Consciousness and Cognition 22 (2013) 1253–1261

Contents lists available at ScienceDirect

Consciousness and Cognition

journal homepage: www.elsevier.com/locate/concog

# Hedonic value of intentional action provides reinforcement for voluntary generation but not voluntary inhibition of action

Jim Parkinson *, Patrick Haggard

*Institute of Cognitive Neuroscience, University College London, London, UK*

ARTICLE INFO

*Article history:*
Received 29 January 2013
Available online 8 September 2013

*Keywords:*
Intention
Volition
Inhibition
Reward
Hedonic value
Reinforcement
Free will
Action
Decision making

ABSTRACT

Intentional inhibition refers to stopping oneself from performing an action at the last moment, a vital component of self-control. It has been suggested that intentional inhibition is associated with negative hedonic value, perhaps due to the frustration of cancelling an intended action. Here we investigate hedonic implications of the free choice to act or inhibit. Participants gave aesthetic ratings of arbitrary visual stimuli that immediately followed voluntary decisions to act or to inhibit action. We found that participants for whom decisions to act produced a strong positive hedonic value for the immediately following visual stimulus made more choices to act than those with weaker hedonic value for action. This finding is consistent with reinforcement learning of action decisions. However, participants who experienced inhibition as generating more positive hedonic value did not choose to inhibit more than other participants. Thus, voluntary inhibition of action did not act as reinforcement for future inhibitory behaviour. Our finding that inhibition of action lacks motivational capacity may explain why self-control is both difficult and limited.



## 1. Introduction

The feeling of deciding and controlling one's own behaviour – of intentional action – is a fundamental aspect of human mental life. However, defining the unique features of actions that make them specifically intentional – as opposed to reactive or "absent-mindedly" reflexive – has proven problematic. A common idea suggests that actions are intentional if the agent 'could have done otherwise'. One psychological interpretation of this idea invokes healthy adults' capacity to withhold or 'veto' actions that they are about to make. Many people recognise the experience of becoming very angry with a friend to the point of saying something they would regret later... and then feeling relieved if they did indeed stop themselves from saying those cross words at the very last minute. We use the term intentional inhibition to refer to this capacity to voluntarily refrain from an impending action just before execution.

Thus, just as intentional action can be defined in terms of behaviour that is selected and executed based upon endogenous (internally generated) processes (Passingham, Bengtsson, & Lau, 2010), so intentional inhibition can be defined as an endogenously-generated last-moment "brake" on an action that is about to be executed. While inhibition of action triggered by external stimuli has been extensively studied (Logan, Cowan, & Davis, 1984; Verbruggen & Logan, 2008), intentional inhibition of action has been neglected until relatively recently, despite growing awareness of the need to accommodate volition within theories of cognitive control (Aron, 2011).

* Corresponding author. Address: Institute of Cognitive Neuroscience, University College London, Alexandra House, 17 Queen Square, London WC1N 3AR, UK. Fax: +44 20 7813 2835.

*E-mail address:* jimparkinson@me.com (J. Parkinson).

1053-8100/$ - see front matter 
http://dx.doi.org/10.1016/j.concog.2013.08.009

Brass and Haggard (2008) included intentional inhibition in a general cognitive model of intentional action, by postulating three distinct decision processes: what action to perform, when to perform it, and whether to actually go ahead with it. Neuroimaging evidence for the whether decision came from a modified version of the Libet task (Brass & Haggard, 2007). Participants were instructed to make volitional key-press actions, and report the timing of their intention to do so as in Libet's experiment (see Libet, Gleason, Wright, & Pearl, 1983), but were also instructed to sometimes cancel the key-press action at the last possible moment. An area in the dorsal fronto-median cortex (dFMC) was active when participants intentionally inhibited their action, compared to when they intentionally acted. This area might therefore house a "brake mechanism" for overriding and inhibiting areas that participate in voluntary action, such as the presupplementary motor area (pSMA; Kühn, Haggard, & Brass, 2009).

Interestingly, Brass and Haggard (2007) also found activations of anterior insula cortex (AIC) on intentional inhibition trials. They speculated that this could reflect a negative hedonic feeling due to the "frustration" of inhibiting an action that had already been prepared. The AIC has previously been associated with the processing of inhibitory failure (Ramautar, Slagter, Kok, & Ridderinkhof, 2006) and disappointment (Chua, Gonzalez, Taylor, Welsh, & Liberzon, 2009). Further, a positive or negative hedonic response to inhibition could provide a valuable reinforcement signal biasing selection of action or inhibition on subsequent occasions. In this way, the "will" might be affectively trained by appropriately reinforcing some courses of action, while reinforcing inhibition from other courses of action.

