 context: participant successfully stops the balloon and loses the respective number of points (A);  
 145 balloon pops, participant loses larger number of points (B). Co-player present condition:  
 146 participant successfully stops the balloon and loses the respective number of points (C); co-player  
 147 stops the balloon, participant loses 0 points (D); balloon pops, participant loses larger number of  
 148 points (E). Analyses focused on trial types A and C.

149

150 As shown in figure 2, in some trials, participants played alone, and should decide *when* to act to  
151 stop the balloon inflating before it burst, weighing the potential risk costs and against the benefits  
152 of acting later. In other trials, participants were told that they were playing with another person,  
153 represented on the screen as a second avatar. In those trials, if the co-player acted first to stop the  
154 balloon, the participant no longer needed to act and hence would not lose any points. However, if  
155 neither player acted, both participants lost a large number of points. Crucially, immediate action  
156 feedback – highlighting the avatar of the actor and the stopped balloon – eliminated ambiguity as  
157 to who was the author of a given outcome. Nevertheless, when the other player was present,  
158 participants' behaviour changed, as they tended to act later to stop the balloon, reported a reduced  
159 sense of agency over the outcomes of *their own* actions, and showed reduced outcome monitoring  
160 at the neural level (Beyer et al., 2017).

161

162 Importantly, our cognitive model of the impact of social context on sense of agency (Beyer et al.,  
163 2017, 2018) generates clear, testable hypotheses, which had remained untested and are addressed  
164 in the current study. Specifically, if sense of agency is reduced in social contexts due to  
165 mentalizing processes interfering with decision-making, then this effect should:

- 166 1. Depend on the social nature of the task, wherein the possible behaviour of other agents  
167 will be actively considered during decision-making. A non-social context that merely  
168 increases uncertainty about upcoming events should not have the same effect.
- 169 2. Be independent of outcome valence. Our model assumes that reduced sense of agency is  
170 the result of cognitive processes during action selection, rather than of post-hoc evaluation  
171 of action outcomes



172 The current experiments are therefore designed to directly test these hypotheses, to exclude key  
173 alternative explanations, while also testing the replicability and generalizability of our previous  
174 findings.

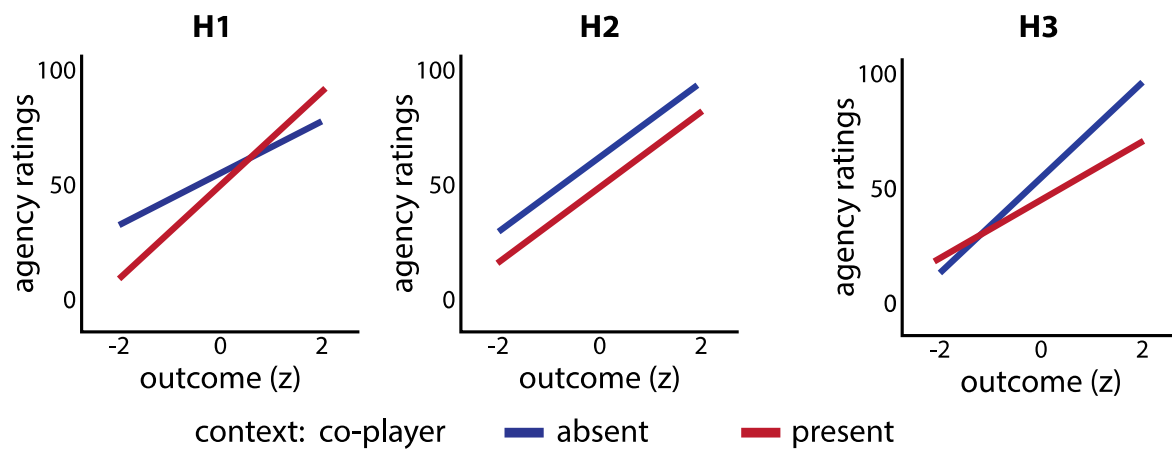
175  
176 Most importantly, our previous studies lacked a non-social control, so the only influence on  
177 participants' decisions was a social agent. This meant that social modulation of sense of agency  
178 could not be distinguished from a general effect of uncertainty on sense of agency, or a more  
179 general change in the perceived risk in the trial, since the social context offered the possibility  
180 that not acting could result in a good outcome (i.e. as the balloon could be stopped by the co-  
181 player). To address this, the first experiment involves two setups that are identical in terms of the  
182 events that participants experience, but differ in their instructions. Namely, one group of  
183 participants receive instructions that any external influence on the task is caused by another  
184 person. The other group is instructed that any influence is caused by a faulty mechanical device –  
185 an "old" balloon pump that can malfunction and stop inflating the balloon. Playing with another  
186 person is expected to lead participants to mentalize about the co-player's behaviour, trying to  
187 understand and predict when the co-player will act, and incorporating such predictions in their  
188 decision-making, in addition to the risk calculations. In contrast, while the faulty pump condition  
189 still introduces uncertainty about upcoming events, and could potentially alter the risk  
190 calculations, it is not expected to engage additional cognitive processes for modelling and  
191 predicting when the pump will fail to inflate the balloon. This allows for a direct test of the  
192 influence of social cognition on sense of agency.

193  
194 While the above setup tests the most important alternative explanation for our previous findings,  
195 still another potential influence remains in the tasks used previously. So far, our studies only

196 involved negative action outcomes, thus we could not exclude the possibility that there was  
197 something specific about negative outcomes in social contexts. Generally, participants may be  
198 motivated to reduce their personal sense of agency for negative events, in line with the concept of  
199 self-serving bias (Bandura, 2002). Yet, even in the presence of a self-serving bias, one could  
200 hypothesise different patterns of interaction between social context and outcome value, depicted  
201 in Figure 3, that carry different implications for the role of self-serving bias in understanding  
202 diffusion of responsibility. Here, outcome value is considered in a relative sense, represented by a  
203 Z-score, where 0 represents average outcomes, and more positive vs. negative values represent  
204 increasingly better vs. worse than average outcomes, respectively. Classically, it has been  
205 assumed that the diffusion of responsibility effect is specifically tied to a self-serving bias, as the  
206 presence of another agent would offer an opportunity to strategically displace responsibility,  
207 away from the self and towards the other, for undesirable outcomes. Within the context of our  
208 task, this hypothesis would predict that agency ratings should be especially reduced in the social,  
209 relative to non-social, context for worse outcomes – as depicted under H1 (figure 3). In contrast,  
210 our previous studies have shown that participants demonstrated a *general* self-serving bias,  
211 giving gradually lower agency ratings with increasingly undesirable (more negative) outcomes  
212 (Beyer et al., 2017, 2018), but this effect was the same across social and non-social contexts – as  
213 depicted under H2. This suggests that diffusion of responsibility is an independent effect that  
214 cannot be explained by a self-serving bias. Finally, one could hypothesise a third pattern of  
215 results, H3, wherein the reduction in agency ratings due to a social context would only be evident  
216 for more desirable outcomes. In such a scenario, particularly low agency ratings for relatively bad  
217 outcomes might result in a floor effect, obscuring the influence of social context. Importantly,  
218 results resembling those of either H2 or H3 would show that diffusion of responsibility could not  
219 be explained *through* a self-serving bias. Our previous work already supported H2. Yet, it

220 remains possible that these results were due to actions always having a (more or less) negative  
 221 outcome, thus creating a situation in which displacing responsibility might be seen as favourable.  
 222 Therefore, in a second experiment, we tested whether the presence of another agent reduces sense  
 223 of agency similarly for overall positive vs. overall negative action outcomes.  
 224 We discuss the implications of our findings for common practices of education and for our  
 225 understanding of social development.

226



227

228 **Figure 3: Hypothetical interactions between self-serving bias and diffusion of responsibility.**  
 229 Across the 3 panels, there is an overall self-serving bias, with agency ratings gradually reducing  
 230 with increasingly less desirable outcomes but each panel carries different implications. Outcome  
 231 value is here *standardised* (Z-scored), ranging from better than average outcome values, i.e.  
 232 positive Z values, to average outcomes (0), towards worse than average outcomes, i.e.  
 233 increasingly negative Z scores. H1: diffusion of responsibility (i.e. lower agency ratings in social,  
 234 than non-social, context) is due to a self-serving bias, as evidenced by a strategic displacement of  
 235 agency with more undesirable outcomes. H2: diffusion of responsibility is independent from a  
 236 self-serving bias. H3: diffusion of responsibility cannot be explained by a self-serving bias, but  
 237 can be overshadowed by it.

238

### 239 Experiment 1

240 If people feel less in control in social action contexts because mentalizing processes interfere  
 241 with decision-making, then this effect should be specific for social influences. However, if mere

242 uncertainty prior to the action or post-hoc counterfactual thinking leads to the subjective loss of  
243 agency, then this should also be observed for non-social sources of alternative trial outcomes.  
244 We compared the agency-reducing effect of the presence of an alternative agent between two task  
245 settings (figures 2 & 3). Both setups were identical in all aspects, except that the alternative agent  
246 was introduced either as a human co-player, or as a non-intentional and non-social mechanical  
247 device.

248

## 249 Methods

250 All measures, manipulations and exclusion of data for the experiments reported here are  
251 explained in the manuscript.

### 252 *Sample size, participants & procedure*

253 For both experiments, we based the experimental methods on previously established findings.  
254 The task we used has been shown to result in reliable, replicable within-subject effect of context  
255 (i.e. alternative agent absent vs. present; Beyer et al., 2017, 2018). Sample size was determined *a*  
256 *priori* based on previous studies, aiming for N=24 per group, and constrained by participant  
257 availability. We planned to test the main effects of interest on agency ratings using multilevel  
258 regression models, given their greater sensitivity and reliability relative to standard statistical  
259 tests (e.g. ANOVAs) that do not simultaneously model variability in effects across and within  
260 participants (Gelman & Hill, 2006; McElreath, 2015). Unfortunately, it remains difficult to  
261 perform classic power calculations for multilevel regression models, due to the heterogeneous  
262 sources of variance that must be taken into account (McElreath, 2015; Westfall et al., 2014).  
263 Therefore, we opted to analyse agency ratings using a Bayesian approach to multilevel  
264 regression. Bayesian methods thus allow us to assess the strength of evidence in our data for the  
265 effects of interest, given our sample size.

