Mistaking opposition for autonomy: psychophysical studies on detecting choice bias

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15 ABSTRACT (200 WORDS LIMIT)

16 Do people know when they act freely and autonomously versus when their actions are
17 influenced? While the human aspiration to freedom is widespread, little research has
18 investigated how people perceive whether their choices are biased. Here, we explored how
19 actions congruent or incongruent with suggestions are perceived as influenced or free. Across
20 three experiments, participants saw directional stimuli cueing left or right manual responses.
21 They were instructed to follow the cue's suggestion, oppose it, or ignore it entirely to make a
22 'free' choice. We found that we could bias participants' 'free responses' towards adherence or
23 opposition, by making one instruction more frequent than the other. Strikingly, participants
24 consistently reported feeling less influenced by cues to which they responded incongruently,
25 even when response habits effectively biased them towards such opposition behaviour. This
26 effect was so compelling that cues that were frequently presented with the *Oppose* instruction
27 became systematically judged as having less influence on behaviour, artificially increasing the
28 sense of freedom of choice. Taken together, these findings demonstrate that acting contrarian
29 distorts the perception of autonomy. Crucially, we demonstrate the existence of a novel illusion
30 of freedom evoked by trained opposition. Our results have important implications for
31 understanding mechanisms of persuasion.

INTRODUCTION

How much do we know about the true reasons for our choices, and about the causes of our decisions? Can we truly estimate if our choices are influenced by external factors?

Research in psychology has long demonstrated the limits of our voluntary control over our decisions: choices can be swayed by factors beyond our control, and beyond our awareness. For example, we may struggle to ignore sensory inputs even when we know these are irrelevant for the decision, and try to ignore them. This is true when visual attention is captured by distractors presented in proximity to the relevant evidence for instance, or when such distractors present similarities with the target information (e.g. Eriksen Flanker Task, Eriksen & Eriksen, 1974). Similarly, information embedded in a stimulus can create interference in the decision process, as shown in the Stroop task (Stroop, 1935) and its variants (e.g. Henik & Tzelgov, 1982; Williams, Mathews, & MacLeod, 1996). Such distractor effects are also observed for non-conscious information. When a target stimulus is preceded by a non-conscious prime stimulus, the participant's response latency, accuracy and choice can all be affected by the prime (Schlaghecken & Eimer, 2004).

Decisions are not only influenced by current information, but also by previous stimulation and previous responses. Learned stimulus-response associations influence future performance (Pavlov, 1927, Rushworth, Passingham, & Nobre, 2002), and simple response repetition also biases current choices (Lages, Boyle, & Jaworska, 2013; Lages & Jaworska, 2012). This influence of past behaviour continues even when it becomes irrelevant or unrewarding, and can only be overcome through additional cognitive control resources (Botvinick, Braver, Barch, Carter, & Cohen, 2001; Goschke, 2003). This is illustrated in task switching paradigms in which participants frequently stick with the response they performed on the previous trial rather than use the response mapping required for the present trial (Arrington & Logan, 2004). This effect is amplified if participants are under high cognitive load, and also if a stimulus is repeated across trials (Demanet, Verbruggen, Liefvooghe, & Vandierendonck, 2010).

While the mechanisms of unwanted influence on choice behaviour have been well documented (Newell & Shanks, 2014) and formally modelled (Lavie, 2010), it remains unclear whether people are able to detect when their choices are biased by such influences. Research in social psychology suggests that people are mostly unaware of the underlying drivers of their decisions (Epstein & Robertson, 2015; Pronin, Lin, & Ross, 2002). Even when participants are conscious of using biased strategies in their decisions, feelings of objectivity prevail (Hansen, Gerbasi, Todorov, Kruse, & Pronin, 2014). Equally, one might feel that extraneous influences are present even when they are not – as during “thought insertion” in psychosis (Frith, 2005). In other words, introspective access to our own decision-making process may be limited. The possibility that individuals are biased without recognising the fact is clearly relevant to understanding individual cognitive autonomy. For example, one's choices might be influenced by some extraneous influence, yet feel authentically one's own, with major social and political implications (Duster, 2008).

Although “decision priming”, whether subliminal or not, has attracted wide scientific interest, surprisingly few studies have systematically investigated the subjective experience of whether

one's decisions are influenced by external information or not. When participants were shown ambiguous random dot kinematograms (RDK) and asked to respond 'freely', their actions were unsurprisingly influenced by small fluctuations in motion energy (Charles and Haggard, 2019). More strikingly, when participants were asked to report their subjective feeling of freedom and independence from the stimulus display on each trial, participants reported being less influenced on trials in which their choice was incongruent with the visual motion information. Hence, a dissociation between objective and subjective freedom of choice (FoC) was evident (Filevich et al., 2013): not only were participants influenced by a stimulus without detecting this influence, but they also experienced an increased sense of autonomy when they opposed the stimulus.

In the present study, we have systematically investigated this link between opposition and subjective freedom. In particular, we aimed at testing whether the increased sense of autonomy observed when opposing a stimulus (Charles & Haggard, 2019) was affected by the objective tendency to respond congruently or incongruently to cues. Across three experiments, we presented participants with random-dot kinematogram stimuli in which the majority of dots moved either leftward or rightward. Each display was accompanied by one of three instructions: to respond congruently to the direction of the motion (Adhere condition), incongruently to it (Oppose condition), or to make a free choice independent of the motion direction (Detach condition). Crucially, in the detach condition, participants were explicitly told not to be influenced in their response choice by the visual display. Thus, we could measure both the extent to which participants successfully ignored stimulus information (by quantifying the objective statistical relation between stimuli and response), and also their ability to introspect this stimulus-independence (by obtaining ratings of subjective freedom of choice).

We then used a structured series of experimental manipulations to investigate the cognitive basis underlying the sense of acting freely. In experiment 1, we presented participants more frequently with one instruction (Adhere or Oppose) than the other, to test if a learned response strategy would bias free choices. In experiment 2, we more specifically associated one direction of motion (left or right RDK stimuli) with one instruction (Adhere or Oppose) to test how using repeatedly one stimulus-response association would affect the perceived influence of that stimulus on behaviour. Finally in experiment 3, we increased the proportions of one direction of motion to test how the repetition of one visual cue would affect how participants perceived their freedom of choice when responding to it. To anticipate on the results, we found that, using a stimulus-response association repeatedly significantly reduced the objective ability to detach, participants preserving using the learned behaviour when attempting to make free responses. Strikingly, we found participants systematically reported feeling freer when acting contrary to the response suggested by the stimulus. This association between opposition and freedom persisted even when participants learned opposition as the habitual response strategy, suggesting an intrinsic increase in the sense of autonomy caused by opposition. Finally, we found that stimuli that were frequently opposed caused a subsequent boost in the sense of freedom when seen again, irrespective of the response they elicited. This suggests that false sense of autonomy can be evoked by trained opposition.

RESULTS

In three experiments, participants were presented with random dot kinematograms (RDK) moving consistently either to the left or to the right (Figure 1) for a fixed duration. At a random time during stimulus presentation, the dots changed colour (red, green, or blue) providing the instruction on how to respond in that particular trial. On (1) *Adhere* trials, participants were to respond congruently with the direction of the motion they perceived in the stimulus; on (2) *Oppose* trials, participants were to respond with the response key on the opposite side to the perceived motion direction; on (3) *Detach* trials, participants were to choose freely which response key to press, while trying to ensure that their choice was not influenced by the direction of dot motion. Each response was classified as congruent with the stimulus direction, or incongruent with it. Following the response, participants were required to give a rating of how much their response choice was influenced by the dot-motion, reporting their subjective experience of being more or less detached from the stimulus on each trial.

IMPACT OF DOMINANT INSTRUCTION ON FREEDOM OF CHOICE

We first tested whether learned responses affected the objective ability to detach from incoming sensory information, and the subjective experience in doing so. To do so, we manipulated the frequency of each instruction across participants' group: One group of participants received the instruction to adhere (i.e. respond congruently to the motion direction) in most trials (*Adhere* group) while a second group received the instruction to oppose (i.e. respond incongruently) in most trials (*Oppose* group). Both groups had the same proportion of *Detach* trials. This design allowed us to test whether a habitual response strategy would influence: (1) the objective ability to detach from the stimuli when given a free choice (objective FoC), and (2) the subjective feeling of freedom (subjective FoC).

Figure 1. Experimental procedure (top) and design (bottom) of experiments 1-3. (Top) Following a fixation cross (A), the stimulus was presented for 2500ms (B). At a random timepoint during stimulation, the dots changed colour to indicate the instruction for that trial (Adhere, Oppose, or Detach; C). After giving their response (D), participants were asked to report their subjective feeling of freedom (E). (Bottom) Experiment 1 manipulated the frequency of instructions between groups so that one group were required to adhere more than to oppose (example highlighted by bold outline), while the other were required to oppose more than to adhere. Experiment 2 manipulated the total frequency of one response (example of Left motor-response group highlighted by bold-outline) by arranging for one stimulus direction to be preferentially associated with Adhere trials (frequently adhered) and the other stimulus direction with Oppose trials (frequently opposed). Experiment 3 manipulated the stimulus frequency so that each group saw more of one stimulus direction than the other (example of Left stimulus group highlighted by bold-outline).