Importantly, action and inhibition may have hedonic value for two quite distinct reasons. First, action and inhibition processes might have different intrinsic hedonic values: for example, inhibiting an action might be intrinsically less satisfying than executing it, as Brass and Haggard (2007) suggested. Second, action and inhibition may each be associated with specific external rewards (Guitart-Masip et al., 2011). These extrinsic relations between action and value are widely studied under the labels of goal-directed action, and decision-making. However, the intrinsic hedonic values of action and inhibition have not been widely studied, and it remains unclear how such intrinsic value guides voluntary action choices. Here we have studied the intrinsic hedonic value of action and inhibition by instrumentally associating free choices to act or inhibit action with arbitrary visual effects, and asking participants to make hedonic judgements of those visual images. Thus, we have studied value of action/inhibition through association with their outcomes, taking advantage of the transmission of value between associated events in the same way as studies of goal-directed decision-making. However, our approach differs in one crucial respect. In goal-directed decision-making studies, the value is transferred from outcome to action or to inhibition. However, in our approach, the outcomes are themselves valueless, and value is transferred in the other direction, from action or from inhibition to outcome. The hedonic value of outcomes thus becomes a useful experimental probe for the intrinsic hedonic value of action and of inhibition (see Fig. 1).

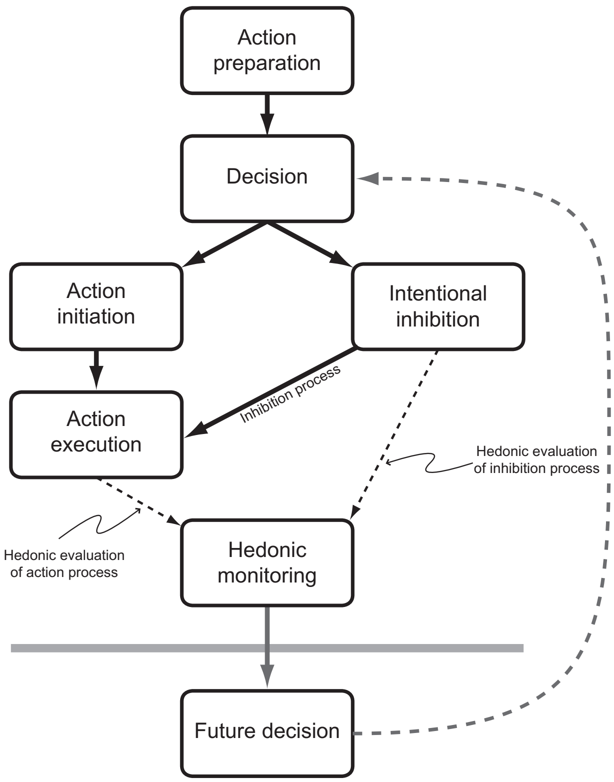


**Fig. 1.** A schematic of hedonic processes involved in volitional action and intentional inhibition. Adapted from Brass and Haggard (2010).

We have therefore investigated the relation between the hedonic value of intentional action and inhibition, and motivational guidance of action choices. Specifically, we asked whether intentional inhibition of action indeed has hedonic consequences, and whether these hedonic consequences might contribute to free decisions to either act or inhibit in the future. This would be in line with suggestions that hedonic pleasure is a key motivational factor – a form of mental "common currency" – behind decision making (Cabanac, 1992; McFarland & Sibly, 1975). Participants were asked to prepare either a left or right hand button press. If they then saw a green arrow, they had to execute the prepared action as quickly as possible (Go trials), but if they saw a white arrow they could make a momentary decision to follow through with the action or inhibit its execution (Volition trials). In order to measure hedonic impact of this decision, meaningless Walsh images (Richmond & Optican, 1990) were presented after each such free-choice trial. Thus a specific image became the effect of either action or of inhibiting action. These images had no hedonic value in themselves, but we hypothesised that they could acquire hedonic value by their association either with action or with inhibition. Thus, we aimed to measure the intrinsic hedonic value of action and inhibition by asking participants to rate their liking for arbitrary images that resulted from action or inhibition. This design also allowed us to assess the motivational impact of hedonic value related to action decisions. Specifically, we asked whether more positive hedonic value for an image paired with action or inhibition would lead to choose action or inhibition in subsequent free choices, as reinforcement learning theories would predict.

## 2. Methods

### *2.1. Participants*

Twenty participants (11 female, mean age 23.6, SD 3.07) were recruited from the UCL participant pool. All were self-reported right-handers, had normal or corrected-to-normal vision and were paid £7.50 for the hour-long total duration of the experiment.