266 48 healthy volunteers (9 male; age 18-31, mean age = 23; 4 left-handed) were recruited for  
267 experiment 1. 24 participants (3 male) performed the task in the social condition, 24 (6 male)  
268 performed the task in the non-social condition. No participants were excluded from data analysis.  
269 For the social version, participants were invited into the lab in pairs, received instructions  
270 together and were told that they would be playing together in the experiment. They were then  
271 brought into separate computer cubicles to perform the task. For the non-social version,  
272 participants were also recruited in pairs, but were not told they would be playing together. In case  
273 one participant failed to attend, the other was assigned to the non-social condition and tested  
274 alone (n=9). After the task, participants filled out a post-experimental questionnaire, were fully  
275 debriefed and paid £7.50 per hour for their participation, plus a bonus based on their task  
276 performance. All participants gave written informed consent and the study was approved by the  
277 local ethics committee.

278

### 279 *Task*

280 The task was similar to that used in (Beyer et al., 2018) and modelled after the balloon analogue  
281 risk task (Lejuez et al., 2002). In each trial, participants saw a small balloon in the centre of the  
282 computer screen, which inflated at constant speed. The image of a pin was presented above the  
283 balloon, such that the balloon would pop when it touched the pin. The balloon would inflate at  
284 variable speed and speed up unpredictably at some point of a given trial, in order to make it risky  
285 to wait until the maximum size possible. At any time, participants could stop the balloon by  
286 pressing the space bar on a standard keyboard.

287

288 In the social version (figure 1), an avatar marked the presence or absence of the alternative agent.  
289 To the left of the balloon, the participant saw an avatar representing themselves. To the right of

290 the balloon, the participant saw either a coloured rectangle (in non-social trials), or another avatar  
291 representing their alleged co-player (in social trials). In social trials, the co-player could  
292 sometimes stop the balloon before, and thus instead of, the participant. In each trial, the avatar  
293 belonging to the player who stopped the balloon was marked by a red rectangle as soon as a  
294 response was made.

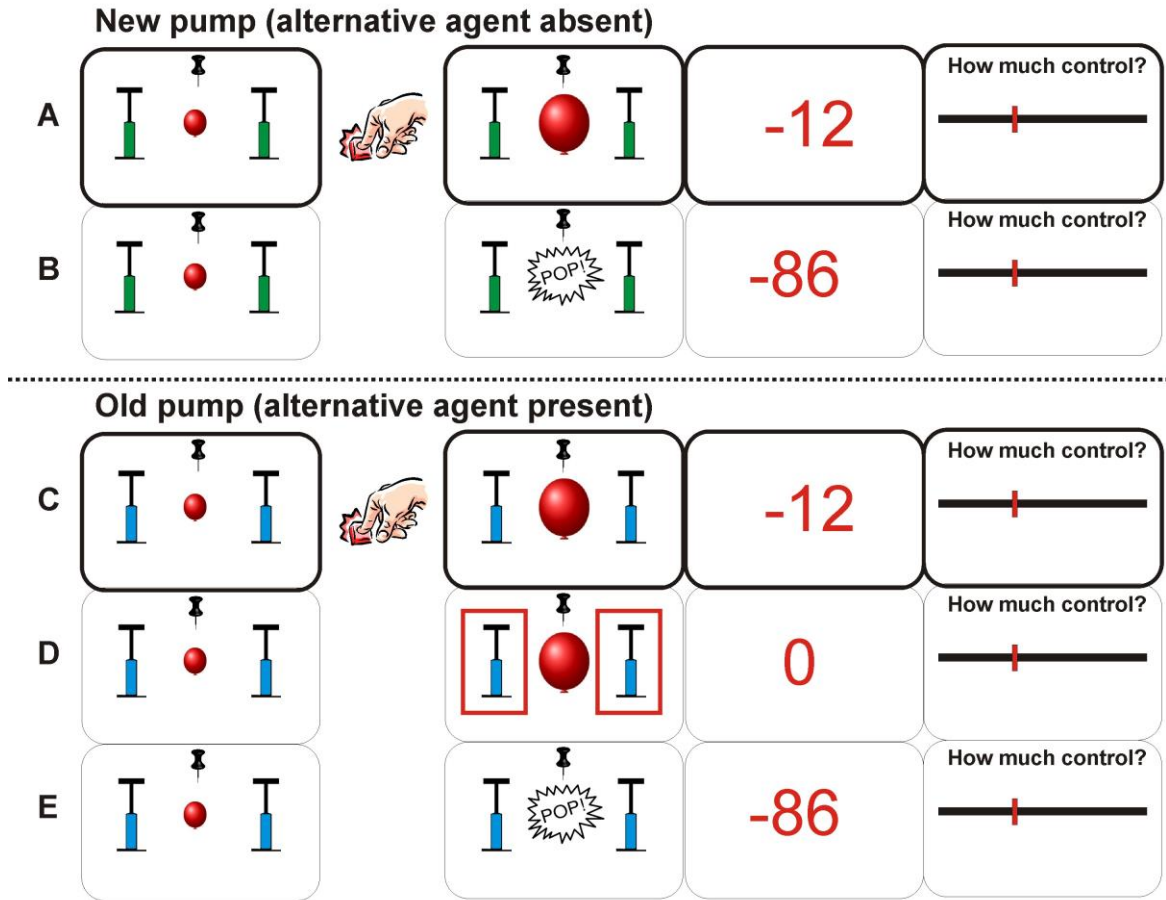
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296 In the non-social version (figure 4), participants saw the image of an air pump that was coloured  
297 either green or blue. Participants were instructed that the green pump was new, and the blue  
298 pump was old. The green pump would always inflate the balloon until it popped, unless the  
299 participant acted. The blue pump might, on some trials, break down before the balloon was fully  
300 inflated, in which case the participant would not lose any points.

301

302 Critically, the social "co-player" and the non-social "faulty pump" were programmed in the same  
303 way: the alternative agent would only act if the participant had acted on the majority of social/old  
304 pump trials and for a maximum of 3 trials per block. The only difference between task versions  
305 was that the pump was introduced as a non-social agent, thus not encouraging the engagement of  
306 mentalizing processes.

307



308

309 **Figure 4: task outline for non-social frame in experiment 1.** Figure shows the different  
 310 conditions for the non-social task version. Within-subject conditions and outcomes were identical  
 311 to the social task version shown in figure 2.

312

313 The payoff structure was as follows: if the balloon popped, participants lost 80-99 points (and the  
 314 social group was told that, in social trials, so would their co-player); if they stopped the balloon,  
 315 they lost 1-60 points; in trials with the alternative agent, if that agent stopped the balloon,  
 316 participants lost 0 points. The other agent (co-player / old pump) was programmed to stop the  
 317 balloon with a likelihood of about 70%, if the participant had acted on the majority of social  
 318 trials, and for a maximum of 3 trials per block. The point at which the co-player acted / the old  
 319 pump broke down varied between 74-86% of the maximum balloon size.

320

321 Participants completed three blocks of 20 trials each with 10 agent absent (co-player absent / new  
322 pump) and 10 agent present (co-player present / old pump) trials per block, randomized on a trial-  
323 wise basis.

324 After the last block, participants in the social group were given the following questions,  
325 answering on visual analogue scales: 'How fair was your co-player' (scale labelled as 'very  
326 unfair' / 'very fair'); 'When you played together with your co-player, in what percentage of trials  
327 did the balloon pop?' (0% / 100%); 'When you played together with your co-player, in what  
328 percentage of trials did YOU stop the balloon?'; 'When you played alone, in what percentage of  
329 trials did you stop the balloon?'; 'When you played with your co-player, did you believe you were  
330 really playing with him/her?' ('Not at all' / 'Completely'). Participants in the non-social group  
331 were only given questions 2-4, re-phrased in regard to the old/new pump instead of the co-player.

### 332 *Data analysis*

333 Our analysis focused on agency ratings in trials in which the participant successfully stopped the  
334 balloon before it burst, as these trials are comparable between contexts in which the alternative  
335 agent (co-player or old pump) was present or absent.

336  
337 Analyses were performed with Bayesian multilevel linear regression models (a.k.a. mixed-effects  
338 models), with the *brms* package (Bürkner, 2017) in R (R Development Core Team, 2008), which  
339 uses Hamiltonian Monte Carlo to sample from the posterior distribution over parameter values,  
340 by means of the Stan programming language (Carpenter et al., 2017). We report the posterior  
341 means (*b*) of the estimated parameters at the population-level (fixed effects), and their associated  
342 95% credible intervals (CI; the central 95% of values in the respective marginal posterior  
343 distribution, indicating the uncertainty around the estimate). We entered trial-wise agency ratings  
344 as the dependent variable, modelled by group (social = .5 vs. non-social = -.5) as a between-



345 subject predictor, with alternative agent context (absent = .5 vs. present = -.5) and outcome value  
346 (Z-scored within participant; (Gelman, 2008) as within-subject predictors. The within subject  
347 predictors were included as variable effects nested within participants (i.e. random intercepts and  
348 slopes model). In a previous study using this paradigm (Beyer, Sidarus et al 2017), we  
349 consistently found regression slopes of less than 5 points. Therefore, we specified the prior for  
350 the population-level effects  $a, b \sim \text{Normal}(0, 5)$  – that is, Normally distributed with a mean of 0  
351 and standard deviation of 5. This reflects that we are ~95% certain that regression slopes will be  
352 within the interval [-10, +10]. We set a Uniform(0, 100) prior on the intercept parameter,  
353 covering the range of the scale. We calculated Bayes Factors (BF) for each regression term using  
354 the Savage-Dickey density ratio (Wagenmakers et al., 2010). As appropriate, we report effects in  
355 favour of the null hypothesis ( $\text{BF}_{01}$ ), or in favour of the alternative hypothesis ( $\text{BF}_{10} = 1/\text{BF}_{01}$ ),  
356 and following (Lee & Wagenmakers, 2014), we describe the strength of evidence as anecdotal ( $1$   
357  $< \text{BF} < 3$ ), moderate ( $3 < \text{BF} < 10$ ), strong ( $10 < \text{BF} < 30$ ) and very strong ( $30 < \text{BF}$ ).

