1 **TITLE:** Detaching from influence in decision-making:
2 objective and subjective freedom of choice

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10 ABSTRACT

11 How much can people resist influence in choice? In this study, we explored participants'
12 abilities to voluntarily detach from irrelevant information to make free choices. Participants
13 saw random-dot-motion stimuli and a colour-cue indicating whether their response should be
14 congruent or incongruent with the direction of dot-motion. Importantly, in a third condition, the
15 colour-cue instructed participants to detach from dot-motion direction and to freely choose
16 how to respond. After each trial, participants rated how much they felt their decision was
17 influenced by the stimulus. Our results showed that participants conflated opposition and
18 independence: responses incongruent with the stimulus were systematically associated with
19 a greater sense of freedom and detachment, whether these responses were instructed or
20 made freely. Further, this effect seemed stronger in participants who tended to oppose the
21 stimulus more frequently. Taken together, these results suggest that feelings of freedom rely
22 on opposing suggestion and breaking from our habits.

23 1 INTRODUCTION

24 Human actions exhibit a “freedom from immediacy” (Shadlen & Gold, 2004), which refers to
25 the ability to organise behaviour so it is not driven merely by current stimulation. Thus, while
26 simpler actions such as reflexes may be the direct result of external stimulus triggers, voluntary
27 actions imply inhibiting such influences. While inhibition of prepotent responses has been
28 widely studied in psychology (Mischel & Baker, 1975; Stroop, 1935), there has been little
29 consideration of the *subjective* aspects of stimulus-independence, freedom of choice and
30 autonomy of voluntary action. Here, we focussed on the subjective experience of acting
31 independently of stimulation. We investigated whether the subjective experience of freedom
32 of choice accurately reflected participants’ ability to silence incoming information and to make
33 decisions unaffected by the stimulus environment.

34 The ability to direct attention towards some items in our sensory field and to ignore
35 others has been studied extensively (Cowan & Morey, 2006; Driver, 2001; He, Cavanagh, &
36 Intriligator, 1996; Treisman & Gelade, 1980). Active suppression of irrelevant information
37 contributes to action-selection processes (Caputo & Guerra, 1998). However, attentional
38 filtering is imperfect: when conflicting information requires that some visual inputs are ignored,
39 response time increases and accuracy decreases (Botvinick, Nystrom, Fissell, Carter, &
40 Cohen, 1999; Eriksen & Eriksen, 1974; Lu & Proctor, 1995; Munoz & Everling, 2004; Stroop,
41 1935). Conflict monitoring models have successfully described the processes whereby
42 effortful cognitive control allows detachment from part of the incoming sensory information. It
43 remains controversial however whether detachment involves simply filtering out unwanted
44 information, or actively suppressing it (Weldon et al., 2013). Thus, limited attentional resources
45 may limit the ability to resist unwanted influences on decision processes, and to decide
46 independently of such influences.

47 The effect of irrelevant and distracting information on our decisions has mostly been
48 studied with perceptual decision-making tasks. Only a handful of studies have tested whether
49 and how these effects extend to “free” choice tasks (Charles & Haggard, 2019; Schlaghecken
50 & Eimer, 2004; Sidarus & Haggard, 2016), in which participants decide for themselves how to
51 respond. In a recent paper, we addressed this question (Charles & Haggard, 2019) by asking
52 participants to perform a random-dot-motion discrimination task in which dot motion was either
53 predominantly unidirectional, prompting a response consistent with the dominant motion
54 direction, or predominantly bidirectional, prompting a free choice of how to respond. We found

that when participants chose ‘freely’, their responses were in fact biased by small, random fluctuations in the motion energy of the visual display shown on screen. This suggests that participants relied on this external information to break the symmetry between responses. Interestingly, participants remained unaware of this influence of sensory information on their “free” choices, since subjective ratings of freedom of choice did not accurately track the objective freedom measured as the degree to which responses were independent of stimulus energy.

Here, we investigated the subjective sense of freedom directly, by testing whether people can voluntarily detach from sensory influences, and whether people have accurate insight into the success of their attempts to detach. Twenty-two participants completed a random-dot motion discrimination task where the instructions on how to respond to the dots changed from trial to trial. Subjects were instructed on each trial to either *adhere* to the stimulus by responding in the direction congruent to the direction of dot motion, to *oppose* it by responding incongruently, or to *detach* from it and make a free choice independent of on the information on the screen. After each response, participants judged the extent to which their responses were independent of, or constrained by, the dot-motion stimulus. We found a modest ability to detach from sensory information, coupled with a strong tendency to feel freer when opposing stimulus information than when adhering to it.

73 2 METHOD

74 2.1 PARTICIPANTS

75 Twenty-two healthy participants (9 males; mean age of 22.59 years, range of 19-24 years)
76 took part in the present study having issued informed consent. This study was on data
77 powered to achieve a 95% chance of detecting a biasing influence of dot-motion on free
78 choices ($d = 0.74$ from Charles and Haggard, 2020) at an alpha of .05. Participants were
79 recruited via the UCL Institute of Cognitive Neuroscience participant pool, and all were
80 compensated for their time. The study was approved by the University College London
81 Department of Psychology Ethics Committee.