### *2.2. Stimuli and procedure*

The experiment was presented using a computer running the Psychophysics Toolbox v3 (Brainard, 1996; Kleiner, Brainard, & Pelli, 2007; Pelli, 1996). Participants sat in front of the computer with the index fingers of both hands placed over two buttons which were denoted by task instruction as "Left" and "Right" responses. Fig. 2 shows the structure of a single trial. Following a fixation cross (duration 1500 ms), a written cue was presented onscreen for 3000 ms stating "PREPARE LEFT" or "PREPARE RIGHT". This was the participants' cue to prepare a button press with the appropriate finger. During pre-experiment instruction, it was repeatedly stressed that participants should be as prepared as possible to perform the cued action.

Half of the trials were randomly selected to be "Go" trials: A centrally-located green arrow appeared, always pointing in the same direction as the previous preparation cue. Participants were instructed to respond as rapidly as possible with the appropriate key-press. If they responded within a response window (see later), they received positive feedback (smiley face for 1700 ms). Failure to respond correctly produced a sad face. The response window for these trials adaptively varied, start-

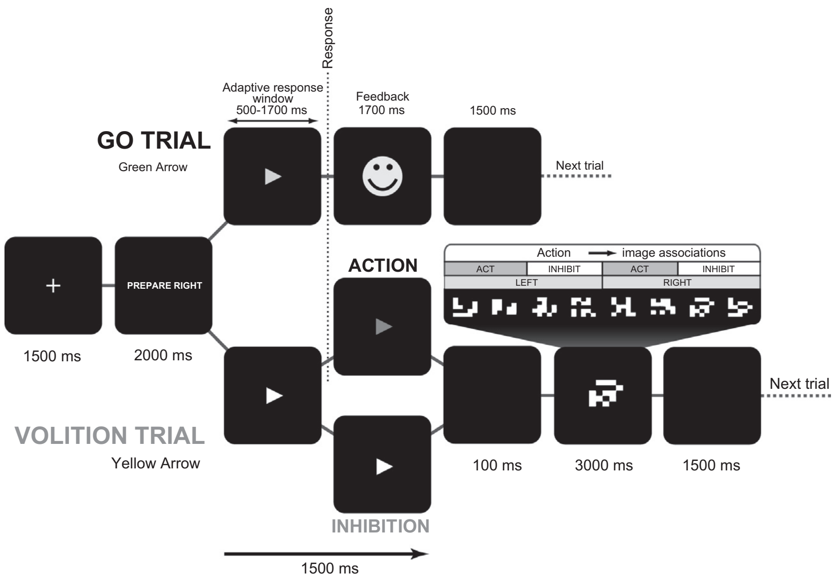


**Fig. 2.** Schematic diagram of the trial sequences.

ing at 1200 ms, reducing by 50 ms every time a participant successfully responded in time to a Go trial (to a minimum of 500 ms), and increasing by 50 ms with every late response, to a maximum of 1700 ms. This meant that the Go task tended to become more difficult as participants responded more successfully. Participants were informed of this, and were repeatedly told in the pre-experiment instruction that it was absolutely necessary to prepare the cued action to respond successfully on Go trials.

The remaining 50% of trials were free-choice trials. A white arrow appeared, again always pointing in the previously prepared direction. Participants were instructed that upon presentation of the white arrow, they should make an immediate choice to either execute the action they had previously prepared, or inhibit making the action. They were told to act on roughly half these trials and inhibit on the others, but to avoid pre-established strategies such as alternating between action and inhibition. It was further stressed that decisions to act or inhibit should be made in response to the white arrow, and that action preparation should be prioritised up until that point, in case the trial was a Go trial requiring a fast response. The response window of Volition trials was 1500 ms. If a participant made an action, the arrow changed from white to grey for the rest of this duration, otherwise the arrow remained white.

Participants were allowed to practice on this procedure involving Go and volition trials prior to the experimental phase. During practice, the experimenter (JP) monitored performance and repeated instructions as appropriate. Practice consisted of 32 trials, 16 Go trials, 8 of each hand; and 16 Volition trials, 8 on each hand.

The experimental phase consisted of four blocks of 48 trials each, 24 Go trials, split evenly between left and right response cues, and 24 Volition trials, again evenly split between left and right response cues. Trial orders were randomised for each participant.