358

## 359 Results

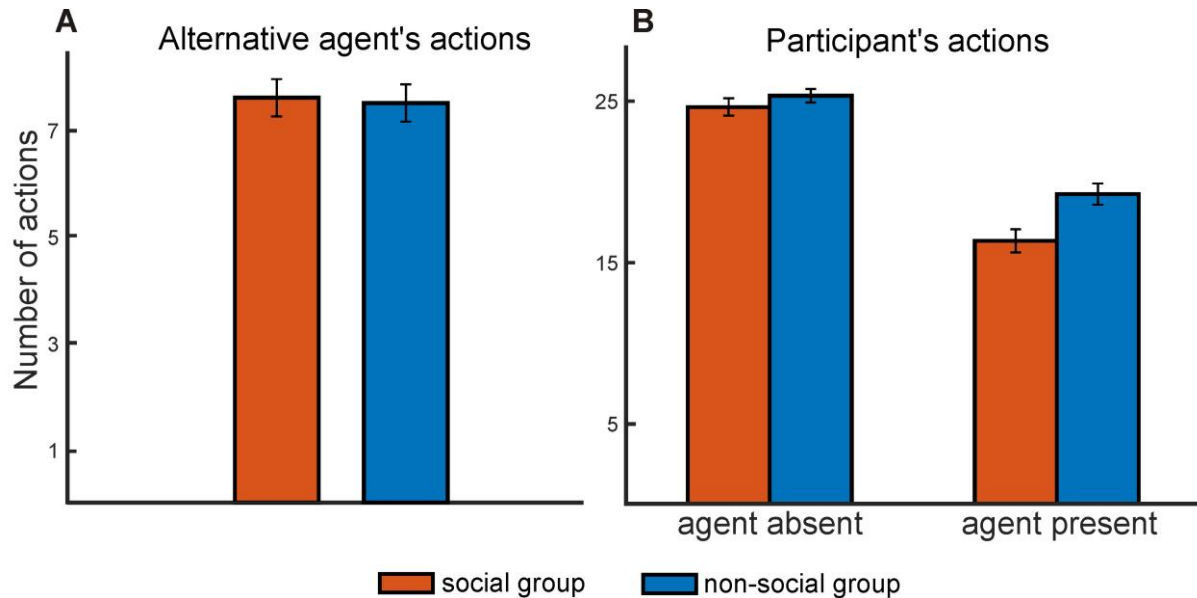
### 360 *Influence of social context on task performance*

361 Comparing task performance between task versions showed, most importantly, no difference  
362 between social (avatar) and non-social (pump) agent groups in the number of trials in which the  
363 alternative agent acted ( $M = 7.6 / 7.5$ ;  $SD = 1.6 / 1.6$ ;  $t_{46} = 0.4$ ,  $p = .656$ ;  $d = .06$ ; Figure 5A). Thus,  
364 participants in the social and non-social versions experienced the same level of external influence  
365 and, in principle, could have formed similar expectations about the probability of the balloon  
366 stopping ‘on its own’.

367

368 Considering the number of trials in which the participant *did* act, a group by context mixed  
369 ANOVA showed significant main effects of group ( $F_{1,46} = 8.0$ ;  $p = .007$ ,  $\eta_p^2 = .15$ ), context ( $F_{1,46}$   
370  $= 236.3$ ;  $p < .001$ ,  $\eta_p^2 = .84$ ), and a significant interaction ( $F_{1,46} = 5.6$ ;  $p = .023$ ,  $\eta_p^2 = .11$ ). Post-  
371 hoc tests revealed that, when the alternative agent was present, participants in the social task  
372 frame acted less frequently than participants in the non-social frame ( $M = 16.3 / 19.2$ ;  $SD = 3.3 /$   
373  $3.0$ ;  $t_{46} = -3.2$ ;  $p = .002$ ;  $d = .92$ ), while there was no difference between groups when the  
374 alternative agent was absent ( $M = 24.6 / 25.3$ ;  $SD = 2.5 / 1.9$ ;  $t_{46} = -1.0$ ;  $p = .304$ ;  $d = .32$ ; Figure  
375 5B). While, as is to be expected, both groups acted less often when the balloon could be stopped  
376 by the alternative agent (paired t-test for agent present vs. absent, social frame:  $t_{23} = 11.7$ ,  $p <$   
377  $.001$ ;  $d = 2.78$ ; non-social frame:  $t_{23} = 10.0$ ,  $p < .001$ ;  $d = 2.32$ ), this effect was stronger if  
378 participants thought they were playing with another person, than if they were playing with a  
379 faulty pump. Thus, even though they had the same experience of external influence on stopping  
380 the balloon, participants who believed the alternative agent in that condition to be another person  
381 relied more on the other agent to act, relative to participants who did not believe that another  
382 person was involved. Since both groups had the same number of trials in which the alternative  
383 agent acted, acting less often in the agent present condition for the social frame group resulted in  
384 a larger number of balloon bursts trials, and hence a slightly inferior task performance, with a  
385 lower gain on average (points gained in the social vs. non-social groups:  $M = 46.6 / 70.6$ ;  $SD =$   
386  $33.9 / 21.1$ ;  $t_{46} = 2.9$ ;  $p = .005$ ;  $d = .85$ ).

387



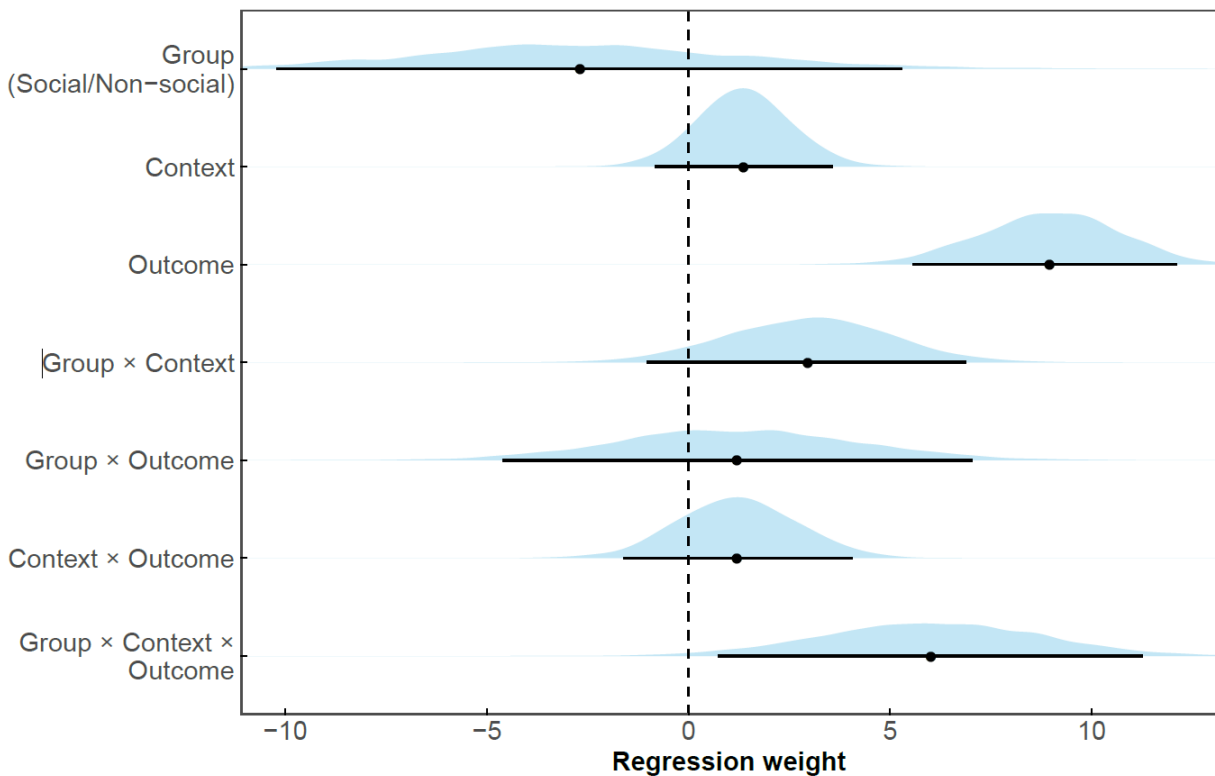
388 **Figure 5:** task performance. Panel A shows the mean number of "actions" by the alternative  
 389 agent, i.e. when co-player acts (social group), or old pump breaks down (non-social group). Panel  
 390 B shows the mean number of successful actions by the participant in both experimental groups,  
 391 as a function of the context (agent absent vs. present).  
 392  
 393

394 We analysed response times (RTs) with a group (social and non-social groups) x context (agent  
 395 absent vs. present) mixed ANOVA. This revealed no significant main effect of group ( $F_{1,46} = 0.9$ ;  
 396  $p = .358$ ,  $\eta_p^2 = .02$ ) or context ( $F_{1,46} = 1.9$ ;  $p = .197$ ,  $\eta_p^2 = .04$ ), nor a significant interaction ( $F_{1,46}$   
 397  $= 1.2$ ;  $p = .285$ ,  $\eta_p^2 = .03$ ; agent absent vs. present for social group:  $M = 6.35 / 6.33$ ;  $SD = .22 /$   
 398  $.30$ ; agent absent vs. present for non-social group:  $M = 6.33 / 6.23$ ;  $SD = .21 / .29$ ). The absence  
 399 of any effect on RTs in this experiment suggests that changes in its design and the way the  
 400 behaviour of the alternative agent was programmed, relative to our previous study (Beyer et al.,  
 401 2017), may have reduced the variance in RTs. Nonetheless, the increased number of balloon  
 402 bursts in the presence of the *social* agent clearly demonstrates that participants tended to wait for  
 403 the other player to act.