82 2.2 STIMULI

83 Stimuli were presented on a computer monitor with a refresh rate of 60Hz and appeared at a
84 5°-diameter aperture centred at the fixation point. Stimuli were random-dot-kinematograms
85 (RDM) of 7 dots moving consistently leftward or rightward (produced in psychtoolbox). The
86 dots were shown for a single frame before being replotted three frames later. When replotted,
87 a subset of the dots were offset from their previous location to produce apparently coherent
88 motion in one direction (to the right or to the left), whilst others were offset and plotted
89 randomly (see Roitman & Shadlen, 2002). To ensure a consistent level of difficulty over all
90 participants, motion coherence (i.e., the proportion of dots moving coherently relative to those
91 replotted randomly) was determined during an initial training session using a preliminary 2-
92 down-1-up staircase procedure (Levitt, 1971, see Methods AA) and was then fixed for the
93 duration of the experiment.

94 At one of three time-points during RDM presentation, the dots in the display changed colour.
95 RDM stimuli were displayed for a total of 2500ms (or 150 frames at 60 Hz), and the colour
96 change occurred randomly at either 650ms (Early), 1250ms (Mid), or 1900ms (Late). Dots
97 were initially presented as white on a black background, and could then change to be red,
98 green, or blue, these three colours being matched for luminance and contrast.

99 2.3 PROCEDURE & DESIGN

100 2.3.1 Staircase

101 The experiment started with an initial training block of 150 trials in which a 2-down-1-up
 102 staircase procedure (Levitt, 1971) was implemented, in order to find the level of motion
 103 coherence at which participants could perform at an accuracy level of 70.7%. Participants
 104 were instructed to respond if the motion was directed to the left or to the right. The coherence
 105 of the RDK stimulus started at a value of 40%, with an initial step size of 6%. The step-size
 106 was then halved every 2n runs until it reached a minimum value of 1.5%. The appropriate
 107 coherence level was computed by calculating the mean coherence over the final 40 trials of
 108 the block, and this coherence level was then set for the remainder of the experiment. For
 109 further detail, see supplementary materials.

110 2.3.2 Main Experiment

Figure 1 – Experimental protocol. After an initial fixation period a dot-motion stimulus was displayed in the centre of the screen for 2500ms with a predominant direction of motion either to the left or to the right. After a randomised variable delay (600ms, 1250ms or 1900ms), the dots changed color, indicating the response mode required. Participants could be asked to make a response congruent with the direction of the motion (adhere), to make a response incongruent with the direction of dot-motion (oppose), or to make a free choice whilst trying not to be influenced by the stimulus (detach). Participants had 1500ms to make a response following stimulus presentation. At the end of each trial, participants were required to rate their subjective freedom of choice, indicating whether they felt their choice was guided entirely by what they saw on the screen or whether they felt they decided independently how to act.

111 The main experiment consisted of 16 blocks of 63 trials. Participants performed the whole
 112 experiment in two sessions of 1.5hr, either on the same day, or on consecutive days. Each

trial started with a fixation cross presented at the centre of the screen for 900ms. The cross was then replaced by the RDM stimulus with dot-motion stimulus moving either to the *left* or to the *right* at random. At some point during the stimulus presentation, the dots changed colour. The colour provided instruction on how to respond to the stimulus on that trial. On (1) *adhere* trials, participants were to respond with the side congruent with the direction of the motion they perceived in the stimulus; on (2) *oppose* trials, participants were to respond with the opposite side than the perceived motion direction; on (3) *detach* trials, participants were to pick freely one button to press, their response choice trying not to be influenced by the direction of the dot motion. Instructions were randomised across trials. The colour change could occur at one of three randomised timings: *early* (600ms), *mid-way* through (1250ms), or *late* (1900ms). The colours used to specify the instructions were counterbalanced across participants (i.e. red, green, and blue cycled through instructing adherence, opposition, or detachment for successive participants). A second fixation cross appeared for 1500ms after the stimulus indicating time to respond. Participants were instructed to respond as accurately and as quickly as possible after stimulus presentation had ended. Following the response, participants were required to estimate how much their response choice was guided by the dot-motion, reporting their subjective experience of being more or less detached from the stimulus. To do so, a scale was presented for 3000ms and participants could move the slider with the '<' and '>' keys to reflect how they felt about their response. One end of the scale indicated absolute independence of the stimulus ('I decided what to do myself, completely independently of what I saw on the screen'), while the other indicated complete dependent on the stimulus ('My response was determined entirely by what I saw on the screen') (due to an error in the coding of the experiment, wording was slightly different for different participants, see supplementary materials for details). Participants were instructed to use the entire range of the scale rather than only the extreme values and that their response should be guided by how they came up with their response on that given trials rather than the instruction on that trial. The side of the scale indicating freedom/constraint was counterbalanced to the left/right over participants.

Therefore, our design was a 2x3x3 within-subjects design with factors *dot-motion direction* x *instruction* x *onset*, with 864 total trials of interest over 16 blocks. In each block, nine further "catch trials" were randomly interleaved. In these, movement coherence was increased to 65%, making the identification of the correct dot-motion direction a trivial task. Their purpose was to ensure that participants could accurately follow instructions to adhere, oppose, or detach, as given by their respective colour changes.