We found that instruction frequency did not affect response accuracy (Figure 2), mean percentage of correct responses being not significantly different in the adhere and oppose instructions [$F(1, 58) = 2.77, p = .102, \eta_p^2 = .046$] or for both groups [$F(1, 58) = 0.59, p = .447, \eta_p^2 = .010$]. Participants responded faster on Adhere than Oppose trials [$F(1, 58) = 7.32, p = .009, \eta_p^2 = .112$], as well as when they responded correctly compared to when they made an

error [$F(1, 58) = 66.25, p < .001, \eta_p^2 = .533$]. We next considered participants' responses when they were instructed to detach from the stimulus, and to make a response free of stimulus influence. Crucially, we found that participants in the Adhere group tended to make more congruent responses on detach trials than participants in the Oppose group [$t(58) = 2.44, p = .018, d = 0.63$, two-tailed]. Indeed, participants in the Oppose Group responded congruently with the stimulus in 46.74% of detach trials, significantly below chance level ($M = 46.74\%$, $SD = 9.06\%$; $t(29) = -1.97, p = .029, d = -0.36$, one-tailed) while participants in the Adhere Group responded congruently with the stimulus in 53.49% of detach trials, marginally deviating from chance ($M = 53.49\%$, $SD = 12.12\%$, $t(29) = 1.58, p = .063, d = 0.29$, one-tailed). Taken together, these results suggest that the dominant instruction affected detach trials: Participants who were required more frequently to adhere in instructed trials, tended to also adhere more in Detach trials, and this effect flipped when opposing became the more frequent instruction. In other words, habitual response strategies continued to prevail even when attempting to detach.

Figure 2. Mean proportion of accurate responses on instructed trials (Adhere, green; Oppose, red) and proportion of motion congruent responses on Detach trials (blue) split by group (Adhere Group, Oppose Group). Error bars reflect standard error of the mean.

We next considered how participants in each group rated their freedom of choice in instructed and free-choice trials. On instructed trials (Adhere and Oppose), participants reported feeling

freer on trials where they were instructed to oppose the motion of the stimulus than when instructed to adhere to it [Figure 3; main effect of instruction; $F(1, 58) = 11.43$, $p = .001$, $\eta_p^2 = .165$]. Moreover, they also reported feeling freer when making an error (e.g. incongruent response on an Adhere trial or a congruent response on an Oppose trial) than when making an accurate response [interaction between instruction and response mode; $F(1, 58) = 88.42$, $p < .001$, $\eta_p^2 = .604$]. Turning to detach trials, we found that when making a response incongruent with the mean stimulus-motion direction, participants felt significantly freer (i.e., more detached from the stimulus) than when making a response congruent with the motion direction [Figure 3; main effect of response mode; $F(1, 58) = 18.12$, $p < .001$, $\eta_p^2 = .238$]. Importantly, this was the case in the Adhere Group [$t(29) = 2.68$, $p = .012$, $d = 0.49$] but also in the Oppose Group [$t(29) = 3.32$, $p = .002$, $d = 0.61$], and the effect did not differ significantly between the groups [$F(1, 58) = 0.37$, $p = .54$]. Since the Oppose group made incongruent responses more frequently than the Adhere, this suggests that opposition was associated with increased sense of freedom, irrespective of whether opposition was the most frequent behaviour or not. In other words, acting contrarian was always associated with an increased sense of freedom, even when opposition was the dominant response tendency.

Figure 3. Mean rating of subjective freedom of choice ratings split by group (Adhere Group, Oppose Group), instruction (Adhere, Oppose, Detach), and response mode (congruent vs incongruent response, relative to stimulus motion direction). Ratings are displayed on the scale provided to participants, ranging from feeling completely influenced (left) to completely free (right). Ratings were averaged for each trial type for each participant. Means are indicated as lines through the boxes, and the width of the boxes reflect +/- 1 standard error across participants.

IMPACT OF LEARNED STIMULUS-RESPONSE ASSOCIATION ON FREEDOM OF CHOICE

While we showed that participants' objective ability to detach was partially compromised by following repeatedly one instruction over the other, we wondered whether this persistence effect would also be observed when one specific stimulus-response association was repeated, as opposed to one instruction. To test this hypothesis, we now modified our previous design so that each stimulus direction was now associated more frequently with one instruction - for instance rightward stimuli would be associated more frequently with the instruction to adhere while leftward stimuli would be associated more frequently to the instruction to oppose. Manipulating the stimulus-response associations in this way meant that one stimulus motion direction was frequently associated with the Adhere instruction and thus a congruent response,

while the other stimulus motion direction was associated with the oppose instruction, and thus an incongruent response. Importantly, the instruction to Adhere or Oppose remained overall equally frequent, allowing us to test rather whether repeatedly associating one stimulus with one strategy would lead participants to (1) continue using that strategy when required to detach from that particular stimulus and (2) associate that repeated strategy with a reduced level of freedom and autonomy. Importantly, our design also meant that participant used more frequently one motor response than the other. We therefore also included a second type of detach trial where the stimulus did not have any obvious motion direction and motion coherence was set to 0 ('motion-neutral', as opposed to 'motion-present' detach trials) to estimate the effect of purely motoric response repetition on the ability to detach.

In instructed trials, we found that participants were more accurate in the condition corresponding to the trained stimulus-response association (see Supplementary Results). As in the first experiment, participants were also faster on Adhere than on Oppose trials [$F(1, 36) = 4.38, p = .044, \eta_p^2 = .108$], and faster for correct than incorrect responses [$F(1, 36) = 39.53, p < .001, \eta_p^2 = .523$].

When required to detach, (Figure 4), we found that participants responded differently to stimuli that they had been trained to adhere and those they had been trained to oppose [$t(37) = 2.56, p = .015, d = 0.42$, two-tailed]: Participants tended to respond more congruently to frequently adhered stimuli [$M = 54.56\%, SD = 10.68\%, t(37) = 1.69, p = .050, d = 0.27$, one-tailed] and to respond more incongruently to stimuli they were trained to oppose [$M = 45.57\%, SD = 10.36\%, t(37) = 2.64, p = .006, d = 0.43$, one-tailed]. This result therefore replicated and extended those of Experiment 1, showing that training with one particular stimulus-response association continued to influence response strategy when required to detach. No effect of motor bias was observed in the motion-neutral trials [proportion of frequent responses compared to chance level on motion-neutral detach trials; $t(37) = 0.66, p = .510, d = 0.11$] and no further differences were observed when considering if the motion energy fluctuations favoured the frequently adhered or frequently opposed stimulus direction [Figure 4; $t(37) = 0.65, p = .520, d = 0.10$], suggesting that purely motor repetition in itself did not affect the ability to detach.

Figure 4. Objective Freedom of Choice ratings split by stimulus-response association (frequently adhered, frequently opposed); accuracy for Adhere (green) and Oppose (red) trials, and the percentage of motion congruent responses for Detach trials (motion-present, blue; motion-neutral, purple). This was averaged for the different trial types for each participant, and means and standard error (error bars) were calculated across participants.

Considering the ratings of freedom of choice (Figure 5), we found that participants reported greater detachment on Oppose than on Adhere trials [$F(1, 36) = 5.13, p = .030, \eta_p^2 = .125$], and when making an error (interaction between response mode and instruction: $F(1, 36) = 33.83, p < .001, \eta_p^2 = .484$), replicating the results of our previous experiment. In detach trials (Figure 5, blue bars), participants again reported they felt freer making a motion incongruent than a motion congruent response [$F(1, 36) = 12.55, p = .001, \eta_p^2 = .258$], confirming that opposition was always associated with an increased sense of freedom. Interestingly however, we also found an unexpected effect of previous opposition in detach trials: participants reported they felt more free when responding to a frequently-opposed stimulus compared to a frequently adhered stimulus [Main effect of stimulus-response association; $F(1, 36) = 4.34, p = .044, \eta_p^2 = .108$]. This was true regardless of the response made on the current trial [$F < 1$]. Hence, when attempting to detach, frequently-opposed stimuli became associated in themselves with

an increased sense of autonomy, irrespective of whether participants actually opposed them on a given trial or not.

Interestingly, no effect of stimulus-response association or motor bias was observed on ratings of freedom in the motion-neutral detach trials (Figure 5, purple, all $F < 1$) suggesting that motor novelty vs. motor repetition did not itself influence subjective freedom.

Figure 5. Mean ratings of subjective ratings of freedom of choice split by stimulus coherence (motion-present, top four bars; motion-neutral, bottom four bars), stimulus-response association (frequently adhered, frequently opposed), instruction (Adhere, Oppose, Detach), and response mode (pro, green bars; anti, red bars). Ratings were averaged for each trial type for each participant. The scale ranges from completely influenced (left) to completely free (right). Means are indicated as lines through the boxes, and the width of the boxes reflect the standard error.

IMPACT OF STIMULUS FREQUENCY ON FREEDOM OF CHOICE

We observed that participants reported feeling freer when presented with a stimulus they had frequently opposed in the past, compared to one frequently adhered to, regardless of their response to it. To further understand how we detach from such visual enticement, we conducted a third experiment manipulating the frequency of the stimulus itself. This allowed us to understand how repetition vs salience of stimuli may influence the ability to detach. The previous design was modified so that now one motion direction (leftward or rightward) was seen more frequently than the other, comparing trials where a frequent stimulus was presented and trials where a rare stimulus was presented.

This manipulation did not significantly affect response accuracy in instructed trials, although a trend was observed towards participants performing better for frequent stimuli [$F(1, 35) = 3.25$, $p = .08$, $\eta_p^2 = .085$]. As previously observed, participants responded more rapidly on Adhere trials compared to Oppose trials [$F(1, 35) = 6.88$, $p = .013$, $\eta_p^2 = .164$]. Accurate responses were again associated with faster response times than inaccurate responses [$F(1, 35) = 41.81$, $p < .001$, $\eta_p^2 = .544$].