404

405 *Influence of social context on sense of agency*

406 Our analyses focused on trials in which the participant stopped the balloon. For these trials, event  
 407 sequences and action-outcome contingencies were identical in the alternative agent absent vs.  
 408 present contexts. The Bayesian multilevel regression model of agency ratings (figure 6) showed  
 409 very strong evidence for a main effect of outcome value ( $b = 8.95$ , 95% CI = [5.55, 12.12],  $BF_{10}$   
 410  $> 4 \times 10^4$ ). Importantly, there was moderate evidence for a group  $\times$  context  $\times$  outcome interaction  
 411 ( $b = 6.01$ , 95% CI = [0.73, 11.26],  $BF_{10} = 6.04$ ; figure 6; full statistics in table 1), suggesting that  
 412 the group manipulation altered the way in which context and outcomes influenced agency ratings.  
 413  
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416

417 **Figure 6: Influences on sense of agency in experiment 1.** Density plots of the posterior fixed  
 418 effects estimates from the Bayesian multilevel model. Points show posterior means, and  
 419 horizontal lines are 95% Credible Intervals. ‘Group’ refers to the social (avatar) vs. non-social  
 420 (pump) factor. ‘Context’ refers to the presence or absence of the alternative agent (i.e. co-player  
 421 present/absent, pump old/new).

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**Table 1: Test statistics for experiment 1.** Estimated fixed effect parameters from the Bayesian multilevel model. Columns show the posterior mean estimate, standard error, lower and upper bounds of the 95% Credible Interval, and Bayes Factors in favour of the null ( $BF_{01}$ ) and alternative ( $BF_{10}$ ) hypotheses. Group: Social vs. Non-social, Context: presence vs. absence of the alternative agent (i.e. co-player present/absent, pump old/new).

Parameter	Estimate	SE	2.5%	97.5%	BF01	BF10
Intercept	61.32	2.85	55.68	67.00	-	-
Group	-2.69	3.93	-10.22	5.28	0.87	1.15
Context	1.36	1.12	-0.84	3.57	2.04	0.49
Outcome	8.95	1.70	5.55	12.12	$<2.5e^{-4}$	$>4 e^4$
Group x Context	2.96	2.02	-1.04	6.88	0.85	1.18
Group x Outcome	1.19	2.98	-4.60	7.03	1.57	0.64
Context x Outcome	1.20	1.47	-1.62	4.06	2.38	0.42
Group x Context x Outcome	6.01	2.71	0.73	11.26	0.17	6.04
<b>Social Group:</b>						
Context	2.84	1.54	-0.23	5.83	0.61	1.63
Outcome	9.55	2.24	5.15	13.99	$< 2.5 \times 10^{-4}$	$> 4 \times 10^3$
Context x Outcome	4.20	2.09	0.21	8.32	0.34	2.97
<b>Non-Social Group:</b>						
Context	-0.12	1.48	-3.07	2.85	3.83	0.26
Outcome	8.35	2.28	3.67	12.71	$< 0.01$	291.42
Context x Outcome	-1.80	1.91	-5.46	2.02	1.72	0.58

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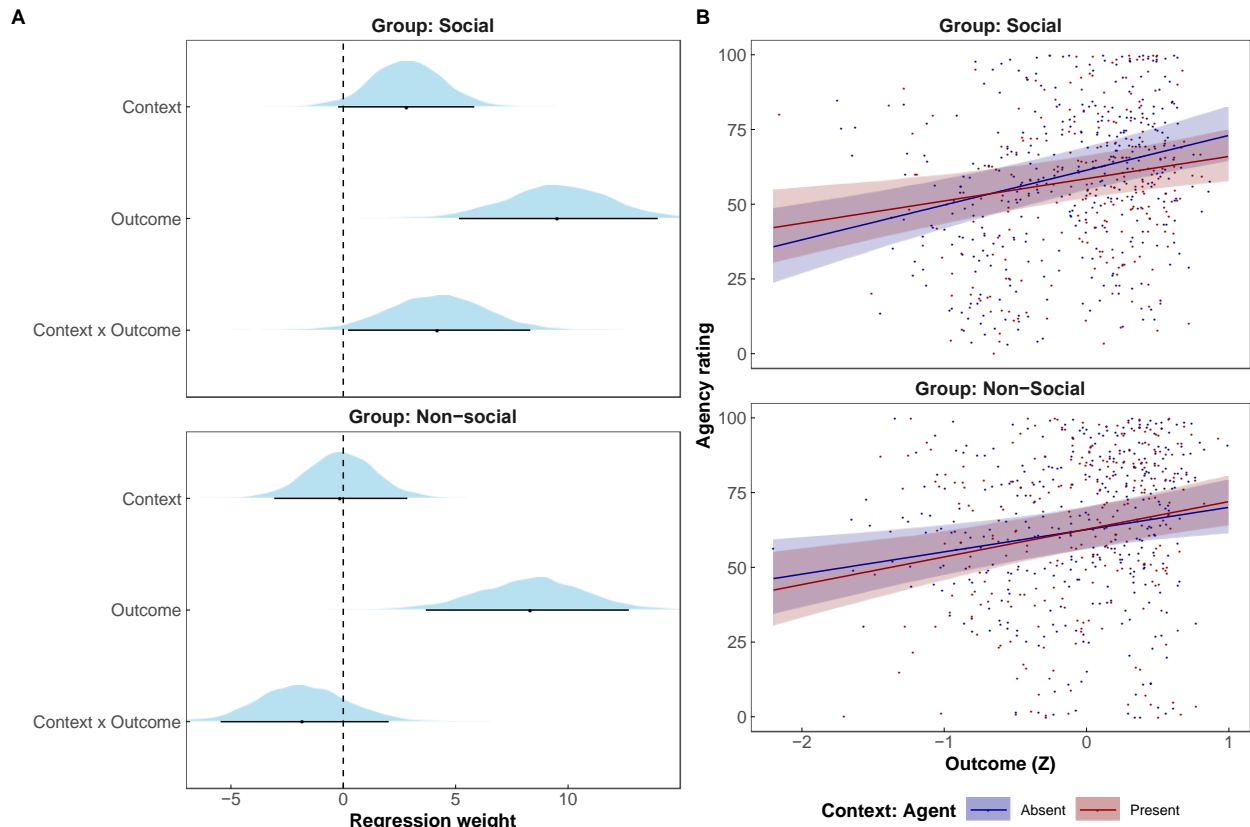
To investigate the three-way interaction, we used our model to estimate the size of the context by outcome interaction within each group (Figure 7). In the social group, we found a context by outcome interaction ( $b = 4.20$ , 95% CI = [0.21, 8.32]), with anecdotal evidence for the alternative hypothesis ( $BF_{10} = 2.97$ ). In the social group, agency ratings were increasingly greater in the agent-absent context compared to the agent-present context (in which the alleged co-player could have acted) with better outcomes. This interaction resulted in anecdotal evidence for a main effect of context ( $b = 2.84$ , 95% CI = [-0.23, 5.83];  $BF_{10} = 1.63$ ), for average outcomes. That is,

439 the previously observed effect of a reduction in agency ratings in social contexts was here largely  
440 restricted to good outcomes, likely due to bad outcomes already leading to a robust reduction in  
441 agency ratings, thus overshadowing the context effects.

442  
443 In contrast, the non-social group showed no robust context by outcome interaction ( $b = -1.80$ ,  
444 95% CI = [-5.46, 2.02]), with anecdotal evidence *for* the null hypothesis ( $BF_{01} = 1.72$ ), nor a  
445 main effect of context ( $b = -0.12$ , 95% CI = [-3.07, 2.85]), with moderate evidence *for* the null  
446 hypothesis ( $BF_{01} = 3.38$ ). Thus, in contrast to the social group, and to our previous findings, the  
447 presence or absence of another possible cause for stopping the balloon, i.e. the old vs. new pump,  
448 did not robustly affect agency ratings.

449  
450 Consistent with the large main effect of outcome value in the full model, both groups showed  
451 very strong evidence for a main effect of outcome (see table 1), with better outcomes linked to  
452 higher agency ratings.

453



454

455 **Figure 7: results for separate analysis of social and non-social groups.** Panel A shows  
 456 smoothed density plots of the posterior distributions of the estimated parameters for the effects of  
 457 context and outcome estimated for the social and non-social group separately. Points show  
 458 posterior means, and horizontal lines are 95% Credible Intervals. Panel B displays the mean  
 459 agency ratings (dots) and fitted values from the model (regression line, and shaded 95% Credible  
 460 Intervals) for the context (alternative agent present vs. absent) by outcome value interactions for  
 461 each group. Note that more positive outcome values (Z) reflect smaller losses, and more negative  
 462 values reflect larger losses.

463

464 Manipulation checks

465 At the end of the experiment, participants in the social task group were asked to rate the fairness  
 466 of their co-player, and whether they had believed they were interacting with the other player, on  
 467 scales from 0-100%. Participants rated their co-player as moderately fair ( $M = 47.6\%$ ;  $SD = 22.7$ )  
 468 and showed a moderate level of belief in the cover story ( $M = 54.8\%$ ;  $SD = 35.1$ ). An average  
 469 rating of  $>50\%$  indicates that participants were moderately convinced that they were interacting  
 470 with the other participant. It should be noted that this rating was collected at the very end of the

471 task, and being given this question itself would likely arouse suspicion. Neither rating was  
472 correlated with the effect of social context on sense of agency (fairness:  $r = .12$ ,  $p = .59$ ; belief in  
473 cover story:  $r = -.06$ ,  $p = .77$ ). Given this lack of correlation, together with the demand  
474 characteristics involved in such debriefing questionnaires, which highlight the possibility of  
475 having been deceived, and our use of mixed effects models, which are robust to outliers, we  
476 decided to not exclude any participants. These questions were not given to the non-social task  
477 group, since there was no alleged other person involved. Including belief ratings a separate  
478 predictor in the model of agency ratings showed no main effect of deception, nor any robust  
479 interactions (see Supplementary Analysis).