147 2.4 ANALYSIS

148 2.4.1 Measures of objective and subjective freedom of choice

149 Our experiment was designed to analyse both objective freedom of choice (i.e. the degree to
150 which participants were truly able to decide independently of the stimulus) and subjective
151 freedom of choice (i.e. the degree to which participants *felt* they were able to act freely of any
152 influence by the stimulus). Responses could be of two possible types: (1) *pro-responses* were
153 those congruent to the dominant dot-motion direction for a given trial, and (2) *anti-responses*
154 were those incongruent to the dominant dot-motion direction. Our analyses of subjective
155 freedom of choice involved an analysis of self-reported estimates of freedom according to
156 instruction, instruction onset time, and response type (all of which are within-subject factors).
157 Our analyses of objective freedom of choice centred on two dependent measures: (1) the
158 proportion of responses made congruent to motion direction for each instruction, and (2) our
159 measure of the association between different response types and stimulus strength (see
160 below). Our two objective measures of freedom of choice were analysed according to the
161 same factors (instruction, onset time, and response type). Regressions were performed to test
162 whether differences in subjective freedom of choice could be explained by differences in
163 objective performance (i.e. in the proportion of motion congruence, in response time, and in
164 reverse correlated motion energy).

165 2.4.2 Motion energy analysis

166 We intended to investigate the correspondence between the strength of the information
167 present in the stimulus and subsequent responses, providing an objective measure of freedom
168 of choice. To do this, we first applied spatiotemporal motion filters to dot position over time to
169 compute motion energy time-courses for each trial (Adelson & Bergen, 1985; Kiani, Hanks, &
170 Shadlen, 2008). This process produced a 140-sample time-course of motion energy (having
171 removed 28 initial/final samples affected by the ramping of the motion energy filter) where
172 positive values corresponds to rightward motion. These values were collapsed across trials
173 and across time, producing motion energy distributions as seen in Figure 2A. Leftward trials
174 were sign-flipped, so that all values would represent the magnitude of motion energy in favour
175 of the dominant motion direction (with negative values representing the magnitude of motion
176 energy in opposition to the dominant motion direction, see Figure 2B). These values were then
177 expressed as z-scores using the overall mean and standard deviation of the distribution,
178 ensuring even and comparable amplitudes across participants (see Figure 2C). Finally, we
179 reverse correlated these normalised distributions according to response type (Figure 2D),
180 sorting individual samples of motion energy according to whether they were followed by a pro-

181 (congruent with the stimulus direction) or an anti- (incongruent with stimulus direction)
 182 response. From these reverse correlated motion energy distributions, we could compute the

Figure 2 – Analysis pipeline for motion energy data. To obtain an objective measure of freedom of choice, we reverse correlated the strength of the signal depicted, ie motion energy, to the response choice. Computing the motion energy from dot coordinates for each trial allowed us to produce two motion energy distributions, one corresponding to left-moving dot-motion stimuli, and one right-moving dot-motion stimuli (A). We then flipped the sign of the negatively-centred distribution resulting in a single motion energy distribution where more positive values represent stronger motion energy in favour of the dominant motion direction, and more negative values represent stronger motion energy in opposition to the dominant motion direction (B). These sign-flipped distributions were then normalised (C), and individual motion energy values were then sorted according to whether they were followed by a pro- (congruent with dominant motion direction) or anti-response (incongruent with dominant motion direction).

183 mean motion energies associated with pro- and anti-responses. The reverse correlated
 184 motion-energy values were then averaged separately for each condition and each
 185 participant and analysed with repeated measure analysis of variance (rANOVA) and paired t
 186 tests (two-tailed, unless specified otherwise) in R.

188 2.6 ACCURACY & RESPONSE MODE UNDER DETACHMENT

189 We first inspected participants' ability to follow and complete the task for each instruction.
190 When asked to adhere to or oppose dot motion, participants generally responded correctly.
191 Figure 3 shows 67.74% (SD = 6.36) of congruent responses on adhere trials, and 34.00% (SD
192 = 8.18%) on oppose trials. These values are predicted from the staircase procedure used to
193 set individual coherence levels. We found no significant difference in accuracy between these
194 two instructed conditions ($F(1, 21) = 4.01, p = .058, \eta_G^2 = 0.015$). We did however find a main
195 effect of instruction onset time ($F(2, 42) = 6.91, p = .003, \eta_G^2 = 0.034$); accuracy dropped
196 when instruction came late relative to both early ($t(21) = 3.24, p = .004, d = 0.77$) or midway
197 through ($t(21) = 2.74, p = .012, d = 0.63$) stimulus presentation. Adhere responses were
198 faster than oppose responses ($F(1, 21) = 6.67, p = .017, \eta_G^2 = 0.015$). A significant effect of
199 instruction time was also observed ($F(2, 42) = 150.77, p < .001, \eta_G^2 = 0.089$); participants
200 responded faster to later instructions (see Supplementary Material for more details).