In motion-present detach trials (Figure 6, blue bars), no effect of stimulus frequency was observed on the proportion of motion congruent responses [frequent stimulus vs rare: $t(36) = 1.08$, $p = .290$, $d = 0.18$; frequent stimulus vs chance level: $t(36) = 1.18$, $p = .250$, $d = 0.19$; rare stimulus vs chance level: $t(36) = 0.48$, $p = .640$, $d = 0.08$], suggesting participants were equally likely to oppose dot-motion as they were to adhere to it, irrespective of whether the motion direction had been seen frequently or not. No further effects were observed on motion-neutral trials, indicating participants had no response bias in the absence of a clear visual cue.

Figure 6. Objective Freedom of Choice split by stimulus frequency (frequent, rare); accuracy for Adhere (green) and Oppose (red) trials, and the percentage of motion congruent responses for Detach trials (motion-present, blue; motion-neutral, purple). This was averaged for the different trial types for each participant, before means and standard error (see error bars) was calculated across participants.

As in our two previous experiments, we observed that freedom was rated higher on Oppose than Adhere trials [$F(1, 35) = 10.29$, $p = .003$, $\eta_p^2 = .227$] and when making an error than when responding correctly [$F(1, 35) = 33.88$, $p < .001$, $\eta_p^2 = .492$]. Further, in detach trials, we replicated the findings of experiment 1 and 2 that participants reported feeling more free when making a response incongruent to the stimulus direction (Figure 7, blue bars), compared to a congruent response [$F(1, 35) = 14.35$, $p < .001$, $\eta_p^2 = .291$]. Interestingly, we observed an interaction between stimulus frequency and response mode [$F(1, 35) = 16.85$, $p < .001$, $\eta_p^2 = .325$], showing that participants reported feeling more free when making an incongruent

response to a rare stimulus, compared to a frequent stimulus [$t(36) = 3.01, p = .005, d = 0.50$]. This suggested that the sense of freedom was increased when opposing a rare occurrence. No further effects were observed in motion-neutral detach trials.

Figure 7. Mean ratings of subjective freedom of choice ratings split by stimulus coherence (motion-present, top four bars; motion-neutral, bottom four bars), stimulus frequency (frequent; rare), instruction (Adhere, Oppose, Detach), and response mode (pro, green bars; anti, red bars). Ratings were averaged for each trial type for each participant. The scale ranges from completely influenced (left) to completely free (right). Means are indicated as lines through the boxes, and the width of the boxes reflect the standard error.

EXPLORING CORRELATIONS BETWEEN SUBJECTIVE AND OBJECTIVE FREEDOM OF CHOICE

In all three experiments, we found that making a motion-incongruent response on detach trials felt significantly freer than motion-congruent responses. Interestingly, this result was observed irrespective of the frequency of congruent or incongruent responses: in experiment 1 and 2. Even when participants made more incongruent responses than congruent responses (as for the Oppose Group and the frequently opposed stimulus condition), participants continued to report higher freedom for the former.

To explore this dissociation between behaviour and subjective autonomy further, we calculated across subjects correlations between the objective and subjective measures of stimulus-independence. To do so, we computed the difference in proportion of each participant's congruent and incongruent responses in the detach condition and tested whether it predicted the difference in subjective freedom ratings between pro and incongruent responses (Figure 8; see Table S1 in Supplementary Materials). This allowed us to test whether those participants who more strongly tended to adhere to the stimulus would also experience higher subjective freedom when opposing.

To increase statistical power, we pooled together the data across all three experiments. Interestingly, we found a significant relation between participants' objective ability to detach and how they rated their freedom of choice in congruent vs incongruent responses (Figure 6.1, regression slope = -19.62, $\beta = 5.31$, $R^2 = .19$, $t(133) = 5.53$, $p < .001$). Namely, those participants who tended to adhere (i.e. made more congruent responses) in the detach condition also reported relatively lower freedom for those congruent responses, and higher freedom for incongruent responses. The intercept of this regression relation shows that, even when participants are objectively detached, tending neither to oppose nor adhere, there remains a strong and significant tendency to rate incongruent responses as subjectively freer ($\beta = 5.32$, $t(133) = 7.06$, $p < .001$, $d = 1.22$). These results suggest that the increased sense of freedom when opposing cannot simply be accounted for through individual differences in behaviour when instructed to detach.

We tested this relation further by considering the specific parts of our design that most encouraged opposition during detachment. To do so, we combined data of the conditions we found were associated with increased rate of incongruent response (Oppose Group of experiment 1, frequently opposed stimuli condition of experiment 2, and frequent stimuli condition of experiment 3). If the regression intercept remains significant for this group, then even when opposition is learned as the most frequent strategy, it would still feel relatively free (3). We also performed the same analysis in conditions that encourage adherence, combining the Adhere Group of experiment 1, the frequently adhered stimuli condition of experiment 2, and rare stimuli condition of experiment 3.

In both regression models, we found that participants rated their subjective freedom higher for incongruent responses than for congruent response, as shown by the intercept of the regressions that was significantly different from 0 for both models (majority Adhere Regression: $b = 6.57$, $t(102) = 6.17$, $p < .001$, $d = 1.22$; majority Oppose Regression: $b = 5.41$, $t(102) = 4.43$, $p < .001$, $d = 0.87$). This meant that even when participants showed an objective tendency to oppose the stimulus, they still experienced greater freedom when opposing. Interestingly, no significant correlation between the degree of detach and the subjective sense of freedom for congruent versus incongruent responses was observed in the dataset for those who tended to oppose more frequently (dataset with majority Oppose behaviour: $p = .130$), suggesting that this effect might be more strongly associated with adherence strategy. Taken together, these results show that both habitual and contrarian behaviour modulated the sense of freedom of choice, independently of each other.

Figure 8. Difference in subjective freedom of choice (FoC) to incongruent minus congruent responses on motion-present detach trials according to the difference in proportion of incongruent minus congruent responses on motion-present detach trials. Each data-point represent one participant, pooling together all participants from all three experiments.

DISCUSSION

How do we know whether we are acting freely or are influenced in our choices? And is our introspection of influence accurately reflecting our learned biases? In the present study, we tested how the tendency to respond congruently or incongruently to suggestion affected the sense of acting autonomously. To do so, we showed participants stimuli that primed a left or a right response and asked them to make a manual choice response by either adhering to the direction suggested, opposing it, or detaching entirely from the visual stimulation and make a choice free from external influence. Crucially, we manipulated the stimulus and response distributions so that participants 1/ had to follow one set of instructions more frequently (experiment 1), 2/ had to respond to one stimulus with one response more frequently (experiment 2), or 3/ were exposed to one stimulus direction more frequently (experiment 3). This systematic set of designs allowed us to test how repeated association between a stimulus and a response could bias free decisions, and also how it could alter the subjective experience of acting freely.

Experiment 1 and 2 revealed that participants' ability to make free choices, i.e. responses that were not influenced by external stimulation in the detach condition, was strongly compromised by implicitly learned stimulus-response associations. In Experiment 1, we observed that when participants were required to detach from the stimulus and attempted not to be influenced by it, they failed to do so. Instead, they tended to act in accordance with the instruction that they had been trained with the most frequently. This meant that participants who were predominantly trained with an Adhere instruction, involving stimulus-congruent responses, persisted in responding congruently with the stimulus when asked to detach. Conversely, those participants who were predominantly trained with an Oppose instruction, persisted in responding incongruently with the stimulus. In other word, stimulus-response mappings formed through repetition persisted in "free choice", consistent with studies of 'task sets'. Our second experiment further clarified this effect. In that experiment, participants were predominantly trained to make stimulus-congruent responses to some stimuli, while predominantly opposing others. As in experiment 1, we found that, instead of detaching from the stimulus, participants tended to persist in responding to it in the way they had been trained. Taken together, these findings suggest that when people learn through instructions to respond to one stimulus with one specific action, they persistently respond to the stimulus in that way, even when instructed not to be influenced by it. Crucially, this demonstrates that the ability to act autonomously and independently of a stimulus is reduced if one has previously learned to make a particular response to that stimulus. In other words, the stronger the conditioned link between a sensory input and a behaviour, the more that same sensory input is likely to influence future action choices and effectively reduce the ability to act autonomously.

Such findings are in broad agreement with the classical concept of conditioned or habitual responding (Pavlov 1929), as well as classic cognitive psychology effects related to switching from one task set to the next. Indeed, the persistence of previously experienced SR mappings on future responses has been demonstrated many times (Kiesel et al., 2010; Koch, Gade, Schuch, & Philipp, 2010). Findings on voluntary task switching show that participants are more effective at using a new task set when they are switching freely to it than when they are forced to do so (Arrington & Logan, 2004). Only a few studies investigated how free choices themselves are impacted by previous experience of SR associations (Molina & Davis, 2018).