Walsh images (Richmond & Optican, 1990) were created by filling a grid of $5 \times 5$ squares randomly with 12 white squares to create simple geometric patterns. A pool of 256 such images were created for the experiment. Of these 256 Walsh images originally generated, 64 were randomly selected for use in a participants' experimental session, 16 assigned randomly to each experimental block. Eight were distractor images for use in the recognition test, and the other eight were presented after Volition trials – two images for each of the four possible action effects defined by combining the action/inhibition factor with the left/right factor. Images were presented for 3 s immediately after the response window on each Volition trial, so that any hedonic value generated by acting or inhibiting would come to be associated with the corresponding image during the course of the block. Participants were instructed to attend to these images for subsequent memory testing.

Because participants made voluntary choices to act or inhibit, the number of times each image was seen could vary. Repeated exposure classically increases positive hedonic value (mere exposure effect; Zajonc, 1968). However, the set of Walsh images was regenerated anew for each block, meaning that exposure-related changes in hedonic value could only occur within blocks but not across blocks. We could thus remove within-block mere exposure effects using a regression model, to separate the residual hedonic component corresponding to the intrinsic hedonic value of intentional action or inhibition from the hedonic value accrued as a result of mere exposure.

Because participants freely chose whether to act or inhibit, it was inevitable that some participants might preferentially act or inhibit, although during the briefing they were given encouragement to utilise the choices to act or inhibit equally in volitional trials, whilst avoiding any strategies which might dictate their choice. Nevertheless, the number of exposures of each image often varied. In order to roughly equalise exposure of the two images associated with each combination of hand and action/inhibition, those two images were alternated. Thus, on the first instance, one of the two images was randomly presented, and the next instance elicited the alternate image, and so on.

At the end of each block, participants performed a recognition task and an hedonic ranking task. In the recognition task, the 8 Walsh images selected for that block were shown together with a further 8 selected not presented in the block. Each image was presented individually, in random order. Participants made un-speeded manual responses to indicate whether they had previously seen each image in that block.

Next, participants made an hedonic ranking of the images they had seen on that block. All 8 images associated with voluntary action/inhibition were presented at once, in random positions. Participants were asked to inspect the 8 images and rank order them in terms of "how much they liked them", from most to least. Because image presentation depended on free choice, some images might never have been seen during the experimental trials in that block. Such images were still presented in both recognition and hedonic value tests, but their hedonic value rating was not analysed.

Following these two tasks, participants were informed that the images in the next block would be different to any already seen. They were then given the opportunity for a short break before the start of the next block.

## 3. Results

### *3.1. Response times and recognition task*

Participants occasionally pressed the wrong response button on Go trials (mean 0.2%, SD 0.5) and Volitional trials (mean 0.4%, SD 1.1). On Go trials, some responses fell outside the response window (mean 9.1%, SD 6.3%). This was to be expected considering that the response time window for Go trials became shorter according to response performance, in order to elicit maximum action preparation in all trials. All error trials were discounted from further analysis.

Mean response times (RT) on Go trials (mean 344 ms, SD 38.3) were significantly faster than for Volition trials in which an action was performed (mean 558 ms, SD 161), $t(19) = 6.43$, $p < .001$, two-tailed. The mean percentage of trials in which participants chose to Act rather than Inhibit was 51.0% (SD 19.8). A one-sample *t*-test comparing the percentage of Actions against a rate of 50% was clearly not-significant, $t(19) = 0.216$, $p = .831$. This indicates that participants did tend to split their voluntary choices evenly between Action and Inhibition.

On the recognition task, participants scored on average 79.3% correct (SD 16.3), significantly better than the chance score of 50%, $t(19) = 8.03$, $p < .001$. This suggested that participants did pay attention to the Walsh images presented on volition trials.

The hedonic value data measured for images associated with Action and Inhibition effects was analysed for overall mean hedonic value, for residual hedonic value after removing effects of mere exposure, and to determine if hedonic value influenced participants' behavioural choices to act or inhibit.

### 3.2. Mean hedonic value

For each participant, hedonic value scores were calculated for each of the 8 images presented within each block, based on the ranking made at the end of each block. The preferred image was scored as 7, and the least preferred scored as 0.

To compare the hedonic value of action and inhibition mean hedonic value scores were computed for images presented after action and after inhibition. In a few instances, a participant's action/inhibition choices might mean they would never be presented with a particular image in a block (for example, if they never chose to inhibit when asked to use their left hand). In this case, the hedonic rating for that image was omitted from the analysis. This occurred for at least one image in the case of eight participants. In the case of the most extreme participant, of the 32 images potentially displayed, seven were omitted.