Figure 3 – Proportion of motion congruent responses made in response to each instruction (green: adhere, red: oppose; blue: detach) and each instruction onset time (x-axis: Early, Mid, Late). Individual points represent each participant's mean proportion of motion-congruent response. Thick horizontal lines represent the population mean. Boxes represent the interquartile range, with the mid-line representing the median. The whiskers extend from the 1st and 3rd quartiles to the smallest and largest values within 1.5*IQR, with any values beyond this being as outliers.

We next considered participants' responses when they were instructed to detach from the stimulus. Across all participants, there was no bias to respond right or left ($t(21) = -0.02$, $p = .983$). More importantly, although there was some variability in the proportion of motion-congruent responses on detach trials, there was no general population-level bias in either direction (i.e., the proportion of motion congruent responses did not differ from chance level of 0.5, $t(21) = -0.20$, $p = .842$). Analysis of the number of motion-congruent responses made by each participant found no deviation from the chance level of .5 (for all 22 Bonferroni-corrected Chi-squared tests against expected frequencies of .5, none reached significance), suggesting that participants had some ability to detach from the stimulus.

2.7 SUBJECTIVE FREEDOM OF CHOICE

Next, we considered participants' subjective experience of freedom of choice, based on participants' estimates of stimulus-independence after each trial. Unsurprisingly, subjective freedom of choice was higher for detach than for instructed trials (main effect of instruction, $F(2, 42) = 66.31$, $p < .001$, $\eta_G^2 = 0.703$; detach > adhere, $t(21) = 9.00$, $p < .001$, $d = 2.60$; detach > oppose, $t(21) = 7.45$, $p < .001$, $d = 1.98$); people felt freer when allowed to decide freely what to respond than when instructed to respond by adhering or opposing dot-motion.

Within the instructed trials (adhere and oppose), we found significant effects of instructions on subjective reports of freedom of choice. Participants reported an increased subjective sense of freedom on oppose trials than on adhere trials ($t(21) = 4.83$, $p < .001$, $d = 0.92$). This effect could not be explained by differences in proportion of correct choices between conditions, as no significant difference in accuracy was observed between the two conditions. A control analysis regressing differences in reported subjective freedom of choice between adhere and oppose trials on differences in accuracy and response time between these two instructions confirmed that the increased sense of freedom when opposing was still present after accounting for differences in performance between the two conditions ($b_{\text{instruction}} = 5.48$, $t(19) = 1.45$, $p = .002$). However, accuracy was related to subjective

Figure 4 – Mean subjective ratings of freedom of choice per participant for each instruction (green: adhere; red: oppose; blue: detach) and response type (pro-responses: top row per instruction, full circles; anti-responses: second row per instruction, hollow circles). Pro- and anti-response means are connected for individual participants within each instruction condition. Means were computed for each participant and each condition, collapsing over all instruction timings (as timing had no effect on ratings).

freedom of choice – we observed an interaction between response type and instruction ($F(2, 42) = 13.75, p < .001, \eta^2_G = 0.022$), revealing a tendency to report greater freedom for incorrect responses (adhere-incorrect > adhere-correct, $t(21) = 4.92, p < .001, d = 1.13$; oppose-incorrect > oppose-correct, $t(21) = 3.68, p = .001, d = 0.77$). This might arise because incorrect responses are likely to be associated with reduced attention to the stimulus display. No effect of instruction timing was observed on subjective freedom of choice ratings ($F(2, 42) = 1.71, p = .193$).

We then focussed on the Detach condition. We found that within detach trials, participants experienced greater freedom for anti-responses than pro-responses ($t(21) = 2.54, p = .019, d = 0.71$). The response was freely chosen in both of these cases, but where the choice happened to oppose dot motion, the subjective sense of freedom of choice was greater. This effect was not due to anti-responses having longer reaction times, as RT was

not predictive of differences in subjective freedom of choice and the effect remained when including RT as a predictor in the regression ($b_{\text{response type}} = -3.94$, $t(20) = 2.38$, $p = .027$; $b_{\text{response time}} = 0.01$, $t(20) = 0.17$, $p = .865$).

In sum, we found a strong and general tendency to associate opposition with a greater sense of freedom; responses on oppose trials were judged to be freer than responses on adhere trials, and participants felt freer on those detach trials where their responses opposed the dot-motion, rather than adhering to it.

2.8 CORRELATION BETWEEN SUBJECTIVE AND OBJECTIVE FREEDOM OF CHOICE

Our results suggested that our participants tended to subjectively mistake opposition for detachment. We tested whether the frequency of responses that adhered to or opposed dot motion on detach trials for each individual participant could explain differences in subjective judgments of freedom for these two types of responses.

Figure 7 – Correlation between the proportion of motion congruent responses in the detach condition (x-axis) and the difference in subjective freedom of choice for motion incongruent and motion congruent responses on detach trials (y-axis). More positive values on the y-axis indicate a greater sense of freedom when opposing the stimulus than when adhering to it, and more negative values indicate a greater sense of freedom when adhering to the stimulus than when opposing it.