Our study brings new light to this question, demonstrating that conditioning does indeed profoundly constrain the capacity for truly autonomous action. We show here that even when people try to ignore current stimulus content, their previous experiences strongly shape behaviour. Importantly, persistence of SR mappings has also been found in subliminal priming paradigms (O'Connor and Neill, 2011), suggesting that it might operate independently of conscious processes of action selection (Ocampo, 2015). Thus, the 'positive priming effect', in which participants tend to respond congruently to a subliminal prime (Le Bars, Hsu, & Waszak, 2016; Schlaghecken & Eimer, 2004; Wenke, Fleming, & Haggard, 2010), could be reversed if the participants had been trained with the incongruent stimulus-response mapping (O'Connor and Neill, 2011). Similarly, it has been observed that increasing the proportion of instructed trials strengthens the positive priming effect on free choices (Bodner and Mulji, 2010). A comparable effect has been observed in the voluntary task switching literature, where a higher proportion of forced task switch trials led to an increased tendency to switch tasks on free choice trials (Fröber & Dreisbach, 2017).

Our findings extend those results to free choices in the presence of supraliminal stimuli (Desender, Van Lierde, & Van den Bussche, 2013; Francken, Gaal, & de Lange, 2011; Kunde, Reuss, & Kiesel, 2012; van Gaal, de Lange, & Cohen, 2012). To act freely in the present study meant detaching from stimulus information. Participants however showed only a limited ability to dissociate from previously learned response strategies. Crucially, we show that these are not merely effects of visual repetition alone, nor of motor priming alone. Repeated presentation of the same stimulus without a bias in responding (experiment 3) or of repeated responding without a bias in stimulation (experiment 2) did not affect subsequent free choices. Thus, future free choices were influenced by the repeated association of one stimulus with a response, but not by patterns of stimulation alone, or by patterns of responding alone (Pavlov, 1927). This finding suggests that volition and habit represent two dissociable, competing and mutually-exclusive routes to action (Haggard, 2019). Classical neurophysiological theories that view autonomous action as a *continuation* of reflex mechanisms (Sechenov, 1863) cannot readily explain this exclusivity. Our results show that repeated experience of a particular stimulus-response mapping results in habitual behaviours that reduce the ability to act autonomously. In other words, true detachment and therefore true freedom from influence may be difficult to achieve after a habit has already been formed, and may require effortful cognitive control to overcome habit-induced response conflicts (Botvinick et al., 2001).

Importantly, our results bring new lights on whether participants are able to introspect the factors that influenced their choices. Crucially, we found that across all three experiments responding incongruently to the stimulus was associated with an increased subjective sense of acting freely and independently from the stimulus, compared to responses that followed the stimulus. Interestingly, this association between opposition and perceived autonomy was present irrespective of how much the stimulus in fact influenced participants' choices. In particular, whether participants more frequently followed the cued response, or more frequently opposed it, they always rated their choice as more autonomous when opposing the action suggested by the current circumstances. Indeed, even those participants who tended statistically to oppose the stimulus direction when required to detach nevertheless felt freer when they made incongruent responses on detach trials than when they made a congruent response (Experiment 1). This result was confirmed further by combining the conditions in each of the three experiments in which participants tended to make more opposing responses. A regression approach showed that the association of freedom and opposition was present

466 even when controlling for participants' dominant response tendency, and for the time they took
467 to make a choice.

468 Taken together, these results show that inhibitory control distort the introspection of one's own
469 choices. In simpler terms, opposition increases the perception of acting freely. These findings
470 replicate and extend previous results on the sense of autonomy and freedom (Charles &
471 Haggard, 2019). Importantly, we demonstrate here that while free choices can be biased by
472 experimental manipulation, the subjective bias caused by inhibitory control persists despite
473 those manipulations, confirming the dissociation between the subjective sense of making free
474 choices and the objective ability to do so. This suggests that, while the objective ability to act
475 freely is significantly affected by learned response strategies and therefore requires to
476 overcome acquired biases, the subjective sense of freedom seems to be influenced mostly by
477 the current circumstances at the time of the decision. Thus, the subjective sense of autonomy
478 seems to be driven largely by signals monitoring local conflict related to the external world, but
479 seems insensitive to monitoring internal conflicts generated by one's own habits. Put another
480 way, to feel free seems to be a matter of acting contrary to the prepotent response, rather than
481 overcoming one's own internal biases. The effect may recall the feeling of resisting external
482 social influence, as when dissenting from the majority opinion (Imhoff & Erb, 2009) or
483 disobeying norms such as traffic laws (Scott-Parker, King, & Watson, 2015). The sense of thrill
484 that accompanies rebellion or resistance to external influence, might be due to the fact that
485 simply acting contrarian increases our sense of autonomy and freedom. As such, our findings
486 might provide empirical evidence and potential cognitive mechanisms underlying social
487 psychology phenomenon such as reactance (Miron & Brehm, 2006; Steindl, Jonas,
488 Sittenthaler, Traut-Mattausch, & Greenberg, 2015). Our results suggest that contrarian
489 behaviours that aim to restore or boost subjective autonomy might actually stem from an
490 underlying metacognitive bias in introspecting one's own decisions.

491 Does the relation between opposition and subjective freedom require conscious
492 awareness of external influence? Previous findings (Wenke, 2010) showed that, when primes
493 were presented subliminally, and participants therefore remained unaware that they might be
494 influenced, they felt more in control over the outcome of their choices when they indeed
495 followed the suggestion of the prime, compared to when they did not. Judgements of control
496 are not identical to judgements of autonomy, but both depend on a common substrate of
497 intentionality and choice. Thus, comparison between our results and those of Wenke et al.'s
498 (2010) favours the view that feelings of autonomy when opposing a prepotent response may
499 require that participants consciously perceive both the stimulus and its implications for
500 behaviour. This would provide further support for a close link between consciousness and
501 conflict monitoring (Dehaene et al., 2003; Mayr, 2004). Confirming this idea, we additionally
502 found that the frequency of a visual cue itself modulated the association between opposition
503 and the sense of freedom. Participants felt significantly freer when opposing a rare stimulus
504 compared to a frequent one (experiment 3). Rare stimuli are inevitably more salient and
505 therefore are also likely to recruit more attentional resources, confirming the tight link between
506 awareness and cognitive control. Indeed, Filevich and colleagues (2013) found that
507 participants reported feeling more free from influence when a stimulus was presented less
508 frequently in a sequence of cues, consistent with our result. Our findings thus identified two
509 distinct factors that boost the subjective sense of autonomy, one related to the stimulus-
510 response mapping, and the second related to the stimulus alone. According to the first factor,
511 any action that overrides the prepotent response is perceived as freer than a response

congruent with the direction of the stimulus, irrespective of what stimulus-response mapping is instructed, and irrespective of how habitual that mapping may be. According to the second factor, the low frequency/high salience of the eliciting stimulus tends to boost perceived autonomy of responding, irrespective of stimulus-response mapping.

One interesting, and to our knowledge novel, result of this study concerns how participants linked an external stimulus to the feeling of acting freely. When participants learned by repeated experience to make stimulus-incongruent responses, they appeared to start associating that stimulus with an increased sense of freedom. Importantly, this effect was present irrespective of whether participants indeed acted independently from that stimulus or not on a specific trial (experiment 2). This finding shows that the sense of freedom that arose from opposing the influence of an external stimulus stuck to that stimulus, so that the stimulus itself becomes associated with acting freely. This result is particularly striking as it demonstrates that the experience of *not* being influenced can be paradoxically evoked by the mere exposure to a visual cue. Such findings resonate with the literature on instrumental conditioning where a stimulus can become associated with a particular emotional (Maren, 2001) or cognitive response (Kirsch, Lynn, Vigorito, & Miller, 2004). Our result could be interpreted as a novel illusion of autonomy, arising from people's limited ability to introspect the reasons for their choices (Charles & Haggard, 2019). Thus, we find that people mistake opposition for autonomy, and fail to experience subjectively the influence of their own objective behavioural habits. As a result, people may feel autonomous despite acting habitually, and may attach their feelings of autonomy to external cues rather than to the generators of their own behaviour. Moreover, our results raise the interesting possibility that the sense of autonomy can be increased artificially by training, since an illusory feeling of freedom could be induced by exposure to things that we have been told to reject. These findings have important implications for understanding how humans generate and maintain the feelings of autonomy that underlie societies. For instance, they could shed new light on social effects such as irrational belief in conspiracy theories or extreme political radicalization. Indeed, a cognitive bias which conflates opposition and freedom could explain why people are likely to feel autonomous when they are led into rebellions or manipulated into acting contrarian.

CONCLUDING REMARKS

People often feel they are capable of making "free" choices; decisions, independent of environmental influence (Stillman, Baumeister, & Mele, 2011). Yet, across three experiments, we find that such free choices, and the ability to introspect into our freedom, can be biased by irrelevant sensory information and previous experiences. More importantly, we find that a central element of the subjective experience of acting freely involves rebelling against the actions suggested by the current stimulus environment. This effect was immune to the effects of habitual, learned SR associations acquired during the experiment itself. Further, the effect transferred to the stimulus evoked the oppose response, since, after repeated training, this stimulus itself came to be associated with a greater sense of acting freely, whether participants chose to oppose it or not. More research will be needed to determine how our findings can be generalised to contexts of autonomous choice outside the laboratory, and how artificially generated feeling of freedom might influence behaviour.

METHOD

EXPERIMENT 1

1.1.1 Participants

A total of 62 participants with normal or corrected-to-normal vision and no history of psychiatric or neurological illness were recruited through the UCL Psychology SONA System. Sample size was based on a previous study (Charles & Haggard, 2019) to detect an influence of signal fluctuations on free choice with 80% power at $\alpha = .05$ (two-tailed t-test with effect size $d = 0.74$; required sample of at least 30 participants per group). The study was approved by the UCL Research Ethics Committee and participants were compensated £12 or university credits for their time. Two participants had to be excluded during the experiment or during analysis: One participant failed to see the dot motion direction even at maximum coherence level and testing was interrupted. One participant used the freedom of choice scale in a highly discretized manner, contrary to instructions, using one end of the scale in more than 98% of the trials and was therefore excluded from analysis. This left 60 participants (43 female; mean age 22.63 ± 3.17 years ranging from 20 to 30), randomly assigned to 30 in Adhere Group and 30 in Oppose Group.