480

481 In both conditions, we assessed participants' perception of how many times they acted in either  
482 condition. Participants were asked on what percentage of trials they stopped the balloon in social  
483 trials / when playing with the old pump. This did not differ between conditions ( $M_{\text{social}} = 65.2$ ;  
484  $SD_{\text{social}} = 14.4$ ;  $M_{\text{non-social}} = 65.7$ ;  $SD_{\text{non-social}} = 18.4$ ;  $t_{46} = -0.1$ ;  $p = .911$ ). They were also asked on  
485 what percentage of social / old pump trials the balloon burst, with participants in the social  
486 condition reporting a greater percentage of bursts than participants in the non-social condition  
487 ( $M_{\text{social}} = 38.5$ ;  $SD_{\text{social}} = 18.0$ ;  $M_{\text{non-social}} = 27.6$ ;  $SD_{\text{non-social}} = 19.3$ ;  $t_{46} = 2.0$ ;  $p = .05$ ). For non-  
488 social trials / playing with the new pump, there was no difference between groups in the  
489 estimated number of times participants stopped the balloon ( $M_{\text{social}} = 77.9$ ;  $SD_{\text{social}} = 15.3$ ;  $M_{\text{non-}}$   
490  $_{\text{social}} = 77.5$ ;  $SD_{\text{non-social}} = 19.4$ ;  $t_{46} = .1$ ;  $p = .943$ ). This demonstrates that participant's impressions  
491 of the balloon bursting were largely in line with their actual experience, as the social group  
492 experienced more bursts, as presumably they waited for the other agent to act; unlike the non-  
493 social group.

494



495 Interim discussion

496 The results of this experiment show that the reduction in sense of agency due to the presence of  
497 another potential agent occurs only when that agent is assumed to be a person (i.e. social agent),  
498 and not when it is assumed to be a mere mechanism. When a non-intentional, non-social agent  
499 could interfere with the balloon inflation in addition to the participant, no reduction in sense of  
500 agency was observed for trials in which the participant successfully acted. Participants behaved  
501 differently towards social agents, relying more on them than on a non-social agent to intervene in  
502 response to increasing risk, and to act before the balloon exploded. These findings show that  
503 social cognition is indeed a crucial factor in these contextual effects on sense of agency.

504  
505 Alternative explanations for reduced sense of agency in the presence of an alternative agent could  
506 have been a shift in subjective outcome value when a no-loss option was possible. Thus, due to  
507 counterfactual thinking ('I could have lost no points'), a small negative outcome could be  
508 perceived as worse than when the no-loss option was not available (in the agent present vs. absent  
509 conditions). Further, increased uncertainty of trial outcomes prior to the action, or prior  
510 experience of non-control (i.e. the balloon stopping 'on its own'), could become associated with  
511 the task condition, thus lowering the overall sense of agency. Crucially, these explanations would  
512 have predicted the same effect for the non-social agent, i.e. the old and faulty pump. As the only  
513 difference between the two groups was the social vs. non-social framing of why the balloon  
514 might occasionally stop "on its own", these findings strongly suggest that social cognition  
515 underlies the agency-reducing effect of the co-player's presence.

516  
517 One other potential difference between conditions could be that the co-player could be perceived  
518 as a capable, somewhat predictable aid in the task, whereas the old pump was clearly labelled as

519 defective and random. However, if this had influenced sense of agency ratings, we would have  
520 predicted the opposite effects of those found here, i.e. participants should experience particularly  
521 low sense of agency when interacting with an unpredictable faulty device.

522 A further difference between task conditions was the presence of a self-representation in the form  
523 of an avatar for the social task group, which was absent for the non-social task group. However,  
524 for the social group, the participant's own avatar was present in both task conditions (co-player  
525 absent or present). Thus, if the presence of such a self-representation affected sense of agency,  
526 this should have resulted in a main effect of group, rather than the observed interaction effect.

527  
528 In contrast to our previous studies, in the social group here we found evidence for a context by  
529 outcome interaction effect, rather than simply a main effect of context. This was due to a stronger  
530 effect of the co-player's presence if the outcome of a given trial was relatively good, i.e. fewer  
531 points were lost. The most likely explanation for this interaction is a floor effect in agency ratings  
532 when outcomes were particularly bad, as participants already rated their sense of agency as very  
533 low, thus not reducing it further due to the co-player's presence. Importantly, the direction of this  
534 interaction is in the opposite direction of what would be predicted based on self-serving bias,  
535 which would predict a stronger displacement of responsibility to others for particularly bad  
536 outcomes.

537  
538 However, overall negative outcome valence remains a potential confound in the tasks used so far.  
539 Previous accounts of diffusion of responsibility have focused on post-hoc justification due to self-  
540 serving bias (Bandura, 2002). This predicts that external attribution of control should occur  
541 particularly for undesirable outcomes. None of our previous studies found evidence for a stronger  
542 effect of social context on sense of agency with increasingly larger losses (Beyer et al., 2017,

543 2018; Ciardo et al., 2020). In fact, the only interaction between social context and outcomes  
544 observed so far showed the opposite pattern, with a reduced effect of social context on sense of  
545 agency for particularly negative outcomes.

546  
547 However, while the effect of social context does not depend on outcome *value* (Z-scored), it may  
548 nevertheless be driven by overall outcome *valence*. Particularly, framing outcomes as generally  
549 negative could still motivate participants to assign some responsibility to their co-player in social  
550 settings, regardless of loss magnitude. As such, a social task frame may simply afford the  
551 displacement of responsibility for negative events. To test this alternative explanation, in the  
552 second experiment, we compared social context effects on sense of agency for positive and  
553 negative outcomes.

554

## 555 **Experiment 2**

556 In this experiment, one group of participants performed a “gain” version of the social task (fig.  
557 8), winning a variable amount of points, while another group performed a “loss” version, losing a  
558 variable amount of points, as in previous experiments.

559

## 560 **Methods**

### 561 *Participants & procedure*

562 44 healthy female volunteers were recruited for experiment 2. Due to low numbers of male  
563 participants being available for testing, only female participants were recruited. 22 participants  
564 performed the task in the gain frame, 22 performed the task in the loss frame. One participant in  
565 the gain frame was excluded from the analysis due to low trial numbers (only 5 trials in which the

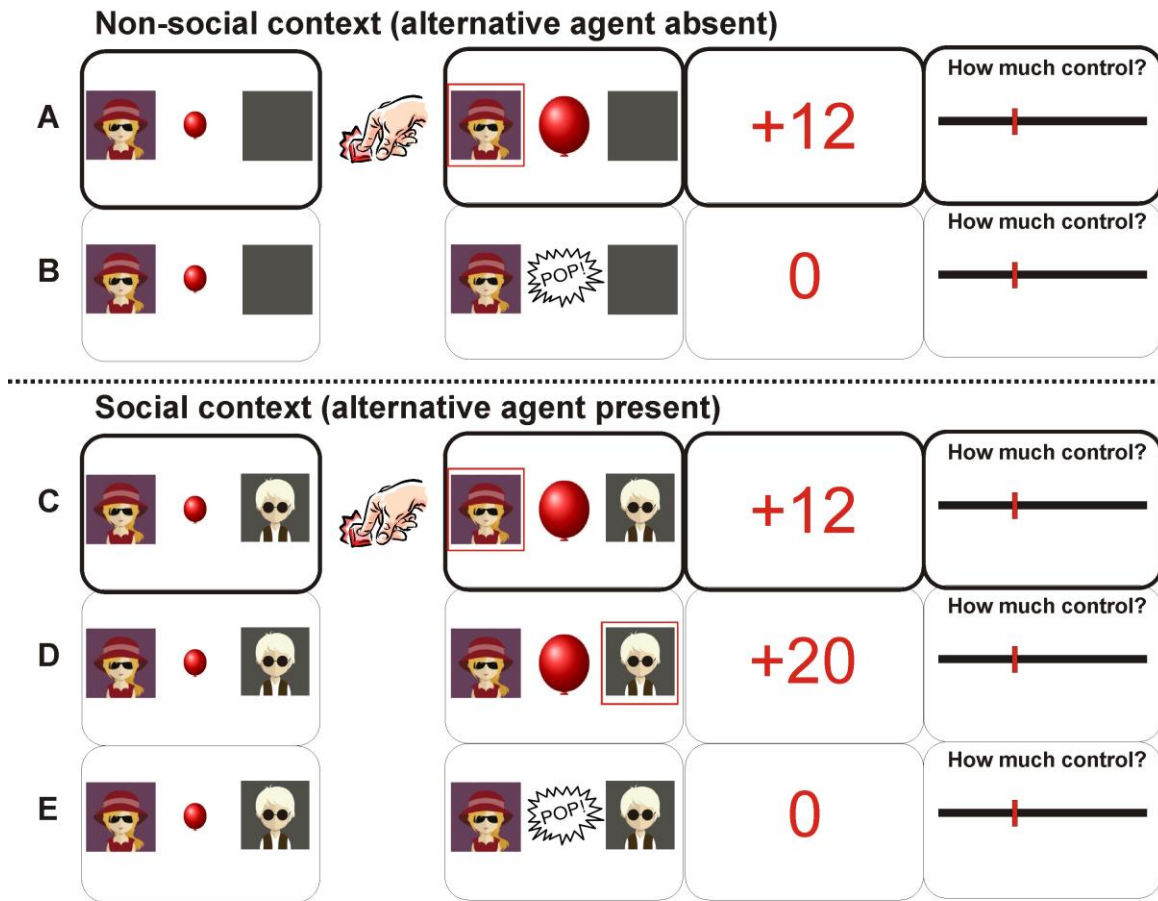
566 participant successfully stopped the balloon in the social context). Thus, data of 43 participants  
567 were included in the analysis (age 19-30, mean age = 23; 2 left-handed).  
568 Participants were invited into the lab in pairs, received instructions together and were told that  
569 they would be playing together in the experiment. They were then brought into separate computer  
570 cubicles to perform the task. After the task, participants filled out a post-experimental  
571 questionnaire, were fully debriefed and paid £7.50 for their participation, plus a bonus based on  
572 their task performance. All participants gave written informed consent, and the study was  
573 approved by the local ethics committee.