To test this we computed Pearson correlation coefficients between the difference in self-reported freedom of choice for motion-congruent and motion-incongruent responses and the difference in the proportion of motion congruent responses and motion incongruent responses in the detach condition (Figure 7). Interestingly, we observed a significant positive correlation

between the difference in subjective freedom reported for motion congruent and motion-incongruent responses and the bias towards motion congruent responses ($r = 0.42, p = .049$). Participants who made more congruent responses tended to report greater freedom when making an incongruent response. This suggests that breaking from a habitual mode of response was associated with increased freedom. Importantly however, we observed that even when regressing out the effect of habit on response, there was still a significant increase in freedom of choice associated with opposing the stimulus, as demonstrated by a positive intercept in the regression ($t(20) = -2.81, p = .011$). This confirmed that there was an intrinsic link between opposition and freedom that could not be solely explained by the fact that opposition was rarer than adherence.

2.9 INFLUENCE OF SIGNAL STRENGTH ON RESPONSE CHOICE

We found that although our participants on the whole held no bias for opposing or adhering to the stimulus when required to detach, they associated a greater sense of freedom with responses that opposed the information shown on screen. In a final set of analysis, we further explored differences between pro- and anti-responses, with the aim of understanding what influenced response choice when required to detach. To do this, we investigated how signal strength impacted participants' tendency to adhere to or oppose the stimulus. Our stimuli involved continuous fluctuations of motion energy. We could therefore use reverse correlation analysis to determine the strength of the motion energy information present in the stimulus that preceded pro- vs anti-responses. The analysis pipeline used to generate this measure can be seen on Figure 2 and is described in the associated methods section.

Unsurprisingly, in instructed trials, correct responses (pro-responses on adhere trials, and anti-responses on oppose trials) were associated with signal strengths above the global stimulus mean. Conversely, incorrect responses were associated with signal strengths below the normalised mean in both conditions (interaction between instruction and response type, $F(1, 21) = 65.18$, $p < .001$, $\eta_G^2 = 0.167$; adhere-correct > adhere-incorrect, $t(21) = 4.69$, $p < .001$, $d = 0.82$; oppose-correct > oppose-incorrect, $t(21) = 6.10$, $p < .001$, $d = 1.12$). These results confirm that trial-by-trial fluctuations in stimulus strength did, as expected, influence response accuracy in instructed trials. Note that no effect of instruction timing was observed ($F(2, 42) = 0.07$, $p = .934$).

Figure 6 – Motion energy values for each instruction (green: adhere; red: oppose; blue: detach) and response type (pro-responses: dark shade; anti-responses: light shade) across subjects. Dotted horizontal line represent the stimulus mean motion energy value across all trials. Large dots represent mean signal strength across participants for each condition and response type. Small dots represent mean signal strength for each participant, each instruction, and each response type.

We then considered how signal strength influenced response choice in detach trials. Surprisingly, we observed that the relationship between signal strength and response type for those trials qualitatively resembled that seen in the oppose condition. That is, anti-response trials had high mean signal strengths, while pro-response trials had lower and more broadly distributed mean signal strengths. However, this difference showed only a trend towards significance: $F(1, 21) = 3.25$, $p = .086$). This hints at a tendency to, when required to detach, oppose perceptual signals that are particularly strong and salient and, conversely, adhere to signals of weaker strength, though this effect requires confirmation.

294 In the present study, we investigated the ability to detach from incoming sensory information
295 and make choices free of influence. We asked participants to respond to a dot motion stimulus
296 by making a response congruent to the direction of dot-motion (adhere), in opposition to the
297 direction of dot-motion (oppose), or to make a response independent of the stimulus by
298 detaching from the information presented to them (detach). By then asking for subjective
299 ratings of freedom of choice, we could estimate not only participants' objective ability to resist
300 immediate suggestion, but also their ability to introspect their success in doing so. We found
301 a strong and general tendency to experience a greater sense of freedom when opposing
302 sensory information than when adhering to it, whether opposition was instructed or was the
303 result of the participant's own choice when they were to detach from the stimulus.

304 Only a few experimental studies have investigated the origins of subjective sense of
305 freedom (Charles & Haggard, 2019; Filevich et al., 2013), despite its major, even constitutive,
306 role in individual mental life. The idea that apparently autonomous decisions are influenced
307 by many subtle factors has been widespread in modern psychology (Packard, 1957; Sunstein,
308 2015; Wilkinson, 2013), but subjective aspects of such influence have been neglected. In a
309 previous study (Charles & Haggard, 2019), we found that when instructed to make a free
310 choice, participants' decisions tended to follow fluctuations in the stimulus, but that participants
311 reported higher subjective freedom when their responses opposed the direction of dot-motion.
312 One interpretation of these findings is that inhibition of a prepotent stimulus-response
313 association in favour of a less habitual response boosts the experience of freedom. The results
314 of the present study replicate and extend these findings. We here introduced adhere, oppose,
315 and detach conditions that established two stimulus-response mappings (of equal strength)
316 and allowed us to test the subjective and objective ability to detach from the stimulus and the
317 established modes of response. We found a general tendency to feel freer when opposing the
318 stimulus than when adhering to it. This was true both when opposition was instructed (on
319 oppose trials) and self-generated (on detach trials). The bias to feel freer when opposing was
320 not simply due to less frequent choices feeling more free; even after accounting for effects of
321 response frequency within the detach condition, we still found increased subjective freedom
322 for responses that opposed dot-motion compared to those that followed it. It may be the case
323 that adherence is in some sense a default mode of response to the world and inhibiting our
324 tendency to follow instruction (by opposing it) boosts our sense of freedom. There may
325 therefore be an intrinsic relationship between response inhibition and the subjective

experience of freedom, consistent with the long-held idea that inhibition is central to the experience of voluntary control (Mayr, 2004).