There was no significant difference between mean hedonic value for Action-associated images (mean 3.49, SD 0.58) and Inhibition-associated images (mean 3.51, SD 0.58: $t(19) = 0.09$, $p = .926$, suggesting that intentional action and intentional inhibition have similar intrinsic hedonic value.

### 3.3. Analysis of Intrinsic and accrued hedonic value

In a second analysis, we used linear regression to separate out hedonic value accrued due to mere exposure (that is, how hedonic value changes within blocks due to repeatedly viewing the images; Zajonc, 1968) from an intrinsic hedonic value independent of repeated exposures. For each participant, the hedonic value score for each image was linearly regressed against the number of exposures to that image, separately for action-related and inhibition-related images. The slope (beta) for each of these regressions was taken as a measure of accrued hedonic value due to exposure, while the intercept was interpreted as an intrinsic hedonic value score, independent of mere exposure effects. This intrinsic score was attributed to the intrinsic hedonic value of the action or inhibition that caused the image, irrespective of how many times it did so.

Fig. 3 shows mean regression lines for Action and Inhibition images. While individual regressions varied in strength (median $r^2 = .136$), the slopes were generally positive, suggesting accrual of hedonic value with repeated exposure. One-sample *t*-tests showed that the slope values for both Action and Inhibition images were greater than zero (Action: $t(19) = 2.19$, $p = .041$; Inhibition: $t(19) = 3.57$, $p = .002$), indicating increasing hedonic value with exposure. There was no significant difference between the slopes ($t(19) = 1.05$, $p = .307$) or intercepts ($t(19) = 0.964$, $p = .347$) for action-related and inhibition-related images. Thus, the rates of accrual of hedonic value with exposure were comparable for action and inhibition, as was the intrinsic hedonic value associated with action and inhibition, after removing effects of exposure.

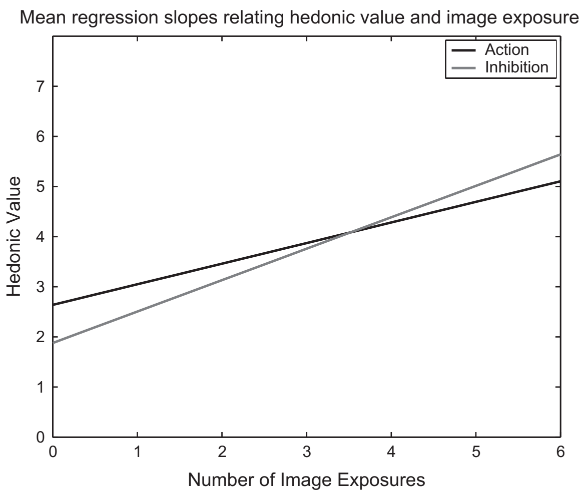


**Fig. 3.** Mean regression slopes relating hedonic value and image exposure.

**Table 1**
Correlation matrix of hedonic value and behavioural choice measures.

| | Action constant (intrinsic hedonic value) | Action slope (accrued hedonic value) | Inhibition constant (intrinsic hedonic value) | Inhibition slope (accrued hedonic value) | Number of actions performed | Number of inhibitions performed |
|---|---|---|---|---|---|---|
| Action constant (intrinsic hedonic value) | – | **−0.901***** | −0.038 | 0.255 | **0.536*** | **−0.561**** |
| Action slope (accrued hedonic value) | | – | −0.003 | −0.235 | −0.414 | 0.428 |
| Inhibition constant (intrinsic hedonic value) | | | – | **−0.865***** | −0.202 | 0.274 |
| Inhibition slope (accrued hedonic value) | | | | – | 0.363 | −0.428 |
| Number of actions performed | | | | | – | **−0.982***** |
| Number of inhibitions performed | | | | | | – |

Values are Pearson's *r*, stars indicate significance, bold values are significant.
* $p < .05$.
** $p < .01$.
*** $p < .001$.

### 3.4. Relations between hedonic value and free choice

Finally, we investigated the motivational capacity of action-related and inhibition-related hedonic value. If the intrinsic hedonic value of choosing to act, or to inhibit, were to give a high hedonic value, participants should generally prefer that choice over the alternative. Our dataset allowed us to compare the motivational capacity for action-related and inhibition-related affects, by correlating across subjects the number of actions performed with the intrinsic and accrued affects for action and for inhibition (as estimated by the intercepts and slopes of the hedonic value/exposure regression, see above). This analysis therefore aimed to test which aspects of hedonic value might drive a participant's decision to act or inhibit.