574

#### 575 *Task*

576 The overall task was similar to that in experiment 1, with the exception that the payoff structure  
577 was different, as it needed to be symmetric for the loss and gain version. In the loss frame, the  
578 payoff structure was as follows: if the balloon burst, the participant lost 20 points (and was told  
579 that in social trials, so would their co-player); if the participant stopped the balloon, they lost 1-20  
580 points depending on the size of the balloon (the bigger the balloon, the fewer points they lost); in  
581 social trials, if the co-player stopped the balloon, the participant lost 0 points. In the gain frame,  
582 the payoff was as follows: if the balloon burst, the participant earned 0 points; if the participant  
583 stopped the balloon, they earned 1-20 points (the bigger the balloon, the more points they  
584 earned); in social trials, if the co-player stopped the balloon, the participant earned 20 points.  
585 Additionally, there was no pin displayed above the balloon, but the balloon popped at a randomly  
586 determined size that varied from trial to trial. At any time, the participant could press the left  
587 button on a standard computer mouse to stop the balloon.

588



589

590 **Figure 8: task outline for experiment 2.** Figure shows the different conditions for the task in the  
 591 gain frame. Task structure was identical for the loss frame, except for outcome value (which  
 592 ranged from 0 to -20). In both gain and loss frames, participants obtain the best outcome when  
 593 the co-player acts, and the worst outcome when the balloon bursts.

594

595 Thus, in both frames, the best outcome was obtained by the co-player's action, the worst if

596 neither player acted, and an outcome in-between these extremes if the participant acted,

597 depending on balloon size. Notably, the overall valence of the outcomes was framed as either

598 something desirable (trying to gain points) or something to be avoided (losing points).

599 At the end of each trial, participants rated how much control they felt they had over the outcome

600 of that trial, on a visual analogue scale ranging from 'no control' to 'complete control'.

601 Participants were instructed that the outcome referred to the number of points they gained or lost

602 on that trial, rather than whether the balloon popped or not.

603  
604 The co-player's behaviour was pre-programmed, such that they would only stop the balloon if the  
605 participant had stopped the balloon on the majority of social trials of that block (i.e. if the  
606 participant had stopped the balloon on at least one social trial more, than the co-player). If this  
607 was the case, the co-player stopped the balloon with a likelihood of about 66%.  
608 Participants played 4 blocks of 30 trials each. In each block, 15 social and 15 non-social trials  
609 were randomly intermixed, resulting in 60 trials per experimental condition.

610  
611 *Data analysis*

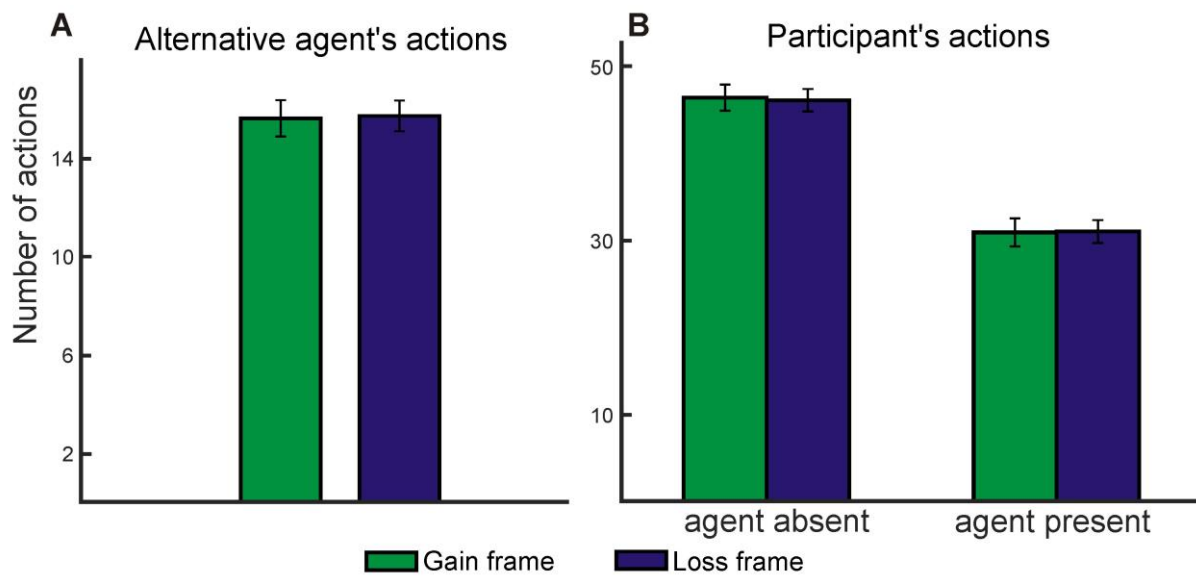
612 Data analysis was performed as for experiment 1, with Bayesian multilevel linear regression  
613 models, with gain and loss frame as a between-subject factor (Gain frame = .5, Loss frame = -.5),  
614 with presence of co-player context (absent = .5, present = -.5) and outcome value (standardized to  
615 have a standard deviation of 0.5; wherein 0 represents average outcomes, and higher values  
616 meaning increasingly more desirable outcomes, i.e. more points gained or fewer points lost) as  
617 within-subject predictors. As before, the within subject factors were included as varying effects  
618 nested within participants. As in experiment 1, we placed a Normal(0, 5) prior distribution on the  
619 fixed effects for all regression parameters, and a Uniform(0, 100) prior on the intercept term.

620  
621 Results

622 *Task performance*

623 General task performance did not differ between groups. There was no significant difference  
624 across groups in number of trials in which the co-player acted (in the agent present condition;  
625 gain vs. loss group:  $M = 15.62 / 15.73$ ;  $SD = 3.25 / 2.81$ ;  $t_{41} = -0.1$ ,  $p = .908$ ;  $d = .04$ ; figure 9A),  
626 and no significant difference in participants' final earnings (gain vs. loss group:  $M = 290 / 290$ ;

627 SD = 24.3 / 21.6;  $t_{41} = 0.02$ ,  $p = .983$ ;  $d = 0$ ). The number of trials in which the participant *did* act  
 628 was analysed with a group (gain vs. loss frame) by context (agent absent vs. present) mixed  
 629 ANOVA. This showed no significant effect of group ( $F_{1,41} < .1$ ,  $p = .953$ ,  $\eta_p^2 < .01$ ), nor a  
 630 significant interaction between the factors ( $F_{1,41} = .1$ ,  $p = .817$ ,  $\eta_p^2 < .01$ ; figure 9B). A significant  
 631 main effect of context ( $F_{1,41} = 221.8$ ,  $p < .001$ ,  $\eta_p^2 = .84$ ) showed that, across groups, participants  
 632 acted significantly less often when the alternative agent was present than absent, since the balloon  
 633 could also be stopped by the co-player (agent absent vs. present for gain group:  $M = 46.4 / 30.9$ ;  
 634  $SD = 6.7 / 7.2$ ;  $t_{20} = 9.63$ ;  $p < .001$ ;  $d = 2.23$ ; agent absent vs. present for loss group:  $M = 46.1 /$   
 635  $31.0$ ;  $SD = 5.8 / 5.9$ ;  $t_{21} = 11.61$ ;  $p < .001$ ;  $d = 2.58$ ).



636  
 637 **Figure 9:** task performance for experiment 2. Figure shows mean number of the alternative  
 638 agent's actions (co-player acts), as well as mean number of successful actions of the participants  
 639 in both experimental groups.  
 640

641 Analysis of RTs with the same mixed ANOVA revealed no significant main effect of group ( $F_{1,41}$   
 642  $= 0.1$ ;  $p = .759$ ,  $\eta_p^2 < .01$ ), nor a significant interaction ( $F_{1,41} = 1.3$ ;  $p = .267$ ,  $\eta_p^2 = .03$ ). A  
 643 significant main effect of context ( $F_{1,41} = 27.4$ ;  $p < .001$ ,  $\eta_p^2 = .40$ ) showed that, across both  
 644 groups, participants acted significantly later in the agent present than in the agent absent

645 condition (agent absent vs. present for gain group:  $M = 6.4 / 6.7$ ;  $SD = .5 / .4$ ; agent absent vs.  
646 present for loss group:  $M = 6.5 / 6.7$ ;  $SD = .4 / .3$ ). Consistent with our previous findings (Beyer  
647 et al 2017), this suggests that participants tended to wait a bit longer to act when an alternative  
648 agent was present, since the best outcome was obtained if the co-player acted instead of them.  
649 Importantly, participants' behaviour was equally affected by the co-player across gain and loss  
650 groups.