We also found tentative evidence to support the idea that our subjects mistook opposition for detachment when deciding how to act in the detach condition. Our investigation of how participants responded to signals of different strengths revealed that where participants were required to detach, they tended to oppose stronger signals and adhere to weaker signals. There are two possible interpretation of this influence of stimulus strength on free choice. First, participants may discard sensory information from decision-making processes, but particularly strong signals may nevertheless leak into decision making and influence choice. This would be consistent with the directed forgetting literature (Anderson & Hanslmayr, 2014; Anderson et al., 2004; Yang, Lei, & Anderson, 2016) where the erasure of information from memory is more efficient for weak compared to stronger content. Alternatively, people may be unable to discard sensory information at all and their response strategy when instructed to detach might be slightly biased towards opposition. Being unable to discard sensory information would extend priming of free choice responses (Eimer & Schlaghecken, 2003; Parkinson & Haggard, 2014) by subliminally presented information to include biasing by supraliminal sensory information. However, we found no evidence supporting simple methods of shifting response strategies on detach trials and positing more complex methods seems unparsimonious. We therefore suggest that people have some ability to detach from incoming sensory information, though their success in doing so may depend on strength of incoming information (Koizumi, Maniscalco, & Lau, 2015). Since the trend to oppose when required to detach was weak in our data, further research will be required to verify these effects.

We were interested here not only in subjective and objective freedom alone, but in the degree to which our subjective experience of freedom accurately tracks our objective ability to be free. Previous research suggests that people may have relatively poor insight into the extent to which their decisions have been influenced by external information (Charles & Haggard, 2019). For example, subliminal primes influence behaviour, but also increase the subjective sense of control over one's actions (Wenke, Fleming, & Haggard, 2010). We observed that the sense of freedom of choice was influenced by the frequency of a particular response, with the inhibition of frequent responses being associated with a boosted sense of freedom. This suggests that we are able to track our own habits, and that our subjective experience of freedom is in part based on our ability to inhibit and be free of those habits. This would then mean that our experience of freedom is not some function of our environment alone, but that it is given by how we deal with our habitual responses to input. Feeling that we

are free of influence depends upon whether acting free of influence requires us to inhibit some dominant mapping of stimulus to action. This is not necessarily illusory in a general sense, though deriving feelings of freedom from inhibition can lead to illusory boosts in freedom as demonstrated by the boosted freedom we found when instructing participants to oppose dot-motion. Follow-up studies should help clarify what form these stimulus-response mappings take, how and why their inhibition boosts our sense of freedom, and how this can lead to metacognitive illusions of freedom of choice.

More generally, further research is needed to achieve a more precise understanding of how free choices are made and to provide a more mechanistic description of the processes involved that might explain the possible preference for opposition when attempting to detach from influence. Conflict monitoring models (Yeung, Botvinick, & Cohen, 2004) describe how irrelevant information is silenced by attentional processes in favour of decision-relevant information. However, in those models, choice is still dictated by external evidence rather than being internally generated as here. Models of evidence accumulation (Mulder, van Maanen, & Forstmann, 2014) may provide a stronger theoretical framework to describe the present task. Indeed, some authors have proposed that accumulation of internal neural noise could be an effective way to model free choices, providing a mechanism for breaking the symmetry between options and for deciding when and how to act in the absence of external information (Schurger, Sitt, & Dehaene, 2012). Such models could potentially be extended to capture how successfully agents discard information they wish to ignore and may speak to any real tendency to oppose information we mean to discard. This will require meaningful response time data, which the present task design precluded.

Being able to detach from our immediate environments is a centrally important feature of human mental life – in order to exercise voluntary agency, we must be able to ignore triggers to act. Habitual opposition is commonly seen in adolescent behaviour (Laursen & Collins, 1994), and this may be seen as an affirmation of independence and autonomy in light of our findings. More broadly, it is important to understand how and why people feel that they are making free and independent decisions in some situations but not in others, understanding the accuracy of those judgment on their own freedom of choice. In a world filled with ever-more subtle attempts at influence and coercion (Sunstein, 2017; Wilkinson, 2013), it is more vital than ever that we understand how we detach from unhelpful or unwanted information and whether we are aware of when we fail to act truly autonomously.

ACKNOWLEDGEMENT

This work was supported by a European Research Council Advanced Grant (HUMVOL, agreement number 323943) to P.H. and a Postdoctoral Fellowship from the British Academy to L.C. We thank Eoin Travers for his help with analysis.

AUTHOR CONTRIBUTIONS

G.W. contributed to designing the experiment, testing participants, analyzing data and writing the manuscript. P.H. and L.H. contributed to designing the experiment, analyzing data and writing the manuscript.