The number of actions and number of inhibitions are inevitably correlated, because the two responses are mutually exclusive. Importantly, however, the constants and slopes of the Action regressions were not correlated with the constants or slopes of the Inhibition regressions (see Table 1), since participants could have independent hedonic valuations for action and inhibition responses. We could thus test whether the intrinsic (constant) and accrued (slope) components had stronger motivational value for action or for inhibition, in the sense of better predicting participants' free choices.

Inspection of the correlation matrix showed that neither the accrued hedonic value for Action, as given by the regression slope, nor the accrued hedonic value for Inhibition correlated with the frequency of action or inhibition. However, the intrinsic hedonic value for action, as given by the regression intercept, correlated strongly ($r = .536$, $p = .015$) with the number of actions performed. This shows that participants for whom the decision to act lead to a positive evaluation of the following image, were motivated to perform more actions. This result may seem unsurprising given concepts of reward-based decision making. In contrast, the intrinsic hedonic value for inhibition was uncorrelated with the number of actions ($r = -.202$, $p = .394$), and therefore also with the number of inhibitions, performed. Because of the correlational nature of these results and the small sample size, we performed additional jack-knife analyses for these two critical correlations. For actions, the mean jack-knife correlation was $r = .536$, $p = .018$. For inhibitions, the mean jack-knife correlation was $r = -.203$, $p = .405$. This is evidence that the correlations were robust despite a small sample size. A direct comparison of the two correlation coefficients using the statistical methods of Steiger (1980) and Williams (1959), showed a significant difference, Williams-T2 = 2.537 $p = .021$. This this test was also subjected to a jack-knife procedure, with mean jack-knife Williams-T2 = 2.503, $p = .006$. Again, this suggests that the difference between these two correlations is robustly significant.

This result was further supported by a multiple regression analysis with number of actions as the outcome variable, with the slopes and constants for both action and inhibition hedonic value entered as predictors using a forward stepwise exclusion criterion. The resulting regression model was significant, $F(1,18) = 7.27$, $p = .015$, $r^2 = .536$, and contained only the constant for action as a significant positive predictor of action behaviour, beta = 3.78, $t(19) = 2.70$, $p = .015$.

To summarise, hedonic value accrued during each block due to mere exposure did not predict behavioural choices to act or inhibit. However, intrinsic hedonic value for Action effects - and Action effects only – did predict behavioural choices to act or inhibit. In contrast, intrinsic hedonic value for Inhibition did not predict behavioural choices to act or inhibit.

## 4. Discussion

People frequently weigh up the advantages and disadvantages to acting or not acting in a given situation. Further, current decisions about whether to act or not depend on the reward or punishment that follow previous experiences of action or inhibition, through the well-understood mechanism of instrumental reinforcement learning (for example, Bunzeck, Dayan, Dolan, & Duzel, 2010; Bunzeck, Guitart-Masip, Dolan, & Duzel, 2011; Evans, Fleming, Dolan, & Averbeck, 2011; Guitart-Masip et al., 2011). By this mechanism, actions are thought to acquire hedonic value through their association with reinforcers. In this sense, reward-based decision making forms the crucial background to voluntary choices between intentional action and intentional inhibition in the world outside the laboratory.

However, the *consequences* of actions may not be the only factor that drives choices to act or inhibit. Actions and inhibitions might also have *intrinsic* hedonic values. We aimed to study these intrinsic values by pairing action or inhibition with arbitrary, valueless visual stimuli, and seeing if those stimuli acquired value in virtue of their associations with action or inhibition. Intrinsic hedonic value has proven difficult to study experimentally, because of the need to remove the confounding influence of reinforcers. Indeed, rewards seem to undermine the intrinsic 'internally-generated' quality associated with voluntary action (Passingham et al., 2010). Rewards are potent stimuli for eliciting instrumental actions: the sight of food encourages us to eat. In this sense, actions triggered by immediate reward may be closer to affordance-driven behaviours than to voluntary actions. Indeed, neuropsychological cases of Anarchic Hand Syndrome provide clear examples of dissociation between volition and reward-directed action (Della Salla, Marchetti, & Spinnler, 1991).

To resolve this confusion, we have developed an experimental situation to study the hedonic status of action and inhibition, in the absence of external reinforcement. Voluntary decisions to act or inhibit action produced visual stimuli that had no value in themselves, but were consistently associated with either action or inhibition. We assumed that participants would develop hedonic value for these arbitrary stimuli during the course of the experiment, by association with the intrinsic hedonic value of the action or inhibition that caused them. This allowed us to investigate whether action and inhibition differ in intrinsic hedonic value, and also whether this hedonic value is able to drive decisions to act or inhibit. In doing so, we aimed to test a hypothesis (Brass & Haggard, 2010) that intentional inhibition is associated with the frustrating negative hedonic value of not performing an action one was preparing to perform.