651

### 652 *Influence of outcome valence on sense of agency and its modulation by social context*

653 As before, our analyses focused on trials in which the participant stopped the balloon, in which  
654 event sequences and action-outcome contingencies were identical for trials with a co-player  
655 present vs. absent. The Bayesian multilevel regression model of agency ratings included the  
656 predictors group (gain vs. loss frame), context (co-player absent vs. present) and outcome  
657 (standardized). This revealed strong evidence for a main effect of context ( $b = 3.01$ , 95% CI =  
658 [1.09, 4.90],  $BF_{10} = 18.3$ ), as well as strong evidence for a context  $\times$  outcome interaction ( $b =$   
659  $3.50$ , 95% CI = [1.32, 5.66],  $BF_{10} = 24.4$ , and very strong evidence for a main effect of outcome  
660 value ( $b = 9.73$ , 95% CI = [6.82, 12.55],  $BF_{01} > 4 \times 10^4$ ); see figure 9, and full statistics in table 2).  
661 Consistent with the social group in Exp. 1 and previous findings (Beyer et al., 2017, 2018),  
662 participants felt more in control over better outcomes, and felt less in control in the social  
663 context, when a co-player was present, compared to the non-social one, when playing alone.  
664 Importantly, as for experiment 1, the interaction between outcome value and social context  
665 demonstrates that a self-serving bias, leading to a strategic displacement of agency for  
666 undesirable outcomes, cannot explain the reduction in agency ratings in the social context. As  
667 figure 10B shows, the difference in agency ratings between social and non-social context  
668 increased for better outcomes, and was absent for particularly bad outcomes.

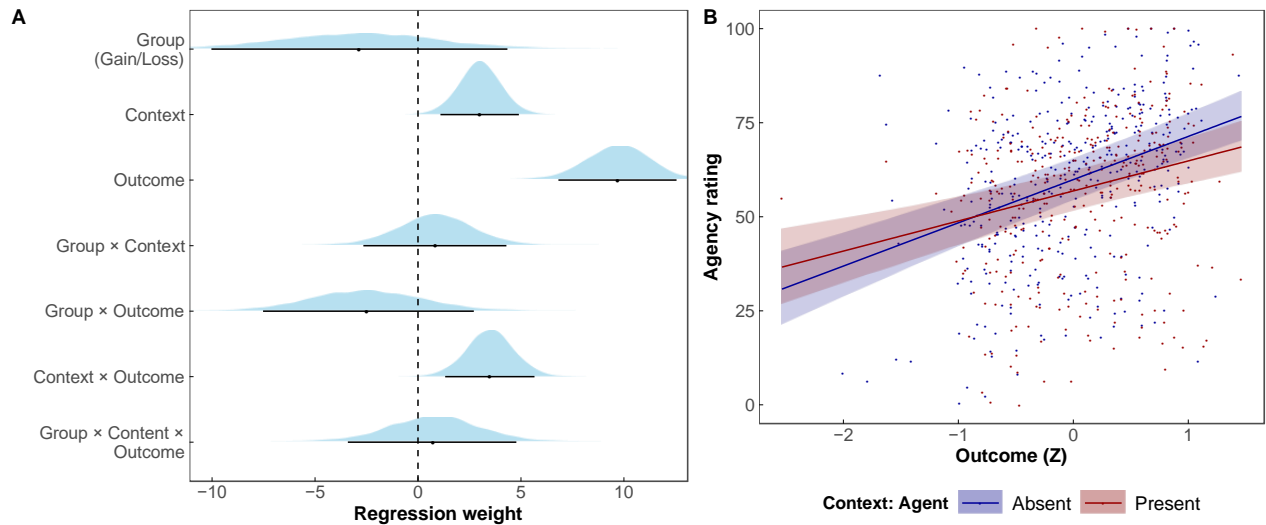


669  
670 Crucially, we found anecdotal evidence against an interaction between gain/loss group and  
671 context ( $b = 0.87$ , 95% CI = [-2.65, 4.29],  $BF_{01} = 2.55$ ), and anecdotal evidence against a group x  
672 context x outcome interaction ( $b = 0.76$ , 95% CI = [-3.41, 4.87],  $BF_{01} = 2.23$ ). Finally, we found  
673 anecdotal evidence against both other effects involving the group term (main effect of group:  $b =$   
674  $-2.84$ , 95% CI = [-10.04, 4.34],  $BF_{01} = 1.08$ ; group x outcome:  $b = -2.46$ , 95% CI = [-7.53, 2.71],  
675  $BF_{01} = 1.26$ ). Together, these findings support our prediction that the previously observed  
676 reduction in agency ratings in the presence of intentional agents was not related to the overall  
677 context of losing money, as similar effects were observed in the context.

678  
679 **Table 2: Test statistics for experiment 2.** Estimated parameters at the population-level from the  
680 Bayesian multilevel model. Estimate is the posterior mean and SE is the posterior standard deviation, with  
681 lower and upper bounds of 95% credibility intervals. Group: Gain vs. Loss frame, Context: presence  
682 vs. absence of the alternative agent (i.e. co-player present/absent).

Parameter	Estimate	SE	2.5%	97.5%	BF01	BF10
Intercept	58.37	2.68	52.66	63.48	-	-
Group	-2.84	3.67	-10.04	4.34	1.08	0.93
Context	3.01	0.96	1.09	4.90	0.05	18.3
Outcome	9.73	1.47	6.82	12.55	$<2.5 \times 10^{-3}$	$> 4 \times 10^4$
Group x Context	0.87	1.75	-2.65	4.29	2.55	0.39
Group x Outcome	-2.46	2.62	-7.53	2.71	1.26	0.80
Context x Outcome	3.50	1.10	1.32	5.66	0.04	24.4
Group x Context x Outcome	0.76	2.09	-3.41	4.78	2.23	0.45

684  
685  
686



687

688 **Figure 10: Influences on sense of agency for experiment 2.** A. Density plots of the posterior  
 689 distributions of the estimated parameters at the population-level from the Bayesian multilevel  
 690 model. Points show posterior means, and horizontal lines are 95% Credible Intervals. ‘Group’  
 691 refers to the gain vs. loss frame. ‘Context’ refers to the presence or absence of the alternative  
 692 agent (i.e. co-player present/absent). B. Mean agency ratings (dots) and fitted values from the  
 693 model (regression line, and shaded 95% Credible Intervals) for the context × outcome value  
 694 interaction effect, collapsed across loss and gain frame groups. Note that more positive outcome  
 695 values (Z) reflect smaller losses or larger gains (loss/gain group), and more negative values  
 696 reflect larger losses or lower gains, respectively.

697

### 698 *Manipulation checks*

699 Ratings of fairness ( $M = 48.9\%$ ;  $SD = 17.2$ ) and believing the cover story ( $M = 52.9\%$ ;  $SD =$   
 700  $22.1$ ) were similar to experiment 1 and did not differ between win/loss groups (fairness Win vs.  
 701 Loss,  $M = 50.6 / 47.2$ ;  $SD = 17.3 / 17.5$ ;  $t_{41} = .66$ ;  $p = .514$ ;  $d = .20$ ; believe Win vs. Loss,  $M =$   
 702  $49.3 / 56.7$ ;  $SD = 21.3 / 22.9$ ;  $t_{41} = 1.11$ ;  $p = .274$ ;  $d = .33$ ). Including belief ratings a separate  
 703 predictor in the model of agency ratings showed no robust evidence for a main effect of  
 704 deception, nor any interactions (see Supplementary Analysis).

705

### 706 Interim Discussion

707 Our findings show that reduced sense of agency in social contexts is not limited to situations in  
708 which action outcomes are undesirable, but also occurs for overall positive outcomes. This is in  
709 line with the hypothesis that the reduction in sense of agency in social contexts is driven by  
710 mentalizing processes, rather than self-serving bias. Across gain and loss frame settings, for  
711 relatively average or good outcomes, participants felt less in control over the consequences of  
712 their own actions when another potential agent was present. Thus, reduced sense of agency in  
713 social context does not depend on a generalised motivation to displace or diffuse responsibility  
714 for negative action consequences. In fact, as seen for the social group of Exp 1, the context by  
715 outcome interaction showed that the effect of context increased with more positive outcomes.

716

## 717 **Discussion**

718 This study tested key predictions derived from our novel model on how social contexts affect an  
719 important non-social aspect of human cognition, namely the emergence of a sense of agency. In a  
720 first experiment, we showed that social context reduces sense of agency, particularly for good  
721 outcomes, but a comparable, non-social, non-intentional influence in the task did not have this  
722 effect. In a second study, we showed that the presence of another social agent led participants to  
723 feel less in control over the consequences of their actions, regardless of whether those  
724 consequences involved overall financial gains or losses. Importantly, in both cases, the alternative  
725 agent had no influence on the outcomes of the participant's action.

726

727 Our findings replicate our previous studies using similar tasks, while significantly extending our  
728 understanding of important phenomena in social psychology. Generally, differences in human  
729 behaviour between non-social and social environments are explained with self-serving biases  
730 (Shepperd et al., 2008), shyness or social referencing (DiMenichi & Tricomi, 2018), or strategic

731 displacement of responsibility (Bandura, 2002). Moreover, social contexts can objectively reduce  
732 control over one's actions and outcomes, and can introduce ambiguity in who caused a given  
733 outcome. Perceived control is an important prerequisite for responsibility: one should reasonably  
734 assume more responsibility for a controllable event than for a non-controllable one. We show that  
735 the presence of others affects the human experience of voluntary action, even when alternative  
736 influences as the ones above are experimentally controlled for.