1.1.2 Stimuli

Participants were presented with a series of random dot kinematograms (RDK) moving either to the left or to the right. The dots were shown for a single frame before being replotted three frames later. When replotted, a subset of the dots were offset from their previous location to produce apparent coherent motion in one direction (to the right or to the left), whilst others were offset and plotted randomly (see Roitman & Shadlen, 2002). The proportion of the dots moving in the same direction representing the motion coherence was adjusted by a Staircase Procedure (see 2.2.3).

At a random time during stimulus presentation, the dots changed colour (red, green, or blue; matched for luminance and contrast) providing the instruction on how to respond in that particular trial. The colour provided the instruction on how to respond to the stimulus on that trial. On (1) *Adhere* trials, participants were to respond congruently with the direction of the motion they perceived in the stimulus; on (2) *Oppose* trials, participants were to respond with the response key on the opposite side to the perceived motion direction; on (3) *Detach* trials, participants were to choose freely which response key to press, while trying to ensure that their choice was not influenced by the direction of dot motion.

1.1.3 Design & Procedure

Protocol. The experiment followed a mixed design with group as the between-subjects variable (Adhere Group, Oppose Group), and instruction condition (Adhere, Oppose, Detach) as the within-subject variable. The main experiment consisted of 7 blocks of 57 trials, totalling to 378 trials of interest (excludes high coherence trials). For the majority Adhere Group, this was split so that 50% were Adhere trials, 16.7% Oppose, and 33.3% Detach. For the majority

Oppose Group: 50% of trials were Oppose trials, 16.7% Adhere, and 33.3% Detach (see Figure 1). This manipulation made it so that one group was required to adhere more than oppose the stimulus (Adhere Group), and the other group to oppose more than adhere (Oppose Group). Each block of trials also included three high coherence trials (coherence set to 65%, one for each instruction type) to ensure that participants could follow instructions accurately in Adhere, Oppose, and Detach trials according to the colour change. The experimental session lasted 80-90 minutes and consisted of two parts; the staircase procedure, and the main experiment.

Staircase Procedure. To account for individual differences in sensitivity to dot motion, the motion coherence of the RDK stimuli was predetermined using a 2-down-1-up staircase procedure (Levitt, 1971). To do so, participants started the experiment with a block of 150 trials in which they were instructed to disregard all colour changes and to place their focus on detecting the direction of dot movement. The staircase procedure lasted 13 minutes. The coherence level was adjusted starting at a motion coherence of 40%. For the first 12 trials, the motion coherence remained at 40% to familiarize participants to the task. Subsequently, the motion coherence changed by a set amount in such a way that two consecutive correct guesses lowered the coherence, and a single error increased the coherence. The step size started at 6% but halved every time the participant made two consecutive errors (until the minimum step-size of 1.5%). The estimate of the appropriate motion coherence was obtained by averaging the coherence over the last 40 trials. This coherence level was used in the rest of the experiment.

Trial procedure. In the main experiment, participants started each trial with a fixation cross, before the stimulus was presented for 2500ms (see Figure 1A & B). At a random time-point between 100ms and 2388ms, the dots changed colour to indicate the instruction for this trial (see Figure 1C). Association between colours and instructions were counterbalanced across participants. After the stimulus disappeared, participants had 1500ms to respond with a left-arrow and right-arrow keypress using their right hand (see Figure 1C). 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 (Figure 1E). 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. The starting position of the slider was set at a random position on each trial. 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"). 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. Which side of the scale corresponded to influenced/free was counterbalanced across participants. Subjective FoC ratings were given on all trials, not just for the detach condition.

1.1.4 Data Analysis

Each response was classified as congruent with the stimulus direction (pro), or incongruent with it (anti); which we termed the response mode. Trials in which no response was given were excluded (Adhere: $M = 4.20\%$ of trials, $SD = 5.65\%$; Oppose: $M = 5.08\%$, $SD = 5.16\%$; Detach: $M = 6.60\%$, $SD = 6.88\%$). Two aspects of detach trial responses were of interest to us: (i) the relation between the response and the stimulus (objective FoC), and (ii) the subjective FoC. Objective FoC was measured as the percentage of motion congruent responses on detach trials (chance level = 50%). Subjective FoC was measured by the mean rating of freedom on the FoC scale.

Statistics. Mean subjective FoC ratings were calculated per participant, split by group, instruction condition, and response mode. Analyses of variance (ANOVAs) were conducted separately for instructed (both Adhere and Oppose), and for Detach trials, using mixed models taking into account which factors was between and within-subject. Mean proportion of motion congruent responses were calculated per participant, split by group and instruction. Analyses of variance (ANOVAs) were conducted separately for instructed (Adhere and Oppose) trials and detach trials. This was followed up with t-tests (two-tailed, unless specified otherwise), comparing the proportion of motion congruent responses, for each stimulus frequency, to chance level. We also compared the proportion of motion congruent responses between Adhere Group and Oppose Group.

EXPERIMENT 2

1.1.5 Participants

39 participants with normal or corrected-to-normal vision were recruited following the same protocol as experiment 1. Sample size was determined by a-priori power analysis based on the subjective FoC observed in experiment 3 (which was run before experiment 2), an effect size of $d = 0.29$ requiring $N=37$ to achieve 80% power, with alpha 0.05 (two-tailed t-test). One participant was excluded as they failed to understand the instructions (they confused which colour was associated with which instruction on several blocks of trials). This left 38 participants (28 females; mean age 22.24 ± 2.94 years ranging from 18 to 30; all right-handed). Participants were randomly assigned to a group, leaving 20 in the group performing a majority of left motor responses and 18 in the group performing a majority of right motor responses.

1.1.6 Design, Stimuli, & Procedure

The experiment followed a mixed design with group (majority left responses, majority right responses) as the between-subjects variable and instruction (Adhere, Oppose, Detach) as the within- subject variables.

The stimuli and procedure for experiment 2 were identical to that of experiment 1, except for the modifications in the proportion of trials: In each block there were 67 trials of interest, giving a total of 469 trials. 59.7% of trials were instructed (half Adhere, half Oppose). Among the

instructed trials, the proportion of leftward and rightward stimuli differed between instructions. On Adhere trials, 75% of stimuli were in a direction congruent to the most frequent response of the group (e.g. rightward for the “majority right responses” group), whilst the remaining 25% were in the other direction. On Oppose trials, 75% of stimuli were in the incongruent direction to the most frequent response of the group (e.g. leftward for the “majority right responses” group), and 25% in the congruent direction (see Figure 1). This distribution meant that participants responded more with one key than the other in the instructed trials. However, it also created an association between instruction and direction. For example, participants in group majority left responses had an association between left-direction stimulus and adherence and right-direction stimulus and opposition. Hence, we separated trials according to whether the stimuli were frequently adhered, or frequently opposed.

The remaining trials (40.3%) corresponded to the Detach instruction. There were two types of Detach trials: 1/ motion-present trials where there was a predominant motion direction to the left or to the right and 2/ motion-neutral trials where the motion coherence was set to 0%. The motion-neutral trials were a subset of detach trials where *all* dots moved at random, and hence had no predominant motion direction. We added these trials so to investigate whether the trained motor response would influence free choices in the absence of visual stimulation (i.e. no clear stimulus-response mapping). Among the Detach trials, a third were moving leftward, a third moving rightward, and a third were motion-neutral. For all detach trials, participants were given the same instruction to respond independently of the stimulus, aiming as not being influenced by the motion to choose a response.

At the end of the experiment, participants were asked to estimate the overall proportion of right responses they had made (across all trials). In this way, we could investigate whether participants were consciously aware response frequencies were experimentally manipulated (see 2.2.4 Bias Awareness, Supplementary Results).

1.1.7 Data Analysis

Data analysis followed the same methods as for experiment 1. On motion-neutral detach trials, small fluctuations in motion energy across the course of the trial could still momentarily favour one direction over the other, even though overall motion energy was balanced across directions. The time-course of the motion energy for each trial was retrieved by applying spatiotemporal motion filters to dot position over time so to compute a time-course of motion direction for each trial (Adelson & Bergen, 1985; Charles & Haggard, 2019; Kiani, Hanks, & Shadlen, 2008). The net motion energy value was calculated by subtracting the amount of rightward motion from leftward motion on each timeframe of stimulus presentation. These values were then standardized against the mean motion energy and standard deviation of all other motion-neutral detach trials to give a zero mean and unit of standard deviation. Thus, motion energy values now reflected fluctuations in motion direction around the mean coherence level. We then reverse correlated the normalized values so that positive values related to fluctuations favouring the frequently adhered direction, whilst negative values reflected fluctuations favouring the frequently opposed direction. The sum across time (area under curve, AUC) was computed. We then divided trials according to whether the fluctuations prior to response favoured the frequently adhered (a positive AUC) or frequently opposed (a

negative AUC) stimuli, and responses were classified by whether they were congruent (pro) or incongruent (anti) to the direction of this fluctuation.