Our results can be summarised as follows. First, we found no difference in the hedonic value of stimuli that followed action and stimuli that followed inhibition. Second, the hedonic value of stimuli could be separated into an intrinsic component, which we assumed arose from the intrinsic hedonic value of action or inhibition, and an accrued component related to the repeated exposure of the same image following repeated action or inhibition decisions. Neither the intrinsic nor accrued component of hedonic value differed between conditions. Third, we found evidence that intrinsic hedonic value for action does drive behaviour, in that participants who showed high intrinsic hedonic value for stimuli linked to action decided to act more frequently than participants for whom stimuli linked to action were less positively evaluated. This is expected from theories of reinforcement learning: if the consequence of an action is pleasant, the action may be repeated (Olds & Milner, 1954). Moreover, our result agrees with research showing that actions themselves can be intrinsically rewarding, in addition to the value of the rewards they are intended to generate (Tricomi, Delgado, & Fiez, 2004). This result supports the notion of a mental "common currency" of hedonic pleasure that drives decision making (Cabanac, 1992; McFarland & Sibly, 1975). Fourth, and most interestingly, this was not the case for inhibition choices: the intrinsic hedonic value for inhibition did not drive decisions to inhibit in the same way as intrinsic hedonic value for action drove decisions to act, even though our data showed that the consequences of inhibition were just as well liked as the consequences of action. Specifically, those participants who had strongly positive evaluation of stimuli that followed inhibition did not choose to inhibit any more frequently than participants who had less positive evaluations of stimuli that followed inhibition.

To summarise, we found a significant difference between the motivational capacities of action and of inhibition intrinsic to action compared to that of inhibition. This difference could be explained by either of two models. According to the first model, the reinforcing effects of hedonic association would be present for both action and inhibition, but their application would be masked and outweighed in the case of inhibition. The second model proposes two separate hedonic association systems with potentially differing strengths for rewarding action and inhibition respectively,

Why might inhibition have lower motivational capacity than action? We offer three suggestions. First, physical action is a salient perceptual event, in a way that inhibition is not. Inhibition might thus be less able to form strong associative ties with rewards, leading to reduced motivational capacity. However, we found that mean hedonic value and accrual of hedonic value were similar for images following action and inhibition choices, which argues against such perceptual differences.

A second view explains the low motivational capacities of inhibition with reference to last-minute contextual adjustments within a computational motor control model (Brass & Haggard, 2008). We asked our participants to inhibit actions just before the moment of execution. Outside the laboratory, such "veto" functions may normally be part of flexible adjustment process that tunes actions to environmental context (Filevich, Kühn, & Haggard, 2012). An action may be prepared at a moment when it seems appropriate, but suddenly rejected if the context changes. Inhibition of an action may make momentary sense in the current context, but there may be no need to represent the hedonic value of inhibition in a broader way applying to future contexts or other occasions. The advantage in inhibiting action on this occasion was due to a context that occurred only transiently. The same reasons may not apply again in another context.

A third view treats intentional inhibition as a form of self-control, and a distinct behavioural choice in its own right. For example, inhibition is sometimes described as a trait of individuals. Measures of phasic inhibition certainly correlate with traits such as impulsivity, and with clinical syndromes (Aron, 2011). This type of inhibition can also be related to the different motivational capacity of action-related and inhibition-related hedonic value shown in our data. We frequently need to learn that withholding a prepotent action is the best course of behaviour. Avoiding overeating at a help-yourself buffet would be one anecdotal example. In reversal learning studies, learning to withhold a response that was previously rewarded depends critically on integrity of both hedonic and executive areas of prefrontal cortex (Remijnse, Nielen, Uylings, & Veltman, 2005). These tasks all involve inhibiting prepotent responses. Impulsive or habitual behaviours can impinge upon more deliberative responses, even when the latter are more rewarding (Dayan, Niv, Seymour, & Daw, 2006). However, our mean hedonic value data do not suggest a difference in reward value for action and inhibition per se, but merely a difference in their susceptibility to reinforcement learning. Finally, our study analysed only decisions between voluntary action and voluntary inhibition. It remains unclear whether decisions to act or inhibit in response to external signals have similar hedonic consequences and motivational capacity. Our focus on internally-generated decisions was based on the strong relation between self-control and hedonic value.