737  
738 In reference to the possible relation between a self-serving bias and diffusion of responsibility  
739 described in the introduction, we found no evidence to support the hypothesis that the diffusion  
740 of responsibility effect is *specifically tied* to a self-serving bias, such that participants  
741 *strategically* displace responsibility to others for undesirable outcomes, as exemplified in H1  
742 (figure 3). The second experiment showed a similar reduction in agency ratings in the alleged  
743 presence of a co-player, relative to playing alone, i.e. diffusion of responsibility, regardless of  
744 whether participants aimed to earn points (gain frame) or avoid losing points (loss frame).  
745 Turning to how agency ratings were affected by *relatively* more desirable vs. more undesirable  
746 outcomes (i.e. within-participants), our findings are consistent with a *general* self-serving bias, as  
747 participants report greater control over better outcomes, but that cannot explain the reduced sense  
748 of control in social contexts. If anything, the interaction pattern observed here was of a greater  
749 effect of social context on the sense of control with relatively better outcomes, consistent with the  
750 pattern of H3 (figure 3). Yet, we suggest this pattern is best explained by a floor effect on ratings  
751 for the more undesirable outcomes, which would overshadow the social context effect. When  
752 considered together with our previous studies (Beyer et al., 2017, 2018; Ciardo et al., 2020)  
753 consistently showing no interactions between outcome value and social context, as depicted in H2  
754 (figure 3), we believe the balance of evidence is most consistent with the hypothesis that the

755 sense of agency is independently influenced by a self-serving bias, reflected in the effect of  
756 outcome, and the diffusion of responsibility seen in social contexts.

757

758 Further supporting a dissociation between the effect on sense of agency of social context and of  
759 outcome value, higher sense of agency for better outcomes was even observed in a completely  
760 non-social task setup (when participants interacted with a pump, Exp 1). Moreover, studies using  
761 implicit measures of sense of agency in non-social settings (Christensen et al., 2016; Takahata et  
762 al., 2012) have shown a consistent pattern of results, suggesting that this effect does not require  
763 explicit, reflective processes. The observed effect of outcome on sense of agency is consistent  
764 with a general self-serving bias, such that participants accept more control over actions with more  
765 desirable consequences. Yet, a second explanation worth noting would be that participants aimed  
766 to achieve the best outcome possible, and thus felt most in control when the observed outcome  
767 closely matched that intention.

768

769 Together, the two experiments presented here provide strong support for our model of social  
770 context influences on sense of agency, developed in earlier studies (Beyer et al., 2017, 2018).  
771 According to this model, the presence of others increases dysfluency in the decision-making  
772 process, by evoking mentalizing processes in addition to task-directed cognition. This dysfluency  
773 then decreases sense of agency, in line with studies demonstrating reduced sense of agency with  
774 increased decision-making difficulty (Chambon et al., 2014; Sidarus et al., 2017b; Sidarus &  
775 Haggard, 2016; Wenke et al., 2010) or increased working memory demands (Hon et al., 2013;  
776 Howard et al., 2016; Wen et al., 2016).

777

778 We propose that the presence of another human agent is a particularly strong source of  
779 dysfluency, due to the complexity of cognitive processes induced by their presence. Recall that,  
780 in the first experiment comparing social and non-social agents, participants in both groups  
781 experienced the same amount of external influence in the task, that is, the balloon was stopped by  
782 the alternative agent (co-player or faulty pump) in the same number of trials. Yet, the presence of  
783 another potential agent only influenced sense of agency when the agent was believed to be a  
784 social, intentional entity, compared to a non-living, presumably random one. Since the only  
785 difference between groups was the framing of the task, differences in the effects of context on  
786 sense of agency between groups likely depend on the cognitive processes associated with the two  
787 task versions. Given that the key difference was whether or not the task instructions involved  
788 another person, mentalizing processes are the most plausible cognitive process to differ between  
789 groups, as is supported by our previous MRI study (Beyer et al., 2018). Plausibly, people try to  
790 build a model of the other putative social agent's behaviour in order to predict what the other  
791 agent will do. Mentalizing about their co-player's potential behaviour, and trying to predict when  
792 and why the co-player might act, would thus serve to help the participant try to avoid the cost of  
793 acting themselves. In contrast, participants in the non-social condition were less influenced by  
794 their previous experience of the faulty pump, and tended to ignore the influence of the pump  
795 during decision-making. This may be because participants could not, or did not expect to, form a  
796 predictive model of the pump's relevant behaviour. When the potential alternative cause of the  
797 balloon stopping was non-social (i.e. the "old pump"), it might seem *a priori* less predictable,  
798 hence, participants might not engage resources in trying to understand its behaviour.

799 In fact, similar effects have recently been found for interactions with a robot (Ciardo et al., 2020),  
800 in a task setting that did not involve monetary payoff, further suggesting that the perception of  
801 intentionality (as suggested even by an inanimate, but interactive robot) is sufficient to induce a

802 reduction in sense of agency. Taking these findings together thus supports our account that  
803 assuming an intentional stance towards the social agent results in continuous efforts at modelling  
804 and predicting their behaviour. Attempting to form this additional predictive model in turn  
805 disrupts the participant's own decision-making and sense of agency.

806  
807 Our interpretation of our findings as supporting a critical role for mentalizing in interfering with  
808 decision-making is further supported by the observation that participants' decisions were indeed  
809 different in social contexts. Participants relied more on the alternative *social* agent to act, even to  
810 their own disadvantage, as it resulted in more trials in which the balloon popped. This suggests  
811 that in addition to deciding *when* to stop the balloon on a given trial, in the presence of a social  
812 agent, participants may have additionally considered *whether* they should act at all. This decision  
813 would depend on their prediction of the co-player's behaviour. The non-social cause of "action"  
814 still increased uncertainty about what might happen in each trial, as the balloon might still stop  
815 "on its own". However, participants acted more frequently in this condition, experiencing fewer  
816 balloon burst. Thus, only social agents led to robust changes in the participants' decision-making  
817 processes, by considering the other's behaviour, in turn disrupting their sense of agency. In line  
818 with this, inter-individual differences in perspective taking have been related to susceptibility to  
819 the bystander effect, with participants higher in perspective taking traits being more strongly  
820 affected by the presence of bystanders (Hortensius et al., 2016).

821

## 822 Limitations and future directions

823 Alternative explanations for our findings should also be considered. Especially when comparing  
824 the social vs. non-social task setups, it is possible that these tasks differed in terms of emotional  
825 processes, in addition to cognitive effects. For example, participants could have experienced

826 interaction with another person as competitive or provocative. Further, it is possible that a  
827 socioeconomic setting, in which one's own losses contribute to a co-player's gain, may affect  
828 sense of agency differently than a non-economic setting. However, the structure of the task and  
829 instructions were such that it could also be perceived as a collaborative, turn-taking game. While  
830 participants have the individual goal of maximising their own payoff, they also have the shared  
831 goal of preventing the balloon from bursting. In fact, as the co-player's behaviour was rated as  
832 moderately fair, we consider it unlikely that the observed loss of agency in social settings is  
833 primarily due to socioeconomic trade-off considerations, or anger.

834 While our core findings are in line with previous studies, the interaction between outcome  
835 magnitude and social context effects has not previously been found. We believe floor effects are  
836 the most likely reason for the absence of a social context effect in trials with relatively bad  
837 outcomes. Nonetheless, it remains possible that deciding to act early could have altered the effect  
838 of social context on sense of agency, which could be explored in future studies. In the current  
839 task, response times were partially related to outcome magnitude, rendering it difficult to estimate  
840 the potentially specific role of response time on the effect of social context on sense of agency.

841 However, the task was designed such that the speed at which the balloon inflated varied both  
842 across and within trials, ensuring that there was no strict relationship between response time and  
843 outcome magnitude. Notably, there was no strong and consistent effect of social context on  
844 response times. Therefore, we do not think this is likely to be a significant confound for the  
845 effects observed here.

846 Further, we mostly tested female participants here. However, in a previous study with a balanced  
847 gender distribution, we found no evidence of gender effects (Beyer et al., 2017).

848



849 It remains to be tested whether this agency-reducing effect of social context depends on the  
850 nature of the interaction. In the present experiment, the interaction was semi-competitive. In  
851 situations where participants engage in a fully shared goal (e.g. joint action setups), or in which a  
852 clear rule-based strategy is offered (such as prescribed turn-taking), the effect of the other's  
853 presence on sense of agency might be absent or even reversed (cf. van der Wel, 2015).  
854 Relatedly, future studies could further address the potential role of perceived uncertainty of the  
855 alternative agent, as this may have differed between the social and non-social task groups in  
856 experiment 1. One possibility is manipulating the predictability of the co-player's behaviour, to  
857 assess whether a more random behavioural pattern affects sense of agency differently than a more  
858 strategic or predictable one.

859  
860 Sense of agency is related to a number of perceptual processes (Tsakiris & Haggard, 2005) and  
861 outcome monitoring (Bednark & Franz, 2014), and is thus presumed to play a crucial role in  
862 voluntary action. Previous research has largely focused on the benefits of social contexts to  
863 human cognition (Devaine et al., 2014; Vanlangendonck et al., 2018). This has neglected its  
864 potentially disruptive effects under some circumstances, as when social context reduces sense of  
865 agency and outcome monitoring (Beyer et al., 2017). Our findings have strong implications for  
866 common educational practices: reduced sense of agency in social contexts may likely affect  
867 feedback-driven learning, making a case for reduced peer influence on individual learning  
868 processes. Moreover, future studies should take into account interpersonal variability in the  
869 sensitivity to social cues, to better understand the role of mentalizing processes in learning from  
870 social feedback, and consequently on social development.

871

872 **Conclusions**

873 In the presence of other people, mentalizing processes can interfere with non-social aspects of  
874 human cognition. In two experiments, we show that the presence of others reduces sense of  
875 agency over gain and loss outcomes, and that this effect is specific to the presence of an  
876 intentional, social agent. Our findings suggest that the presence of other people can have  
877 fundamental effects on how we perceive our own actions and outcomes. This has important  
878 implications for our understanding of human behaviour in social environments. Even without an  
879 explicit motivation for self-serving displacement of responsibility, the presence of others can  
880 affect our subjective sense of agency. An anticipated lack of control might reduce an individual's  
881 motivation to take action in a social situation, while reduced outcome monitoring could be linked  
882 to reduced learning from action consequences. Thus, further studies should focus on the effects  
883 that a reduced sense of agency in social situations might have on subsequent learning and  
884 decision-making.

885

#### 886 **Open Practices**

887 Data is available in de-identified form on Open Science Framework (<https://osf.io/2s7kb/>).

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