Trials in which no response were given were excluded (Adhere: $M = 3.36\%$, $SD = 3.14\%$; Oppose: $M = 3.20\%$, $SD = 3.70\%$; motion-present Detach: $M = 5.33\%$, $SD = 4.05\%$; motion-neutral Detach: $M = 4.64\%$, $SD = 3.84\%$).

Statistics. Mean proportions of motion congruent responses and mean subjective freedom of choice ratings were calculated per participant, split by instruction, stimulus-response association, and response mode. Analyses of variance (ANOVAs) were conducted separately for instructed (Adhere and Oppose) trials and detach trials, as before. Group was included as a factor for all but the motion-neutral trials, for which the number of trials was insufficient. ANOVA on detach trials included the additional factor of motion-evidenced/motion-neutral stimulation.

EXPERIMENT 3

1.1.8 Participants

42 participants were tested using similar procedures to experiment 1 and 2. This exceeded the minimum sample size of 28 as indicated by a priori power analysis of detach responses from experiment 1 (sample size indicated to achieve power of 80% for two-tailed t-test with effect size $d = 0.55$).

Five participants were excluded. This was either because they failed to see the dot motion direction during the staircase procedure (two participants), because they used the subjective FoC scale in a highly discretized manner using one end of the scale in more than 98% of trials (one participant) or because they made no mistakes on instructed trials with the rare stimulus direction, making it impossible to compare accuracy across response modes (2 participants). This left 37 participants (24 females; mean age 24.35 ± 2.94 ranging from 18 to 30, all but five right-handed). With random allocation, 20 participants were assigned to the majority leftward stimuli group, and 17 to the majority rightward stimuli group.

For analysis of motion-neutral detach trials only, one further participant (from the majority rightward group) was excluded from subjective FoC analyses due to a lack of congruent responses on motion-neutral trials favouring the frequent stimulus direction.

1.1.9 Design, Stimuli, & Procedure

The experiment followed a mixed design with group (majority left-direction stimuli, majority right-direction stimuli) as the between-subjects factor, and instruction condition (Adhere, Oppose, Detach) and stimulus frequency (frequent stimulus, rare stimulus) as the within-subjects factors.

Stimuli and procedure were identical to those of experiment 1 and 2 and included motion-neutral trials as described under experiment 2. The main modification was that 75% of all trials

(except motion-neutral trials) had stimuli moving in the frequent direction (as determined by which group participants were assigned to), whilst the other 25% moved in the other direction (rare stimulus). A total of seven blocks with 60 trials of interest (excluding high coherence trials) was presented, giving a total of 420 trials of interest. In each block, 36 trials (60%) were instructed (half Adhere, half Oppose). The remaining 24 (40%) were detach trials; of which six (25%) were motion-neutral and 18 (75%) motion-present.

At the end of the experiment, participants were asked to estimate the proportion of leftward versus rightward stimuli. This question aimed to investigate whether participants were aware of the manipulation of stimulus frequency (see 2.1.4 Bias Awareness, Supplementary Results, for the findings).

1.1.10 Data Analysis

As in Experiment 2, motion-neutral trial responses were classified as pro or anti if they went with or against the covert biases of the stimulus, which would slightly favour the frequent or the rare direction. Again, trials in which no response were given were excluded from the analysis (Adhere: $M = 8.34\%$, $SD = 10.38\%$; Oppose: $M = 8.71\%$, $SD = 10.91\%$; motion-present Detach: $M = 10.56\%$, $SD = 14.35\%$; motion-neutral Detach: $M = 10.94\%$, $SD = 16.45\%$).

Statistics. Mean proportion of motion congruent responses and mean subjective freedom of choice ratings were calculated per participant, split by instruction, stimulus frequency, and response mode. Analyses of variance (ANOVAs) were conducted separately for instructed (Adhere and Oppose), motion-present detach trials, and motion-neutral trials. Group was included as a factor for all but the motion-neutral trials, as the trial number was insufficient for this. ANOVA on detach trials included all detach trials, with stimulus coherence (i.e. motion-present vs motion-neutral) included as a factor.

ACKNOWLEDGEMENT

This work was supported by a British Academy Post-doctoral Fellowship to LC. We thank Ian Yeung for his help with the testing of participants.

AUTHORS CONTRIBUTIONS

A.K. contributed to designing the experiment, testing participants, analyzing data and writing the manuscript. P.H. and GW contributed to designing the experiment, interpreting data and writing the manuscript. L.C. contributed to designing the experiment, testing participants, analyzing data and writing the manuscript.

DECLARATION OF CONFLICTING INTERESTS

The authors declare there is no conflict of interests.

REFERENCES

- Adelson, E. H., & Bergen, J. R. (1985). Spatiotemporal energy models for the perception of motion. *Journal of the Optical Society of America A*, 2(2), 284. <https://doi.org/10.1364/JOSAA.2.000284>
- Arrington, C. M., & Logan, G. D. (2004). The cost of a voluntary task switch. *Psychological Science*, 15(9), 610–615. <https://doi.org/10.1111/j.0956-7976.2004.00728.x>
- Bodner, G. E., & Mulji, R. (2010). Prime Proportion Affects Masked Priming of Fixed and Free-Choice Responses. *Experimental Psychology*, 57(5), 360–366. <https://doi.org/10.1027/1618-3169/a000043>
- Botvinick, M., Braver, T. S., Barch, D. D. M., Carter, C. S., & Cohen, J. D. (2001). Conflict monitoring and cognitive control. *Psychological Review*, 108(3), 624–652. <https://doi.org/10.1037/0033-295X.108.3.624>
- Charles, L., & Haggard, P. (2019). Feeling free: External influences on endogenous behaviour. *Quarterly Journal of Experimental Psychology*, 174702181988806. <https://doi.org/10.1177/1747021819888066>
- Dehaene, S., Artiges, E., Naccache, L., Martelli, C., Viard, A., Schürhoff, F., ... Martinot, J. L. (2003). Conscious and subliminal conflicts in normal subjects and patients with schizophrenia: The role of the anterior cingulate. *Proceedings of the National Academy of Sciences of the United States of America*, 100(23), 13722–13727. <https://doi.org/10.1073/pnas.2235214100>
- Demanet, J., Verbruggen, F., Liefoghe, B., & Vandierendonck, A. (2010). Voluntary task switching under load: Contribution of top-down and bottom-up factors in goal-directed behavior. *Psychonomic Bulletin and Review*, 17(3), 387–393. <https://doi.org/10.3758/PBR.17.3.387>
- Desender, K., Van Lierde, E., & Van den Bussche, E. (2013). Comparing Conscious and Unconscious Conflict Adaptation. *PLoS ONE*, 8(2), e55976. <https://doi.org/10.1371/journal.pone.0055976>
- Duster, T. (2008). Introduction to unconscious racism debate. *Social Psychology Quarterly*. <https://doi.org/10.1177/019027250807100102>
- Epstein, R., & Robertson, R. E. (2015). The search engine manipulation effect (SEME) and its possible impact on the outcomes of elections. *Proceedings of the National Academy of Sciences*, 112(33), E4512–E4521. <https://doi.org/10.1073/pnas.1419828112>
- Eriksen, B. A., & Eriksen, C. W. (1974). Effects of noise letters upon the identification of a target letter in a nonsearch task. *Perception & Psychophysics*. <https://doi.org/10.3758/BF03203267>

- 822 Filevich, E., Vanneste, P., Brass, M., Fias, W., Haggard, P., & Kühn, S. (2013). Brain correlates
823 of subjective freedom of choice. *Consciousness and Cognition*, 22(4), 1271–1284.
824 <https://doi.org/10.1016/j.concog.2013.08.011>
- 825 Francken, J. C., Gaal, S. van, & de Lange, F. P. (2011). Immediate and long-term priming
826 effects are independent of prime awareness. *Consciousness and Cognition*, 20(4), 1793–
827 1800. <https://doi.org/10.1016/j.concog.2011.04.005>
- 828 Frith, C. D. (2005). The neural basis of hallucinations and delusions. *Comptes Rendus -*
829 *Biologies*, 328(2), 169–175. <https://doi.org/10.1016/j.crvi.2004.10.012>
- 830 Fröber, K., & Dreisbach, G. (2017). Keep flexible – Keep switching! The influence of forced
831 task switching on voluntary task switching. *Cognition*, 162, 48–53.
832 <https://doi.org/10.1016/j.cognition.2017.01.024>
- 833 Goschke, T. (2003). Voluntary action and cognitive control from a cognitive neuroscience
834 perspective. In *Voluntary action: Brains, minds, and sociality*. (pp. 49–85). Retrieved from
835 <https://psycnet.apa.org/record/2003-06267-003>
- 836 Hansen, K., Gerbasi, M., Todorov, A., Kruse, E., & Pronin, E. (2014). People Claim Objectivity
837 After Knowingly Using Biased Strategies. *Personality and Social Psychology Bulletin*,
838 40(6), 691–699. <https://doi.org/10.1177/0146167214523476>
- 839 Henik, A., & Tzelgov, J. (1982). Is three greater than five: The relation between physical and
840 semantic size in comparison tasks. *Memory & Cognition*, 10(4), 389–395.
841 <https://doi.org/10.3758/BF03202431>
- 842 Imhoff, R., & Erb, H.-P. (2009). What motivates nonconformity? Uniqueness seeking blocks
843 majority influence. *Personality & Social Psychology Bulletin*, 35(3), 309–320.
844 <https://doi.org/10.1177/0146167208328166>
- 845 Kiani, R., Hanks, T. D., & Shadlen, M. N. (2008). Bounded Integration in Parietal Cortex
846 Underlies Decisions Even When Viewing Duration Is Dictated by the Environment.
847 *Journal of Neuroscience*, 28(12), 3017–3029. <https://doi.org/10.1523/JNEUROSCI.4761-07.2008>
- 849 Kiesel, A., Steinhauser, M., Wendt, M., Falkenstein, M., Jost, K., Philipp, A. M., & Koch, I.
850 (2010). Control and interference in task switching-a review. *Psychological Bulletin*, 136(5),
851 849–874. <https://doi.org/10.1037/a0019842>
- 852 Kirsch, I., Lynn, S. J., Vigorito, M., & Miller, R. R. (2004). The Role of Cognition in Classical
853 and Operant Conditioning. *Journal of Clinical Psychology*, 60(4), 369–392.
854 <https://doi.org/10.1002/jclp.10251>
- 855 Koch, I., Gade, M., Schuch, S., & Philipp, A. M. (2010). The role of inhibition in task switching:
856 A review. *Psychonomic Bulletin and Review*, 17(1), 1–14.
857 <https://doi.org/10.3758/PBR.17.1.1>