DECLARATION OF CONFLICTING INTERESTS

The authors declare there is no conflict of interests.

405 REFERENCES

- 406 Adelson, E. H., & Bergen, J. R. (1985). Spatiotemporal energy models for the perception of
407 motion. *Journal of the Optical Society of America A*, 2(2), 284.
408 <https://doi.org/10.1364/JOSAA.2.000284>
- 409 Anderson, M. C., & Hanslmayr, S. (2014). Neural mechanisms of motivated forgetting. *Trends*
410 *in Cognitive Sciences*. <https://doi.org/10.1016/j.tics.2014.03.002>
- 411 Anderson, M. C., Ochsner, K. N., Kuhl, B., Cooper, J., Robertson, E., Gabrieli, S. W., ...
412 Gabrieli, J. D. E. (2004). Neural Systems Underlying the Suppression of Unwanted
413 Memories. *Science*. <https://doi.org/10.1126/science.1089504>
- 414 Botvinick, M., Nystrom, L. E., Fissell, K., Carter, C. S., & Cohen, J. D. (1999). Conflict
415 monitoring versus selection-for-action in anterior cingulate cortex. *Nature*, 402(6758),
416 179–181. <https://doi.org/10.1038/46035>
- 417 Caputo, G., & Guerra, S. (1998). Attentional selection by distractor suppression. *Vision*
418 *Research*, 38(5), 669–689. [https://doi.org/10.1016/S0042-6989\(97\)00189-2](https://doi.org/10.1016/S0042-6989(97)00189-2)
- 419 Charles, L., & Haggard, P. (2019). Feeling free: External influences on endogenous behaviour.
420 *Quarterly Journal of Experimental Psychology*, 174702181988806.
421 <https://doi.org/10.1177/1747021819888066>
- 422 Cowan, N., & Morey, C. C. (2006). Visual working memory depends on attentional filtering.
423 *Trends in Cognitive Sciences*. <https://doi.org/10.1016/j.tics.2006.02.001>
- 424 Driver, J. (2001). A selective review of selective attention research from the past century.
425 *British Journal of Psychology*, 92, 53–78.
- 426 Eimer, M., & Schlaghecken, F. (2003). Response facilitation and inhibition in subliminal
427 priming. *Biological Psychology*. [https://doi.org/10.1016/S0301-0511\(03\)00100-5](https://doi.org/10.1016/S0301-0511(03)00100-5)
- 428 Eriksen, B. A., & Eriksen, C. W. (1974). Effects of noise letters upon the identification of a

429 target letter in a nonsearch task. *Perception & Psychophysics*.
430 <https://doi.org/10.3758/BF03203267>

431 Filevich, E., Vanneste, P., Brass, M., Fias, W., Haggard, P., & Kühn, S. (2013). Brain
432 correlates of subjective freedom of choice. *Consciousness and Cognition*, 22(4), 1271–
433 1284. <https://doi.org/10.1016/J.CONCOG.2013.08.011>

434 Haggard, P. (2019). The Neurocognitive Bases of Human Volition. *Annual Review of*
435 *Psychology*, 70(1), annurev-psych-010418-103348. [https://doi.org/10.1146/annurev-](https://doi.org/10.1146/annurev-psych-010418-103348)
436 [psych-010418-103348](https://doi.org/10.1146/annurev-psych-010418-103348)

437 He, S., Cavanagh, P., & Intriligator, J. (1996). Attentional resolution and the locus of visual
438 awareness. *Nature*. <https://doi.org/10.1038/383334a0>

439 Kiani, R., Hanks, T. D., & Shadlen, M. N. (2008). Bounded Integration in Parietal Cortex
440 Underlies Decisions Even When Viewing Duration Is Dictated by the Environment.
441 *Journal of Neuroscience*, 28(12), 3017–3029.
442 <https://doi.org/10.1523/JNEUROSCI.4761-07.2008>

443 Koizumi, A., Maniscalco, B., & Lau, H. C. (2015). Does perceptual confidence facilitate
444 cognitive control? *Attention, Perception, and Psychophysics*, 77(4), 1295–1306.
445 <https://doi.org/10.3758/s13414-015-0843-3>

446 Laursen, B., & Collins, W. A. (1994). Interpersonal Conflict During Adolescence. *Psychological*
447 *Bulletin*. <https://doi.org/10.1037/0033-2909.115.2.197>

448 Levitt, H. (1971). Transformed up- down methods in psychoacoustics. *Journal of the Acoustics*
449 *Society of America*. <https://doi.org/10.1121/1.1912375>

450 Lu, C.-H., & Proctor, R. W. (1995). of the Simon and spatial Stroop effects. *Psychonomic*
451 *Bulletin & Review*, 2(2), 174–207.

452 Mayr, U. (2004). Conflict, consciousness, and control. *Trends in Cognitive Sciences*, 8(4),
453 145–148. <https://doi.org/10.1016/j.tics.2004.02.006>

- 454 Mischel, W., & Baker, N. (1975). Cognitive appraisals and transformations in delay behavior.
455 *Journal of Personality and Social Psychology*. <https://doi.org/10.1037/h0076272>
- 456 Mulder, M. J., van Maanen, L., & Forstmann, B. U. (2014). Perceptual decision neurosciences
457 - a model-based review. *Neuroscience*.
458 <https://doi.org/10.1016/j.neuroscience.2014.07.031>
- 459 Munoz, D. P., & Everling, S. (2004). Look away: The anti-saccade task and the voluntary
460 control of eye movement. *Nature Reviews Neuroscience*.
461 <https://doi.org/10.1038/nrn1345>
- 462 Packard, V. (1957). *The hidden persuaders*. Retrieved from
463 <http://www.normadiconline.com/the/the-hidden-persuaders-1.pdf>
- 464 Parkinson, J., & Haggard, P. (2014). Subliminal priming of intentional inhibition. *Cognition*,
465 130(2), 255–265. <https://doi.org/10.1016/j.cognition.2013.11.005>
- 466 Roitman, J. D., & Shadlen, M. N. (2002). Response of neurons in the lateral intraparietal area
467 during a combined visual discrimination reaction time task. *The Journal of Neuroscience*,
468 22(21), 9475–9489. [https://doi.org/10.1016/S0377-2217\(02\)00363-6](https://doi.org/10.1016/S0377-2217(02)00363-6)
- 469 Schlaghecken, F., & Eimer, M. (2004). Masked prime stimuli can bias “free” choices between
470 response alternatives. *Psychonomic Bulletin & Review*, 11(3), 463–468.
471 <https://doi.org/10.3758/BF03196596>
- 472 Schurger, A., Sitt, J. D., & Dehaene, S. (2012). An accumulator model for spontaneous neural
473 activity prior to self-initiated movement. *Proceedings of the National Academy of*
474 *Sciences*, 109(42), E2904–E2913. <https://doi.org/10.1073/pnas.1210467109>
- 475 Shadlen, M. N., & Gold, J. I. (2004). The neurophysiology of decision-making as a window on
476 cognition BT - The Cognitive Neurosciences. *The Cognitive Neurosciences*, 1229–1241.
477 Retrieved from
478 [https://groups.oist.jp/sites/default/files/img/ocnc/2004/Shadlen.pdf%5Cnpapers3://public](https://groups.oist.jp/sites/default/files/img/ocnc/2004/Shadlen.pdf%5Cnpapers3://publication/uuid/69127C42-5657-4129-8220-FE1F59F14EF8)
479 [ation/uuid/69127C42-5657-4129-8220-FE1F59F14EF8](https://groups.oist.jp/sites/default/files/img/ocnc/2004/Shadlen.pdf%5Cnpapers3://publication/uuid/69127C42-5657-4129-8220-FE1F59F14EF8)

- 480 Sidarus, N., & Haggard, P. (2016). Difficult action decisions reduce the sense of agency: A
481 study using the Eriksen flanker task. *Acta Psychologica*, 166, 1–11.
482 <https://doi.org/10.1016/J.ACTPSY.2016.03.003>
- 483 Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental*
484 *Psychology*. <https://doi.org/10.1037/h0054651>
- 485 Sunstein, C. R. (2015). The Ethics of Nudging. *Yale Journal on Regulation*, 32. Retrieved from
486 [https://heinonline.org/HOL/Page?handle=hein.journals/yjor32&id=419&div=16&collectio](https://heinonline.org/HOL/Page?handle=hein.journals/yjor32&id=419&div=16&collection=journals)
487 [n=journals](https://heinonline.org/HOL/Page?handle=hein.journals/yjor32&id=419&div=16&collection=journals)
- 488 Sunstein, C. R. (2017). Misconceptions About Nudges. *SSRN Electronic Journal*.
489 <https://doi.org/10.2139/ssrn.3033101>
- 490 Treisman, A. M., & Gelade, G. (1980). A feature-integration theory of attention. *Cognitive*
491 *Psychology*. [https://doi.org/10.1016/0010-0285\(80\)90005-5](https://doi.org/10.1016/0010-0285(80)90005-5)
- 492 Weldon, R. B., Mushlin, H., Kim, B., & Sohn, M. H. (2013). The effect of working memory
493 capacity on conflict monitoring. *Acta Psychologica*.
494 <https://doi.org/10.1016/j.actpsy.2012.10.002>
- 495 Wenke, D., Fleming, S., & Haggard, P. (2010). Subliminal priming of actions influences sense
496 of control over effects of action. *Cognition*, 115(1), 26–38.
497 <https://doi.org/10.1016/J.COGNITION.2009.10.016>
- 498 Wilkinson, T. M. (2013). Nudging and manipulation. *Political Studies*, 61(2), 341–355.
499 <https://doi.org/10.1111/j.1467-9248.2012.00974.x>
- 500 Yang, T., Lei, X., & Anderson, M. (2016). Decreased inhibitory control of negative information
501 in directed forgetting. *International Journal of Psychophysiology*.
502 <https://doi.org/10.1016/j.ijpsycho.2015.09.007>
- 503 Yeung, N., Botvinick, M., & Cohen, J. D. (2004). The neural basis of error detection: Conflict
504 monitoring and the error-related negativity. *Psychological Review*, 111(4), 931–959.

505 <https://doi.org/10.1037/0033-295X.111.4.931>

506