- 858 Kunde, W., Reuss, H., & Kiesel, A. (2012). Consciousness and cognitive control. *Advances in*
 859 *Cognitive Psychology*. University of Finance and Management in Warsaw.
 860 <https://doi.org/10.2478/v10053-008-0097-x>
- 861 Lages, M., Boyle, S. C., & Jaworska, K. (2013). Flipping a coin in your head without monitoring
 862 outcomes? Comments on predicting free choices and a demo program. *Frontiers in*
 863 *Psychology*, 4(DEC), 925. <https://doi.org/10.3389/fpsyg.2013.00925>
- 864 Lages, M., & Jaworska, K. (2012). How Predictable are “Spontaneous Decisions” and “Hidden
 865 Intentions”? Comparing Classification Results Based on Previous Responses with
 866 Multivariate Pattern Analysis of fMRI BOLD Signals. *Frontiers in Psychology*, 3(MAR), 56.
 867 <https://doi.org/10.3389/fpsyg.2012.00056>
- 868 Lavie, N. (2010). Attention , Distraction , and Cognitive Control Under Load.
 869 <https://doi.org/10.1177/0963721410370295>
- 870 Le Bars, S., Hsu, Y. F., & Waszak, F. (2016). The impact of subliminal effect images in
 871 voluntary vs. stimulus-driven actions. *Cognition*, 156, 6–15.
 872 <https://doi.org/10.1016/j.cognition.2016.07.005>
- 873 Maren, S. (2001). NEUROBIOLOGY OF PAVLOVIAN FEAR CONDITIONING. *Annual Review*
 874 *of Neuroscience*, 24(1), 897–931.
 875 <https://doi.org/10.1146/annurev.psych.55.090902.141409>
- 876 Mayr, U. (2004). Conflict, consciousness, and control. *Trends in Cognitive Sciences*, 8(4),
 877 145–148. <https://doi.org/10.1016/j.tics.2004.02.006>
- 878 Miron, A. M., & Brehm, J. W. (2006). Reactance Theory - 40 Years Later. *Zeitschrift Fur*
 879 *Sozialpsychologie*, 37(1), 9–18. <https://doi.org/10.1024/0044-3514.37.1.9>
- 880 Molina, M. T., & Davis, G. (2018). Unconscious priming dissociates ‘free choice’ from
 881 ‘spontaneous urge’ responses. *Consciousness and Cognition*, 60, 72–85.
 882 <https://doi.org/10.1016/j.concog.2018.02.003>
- 883 Newell, B. R., & Shanks, D. R. (2014). Unconscious influences on decision making: A critical
 884 review. *Behavioral & Brain Sciences*, 37(1), 1–19.
 885 <https://doi.org/10.1017/S0140525X12003214>
- 886 O'Connor, P. A., & Neill, W. T. (2011). Does subliminal priming of free response choices
 887 depend on task set or automatic response activation? *Consciousness and Cognition*,
 888 20(2), 280–287. <https://doi.org/10.1016/j.concog.2010.08.007>
- 889 Ocampo, B. (2015). Unconscious manipulation of free choice by novel primes. *Consciousness*
 890 *and Cognition*, 34, 4–9. <https://doi.org/10.1016/j.concog.2015.03.007>
- 891 Pronin, E., Lin, D. Y., & Ross, L. (2002). The bias blind spot: Perceptions of bias in self versus
 892 others. *Personality and Social Psychology Bulletin*, 28(3), 369–381.

- 893 <https://doi.org/10.1177/0146167202286008>
- 894 Roitman, J. D., & Shadlen, M. N. (2002). Response of neurons in the lateral intraparietal area
895 during a combined visual discrimination reaction time task. *The Journal of Neuroscience*,
896 22(21), 9475–9489. [https://doi.org/10.1016/S0377-2217\(02\)00363-6](https://doi.org/10.1016/S0377-2217(02)00363-6)
- 897 Schlaghecken, F., & Eimer, M. (2004). Masked prime stimuli can bias quot;freequot; choices
898 between response alternatives. *Psychonomic Bulletin and Review*, 11(3), 463–468.
899 <https://doi.org/10.3758/BF03196596>
- 900 Scott-Parker, B., King, M. J., & Watson, B. (2015). The psychosocial purpose of driving and its
901 relationship with the risky driving behaviour of young novice drivers. *Transportation*
902 *Research Part F: Traffic Psychology and Behaviour*, 33, 16–26.
903 <https://doi.org/10.1016/j.trf.2015.06.004>
- 904 Steindl, C., Jonas, E., Sittenthaler, S., Traut-Mattausch, E., & Greenberg, J. (2015).
905 Understanding psychological reactance: New developments and findings. *Zeitschrift Fur*
906 *Psychologie / Journal of Psychology*, 223(4), 205–214. [https://doi.org/10.1027/2151-](https://doi.org/10.1027/2151-2604/a000222)
907 2604/a000222
- 908 Stillman, T. F., Baumeister, R. F., & Mele, A. R. (2011). Free will in everyday life:
909 Autobiographical accounts of free and unfree actions. *Philosophical Psychology*, 24(3),
910 381–394. <https://doi.org/10.1080/09515089.2011.556607>
- 911 Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental*
912 *Psychology*. <https://doi.org/10.1037/h0054651>
- 913 van Gaal, S., de Lange, F. P., & Cohen, M. X. (2012, May 7). The role of consciousness in
914 cognitive control and decision making. *Frontiers in Human Neuroscience*. Frontiers Media
915 S. A. <https://doi.org/10.3389/fnhum.2012.00121>
- 916 Wenke, D., Fleming, S. M., & Haggard, P. (2010). Subliminal priming of actions influences
917 sense of control over effects of action. *Cognition*, 115(1), 26–38.
918 <https://doi.org/10.1016/j.cognition.2009.10.016>
- 919 Williams, J. M. G., Mathews, A., & MacLeod, C. (1996). The Emotional Stroop Task and
920 Psychopathology. *Psychological Bulletin*, 122(1), 3–24. [https://doi.org/10.1037/0033-](https://doi.org/10.1037/0033-2909.120.1.3)
921 2909.120.1.3
- 922
- 923

SUPPLEMENTARY MATERIALS

SUPPLEMENTARY METHOD

1.1.11 Block Design

Experiment 1. The combination of orientation (left and right) and instruction type (Adhere, Oppose, Detach) generated 6 possible outcomes (i.e. orientation left to adhere; orientation right to adhere, etc) as an experimental trial in each group. Due to the between-subjects design, each group was assigned more Adhere trials than Oppose trials, or more Oppose trials than Adhere trials, whilst the proportion of Detach trials remained the same. Hence, Adhere Group had 50% Adhere trials and 17% Oppose trials (33% detach trials), whilst Oppose Group had 17% Adhere trials, 50% Oppose trials (and 33% Detach trials). Each block consisted of 54 trials consisting of the proportions mentioned above. This left a total of 378 trials of interest over 7 blocks. Additionally, each block of trials included 3 high coherence trials.

Experiment 2. The mixed experimental design was so that each group was assigned to either group majority left responses, or group majority right responses. Hence, the combination of orientation (left and right) and instruction type (Adhere, Oppose, Detach) was altered so that there was more Adhere for one direction, and more Oppose for the other direction. Using group left as an example, the Adhere trials (30% of all trials) consisted of 75% left-direction stimuli, and 25% right-direction stimuli. On Oppose trials (30% of all trials), 75% was right-direction stimuli and 25% left-direction stimuli. The percentage of Detach trials was 40%, of which 75% were motion-present at 25% motion-neutral. For each group, there was a total of 67 randomly arranged experimental trials of interest per block (and a total of 469 trials of interest over 7 blocks) following the proportions mentioned above. Additionally, each block of trials included 3 high coherence trials.

Experiment 3. Again, the mixed experimental design was so that participants were assigned to see either left-ward stimulus frequently, or right-ward. Hence, the combination of orientation (left, right) and instruction type (Adhere, Oppose, Detach) was so that there was more of one direction than the other across all three instruction types. Overall, 75% of all trials was one direction (e.g. leftward for group majority left), and 25% the other (e.g. rightward for group majority right). 30% of trials were Adhere, 30% were Oppose, 27% Detach (two thirds motion-present at one third motion-neutral). For each group, there was a total of 60 randomly arranged experimental trials of interest per block (and a total of 420 trials of interest over 7 blocks) following the proportions mentioned above. Additionally, each block of trials included 3 high coherence trials.

1.1.12 Staircase Procedure

The coherence level of RDM displays in the main experiment was adjusted to the individual accuracy rate of 70.7% through a 2-down-1-up staircase procedure (Levitt, 1971). The procedure presented participants with a series of RDM displays, starting at a motion coherence of 40%. The instruction was to respond with a left or right button press congruent to the direction they believed the dots to be moving in. For the first 12 trials, the motion coherence

remained at 40% to get participants used to this task. Subsequently, the motion coherence changed in such a way that two consecutive correct guesses lowered the coherence, and a single error increased the coherence. The motion coherence was increased/decreased by a set value (the step-size). This started at 6% but halved every time the participant had two consecutive errors (until the minimum step-size of 1.5%). The staircase procedure obtained the estimate of the motion coherence needed by averaging the coherence over the last 40 trials (out of 150).

SUPPLEMENTARY RESULTS

1.1.13 Bias awareness

Experiment 2. All participants were asked to estimate the proportion of right responses across all trials of the experiment on a scale from 0 (only left responses) to 100 (only right responses). An estimate of 50 would reflect 50/50 left and right responses. A one-sample t-test was performed for each group, comparing the estimated perceptual bias to chance level (50%). Both descriptive statistics and t-test comparisons are reported in Table S1. The null effect for both groups meant that participants did not feel they responded more of one button than the other, and hence were not aware of our response bias manipulation.

Table S1

Bias Awareness: Means and Standard Deviation for Estimated Proportion of Right Responses (by group), and T-test Comparison to Chance Level (50%)

Group	M	SD	t	df	p	d
Group Majority Left Responses	48.80%	17.21%	0.31	19	.760	0.07
Group Majority Right Responses	52.33%	19.39%	0.51	17	.620	0.12

Experiment 3. All participants were asked to estimate the proportion of right-direction trials on a scale from 0 (all left-direction trials) to 100 (all right-direction trials). A one-sample t-test was performed for each group, comparing the estimated perceptual bias to chance level (50%). Both descriptive statistics and t-test comparisons are reported in Table S2. The null effect for group majority leftward stimuli suggest that participants did not feel they saw either direction more than the other, and hence were not aware of our stimulus frequency manipulation. However, group majority rightward stimuli reported significantly more right-direction trials than left-direction trials, suggesting an awareness of the stimulus frequency manipulation

Table S2

Bias Awareness: Means and Standard Deviation for Estimated Proportion of Right-direction Trials (by group), and T-test Comparison to Chance Level (50%)

Group	M	SD	t	df	p	d
Group Majority Leftward Stimuli	48.70%	19.99%	0.291	19	.770	0.07

Group Majority Rightward Stimuli	59.29%	13.95%	2.75	16	.014	0.67
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1.1.14 Reaction Time on Detach Trials

Experiment 1. There was no main effect of response mode for reaction time on detach trials responses [$F(1, 58) = 2.21, p = .142, \eta_p^2 = .000$], reflecting that a congruent response was no easier made than an incongruent response. There was also no main effect of group [$F(1, 58) = 0.01, p = .906, \eta_p^2 = .000$], or an interaction between group and response mode [$F(1, 58) = 0.12, p = .730$], suggesting that being trained for one strategy (Adhere Group vs Oppose Group) does not influence the ease at which participants go with or against that strategy on detach trials as measured in reaction time.

Figure S1. Mean reaction time in milliseconds on Experiment 1 split by instruction (Adhere, Oppose, Detach), group (Adhere Group, Oppose Group), and response mode (congruent responses, white bars; incongruent responses, grey bars).

Experiment 2. On motion-present detach trials, there was no difference in the reaction time between a congruent and an incongruent response [main effect response mode; $F(1, 36) = 1.70, p = .201, \eta_p^2 = .045$]. There was also no main effect of stimulus-response association [$F(1, 36) = 0.04, p = .846, \eta_p^2 = .001$], or an interaction between stimulus-response association and response mode [$F(1, 36) = 1.28, p = .266, \eta_p^2 = .034$]. This suggests that being trained for one strategy at one particular stimulus does not influence the ease at which participants go with or against that strategy on detach trials as measured in reaction time.

The results on motion-neutral detach trials were similar to that of motion-present detach trials, with no main effect of response mode [$F(1, 36) = 0.73, p = .398, \eta_p^2 = .019$] stimulus-response association [$F(1, 36) = 0.23, p = .634, \eta_p^2 = .006$], or interaction between response mode and stimulus-response association [$F(1, 36) = 2.50, p = .122, \eta_p^2 = .063$]. This suggests that regardless of fluctuations in motion energy favouring one direction over the other, or whether a motor response is one made frequently or rarely over past trials, there is no difference in the ease at which participants make such a response on detach trials.

Figure S2. Mean reaction time in milliseconds on Experiment 2 split by instruction (Adhere, Oppose, Detach), stimulus-response association (frequently adhered, frequently opposed), and response mode (congruent responses, white bars; incongruent responses, grey bars).

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1022 **Experiment 3.** Again, there was no difference in the reaction time on detach trials between a
 1023 congruent and an incongruent response [main effect response mode; $F(1, 35) = 0.39, p = .538,$
 1024 $\eta_p^2 = .011$]. There was also no main effect of stimulus frequency [$F(1, 35) = 0.81, p = .373, \eta_p^2$
 1025 $= .023$]. This suggests that seeing one stimulus direction more often than the other does not
 1026 influence the ease at which one can detach from that stimulus as reflected in reaction times.
 1027 There was, however, a 3-way interaction with group, response mode, and stimulus frequency,
 1028 which is reported and discussed in Supplementary Results.

1029 Motion-neutral detach trials also had no difference in reaction time between response modes
 1030 [$F(1, 35) = 0.07, p = .788, \eta_p^2 = .002$] or stimulus frequency [$F(1, 36) = 0.16, p = .691, \eta_p^2 = .005$].
 1031 Hence, all detach trials suggested that the frequency at which a cue is presented does not
 1032 influence the ability to detach from that cue as measured in reaction time.

1033 **Figure S3.** Mean reaction time in milliseconds split by instruction (Adhere, Oppose, Detach),
 1034 stimulus frequency (frequent, rare), and response mode (congruent responses, white bars;
 1035 incongruent responses, grey bars).
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GROUP DIFFERENCES ON EXPERIMENT 2 AND 3

Experiment 2. The same was true for experiment 2, where participants were assigned to press either more of the right button than the left, or more of the left button than the right. Whether making more of a right or left button press influenced the ability to detach or subjective rating of detachment was not of interest to our hypotheses. We did however observe group-dependent findings for accuracy on instructed trials [interaction group and stimulus-response association: $F(1, 36) = 7.91, p = .008$], as well as proportion of motion congruent responses on detach trials [interaction group and motion coherence: $F(1, 36) = 4.16, p = .049$].

The group differences observed were perhaps due to a population-based preference for making one motor response over the other, which interacted with our response frequency manipulations.

Experiment 3. For experiment 3, participants were assigned to either see mostly leftward stimuli, or mostly rightward stimuli. We were interested in the ability to detach and subjective introspection of detachment from the stimulus, and how it differed between a frequent and a rare stimulus. Group differences in our statistical analyses, reflecting that seeing a lot of rightward motion compared to leftward motion influenced subjective and objective FoC, were not of interest in regard to our hypotheses. However, we observed group difference in on instructed trials for subjective rating of freedom [interaction group, instruction, and stimulus frequency: $F(1, 36) = 5.03, p = .031$], as well as accuracy [interaction group and stimulus frequency: $F(1, 36) = 7.29, p = .011$].

The group differences observed were likely due to increased or decreased sensitivity to one motion over the other. Previous research has indicated that subjects that have English or another left-to right reading language have a higher sensitivity for leftward motion (Morikawa & McBeath, 1991), but more research is needed to determine the cause of our group effects.

REGRESSION

Table S3

Regressing difference in subjective freedom of choice from incongruent to pro responses with motion consistency and difference in reaction time (RT) as predictors. Datapoints are combined across experiments.

	b	t	df	p
Adhere Group, frequently adhered stimuli, rare stimuli combined				
Intercept	6.57	6.17	102	.000
Motion Consistency*	-9.87	2.73	102	.008
RT difference pro	0.02	2.25	102	.026

Oppose Group, frequently opposed stimuli, frequent stimuli combined				
Intercept	5.41	4.28	102	.000
Motion Consistency*	-13.36	2.54	102	.130
RT difference incong-cong	-0.01	0.81	102	.420

Note. Motion consistency measured as proportion of incongruent responses minus the proportion of congruent responses on detach trials.

Figure S4. Difference in subjective freedom of choice (FoC) to incongruent minus congruent responses on motion-present detach trials correlated with difference in proportion of incongruent minus congruent responses on motion-present detach trials. This is split by each experiment, and the experiment-specific main manipulation (Adhere Group vs Oppose Group on Experiment 1; frequently adhered vs frequently opposed stimuli on Experiment 2; frequent vs rare stimuli on Experiment 3)

SUPPLEMENTARY REFERENCES

Morikawa, K., & McBeath, M. K. (1992). Lateral motion bias associated with reading direction. *Vision Research*, 32(6), 1137–1141. [https://doi.org/10.1016/0042-6989\(92\)90014-A](https://doi.org/10.1016/0042-6989(92)90014-A)

Levitt, H. (1971). Transformed Up-Down Methods in Psychoacoustics. *The Journal of the Acoustical Society of America*, 49(2B), 467–477. <https://doi.org/10.1121/1.1912375>