Recent psychological studies confirm that such self-control is both effortful (Schmeichel & Vohs, 2009) and limited (Muraven & Baumeister, 2000). Our results suggest one important reason for the difficulty of self-control: even when inhibition brings a reward, those rewards are not very effective in motivating behavioural choices on future occasions. Recent views of self-control (Baumeister & Tierney, 2011) point out that self-control can be learned. Our data do not disagree with this view, but the low motivational power associated with inhibition can perhaps explain why self-control is relatively harder to learn than goal-oriented behaviours.

Recent work in reward-based decision-making and 'neuroeconomics' has considered action inhibition within the framework of temporal discounting. That is, people may inhibit making an action that attracts a reward in order to receive a greater reward at a later time – 'delayed gratification' (Glimcher, Kable, & Louie, 2007; Platt & Glimcher, 1999). Our results suggest why people sometimes find it difficult to inhibit current action in order to obtain rewards. Delayed gratification requires individuals to intentionally inhibit now in order to gain later. Our data suggests that intentional inhibition has, in and of itself, little or no motivational power. In contrast, immediate action, has, of course, strong motivational power (Dayan et al., 2006). Although the agent rationally knows that rewards lie in the long-term, via intentional inhibition, the only option providing current motivation is that of immediate action. Our data show, for the first time, that a difference exists between the motivational capacity of inhibition and of action, even when the actual hedonic values of each are balanced, and when outcome values are minimal and arbitrary.

To conclude, we have investigated the hedonic impacts of making intentional actions and of intentionally inhibiting such actions, using a novel paradigm to highlight the intrinsic hedonic value due to action and inhibition. We found that action and inhibition produced similar hedonic evaluation of a subsequent stimulus. However, these hedonic evaluations had quite different impacts on participants' behaviour. Strong positive hedonic value related to actions was associated with a bias to choose actions over inhibition. Conversely, strong positive hedonic value related to inhibition was not associated with a tendency to choose to inhibit. Even when inhibition is rewarding, those rewards may be poor at motivating subsequent decisions to inhibit. Inhibition disorders are common in many psychopathologies, and many therapies aim to teach improved inhibition. Our data suggests that such therapies will be more effective if they focus on the negative hedonic consequences of action than if they focus on the positive hedonic consequences of inhibition.

## Acknowledgments

This research was supported by ESRC/ESF ECRP grant RES-062-23-2183 to PH, by a British Academy small grant SG102289 to PH. PH was additionally supported by a Leverhulme Trust Major Research Fellowship, an ESRC Professorial Research Fellowship and by ERC Advanced Grant HUMVOL.

## References

Aron, A. R. (2011). From reactive to proactive and selective control: Developing a richer model for stopping inappropriate responses. *Biological Psychiatry, 69*(12), 55–68.
Baumeister, R. F., & Tierney, J. (2011). *Willpower: Rediscovering the greatest human strength*. London: The Penguin Press.
Brainard, D. H. (1996). The psychophysics toolbox. *Spatial Vision, 10*(4), 433–436.
Brass, M., & Haggard, P. (2007). To do or not to do: The neural signature of self-control. *Journal of Neuroscience, 27*(34), 9141–9145.
Brass, M., & Haggard, P. (2008). The what, when, whether model of intentional action. *The Neuroscientist, 14*(4), 319–325.
Brass, M., & Haggard, P. (2010). The hidden side of intentional action: The role of the anterior insular cortex. *Brain Structure and Function, 214*(5–6), 603–610.
Bunzeck, N., Dayan, P., Dolan, R. J., & Duzel, E. (2010). A common mechanism for adaptive scaling of reward and novelty. *Human Brain Mapping, 31*(9), 1380–1394.
Bunzeck, N., Guitart-Masip, M., Dolan, R. J., & Duzel, E. (2011). Contextual novelty modulates the neural dynamics of reward anticipation. *Journal of Neuroscience, 31*(36), 12816–12822.
Cabanac, M. (1992). Pleasure: The common currency. *Journal of Theoretical Biology, 155*(2), 173–200.
Chua, H. F., Gonzalez, R., Taylor, S. F., Welsh, R. C., & Liberzon, I. (2009). Decision-related loss: Regret and disappointment. *NeuroImage, 47*(4), 2031–2040.
Dayan, P., Niv, Y., Seymour, B., & Daw, N. D. (2006). The misbehavior of value and the discipline of the will. *Neural Networks, 19*(8), 1153–1160.
Della Salla, S., Marchetti, C., & Spinnler, H. (1991). Right-sided anarchic (alien) hand: A longitudinal study. *Neuropsychologia, 29*(11), 1113–1127.
Evans, S., Fleming, S. M., Dolan, R. J., & Averbeck, B. B. (2011). Effects of emotional preferences on value-based decision-making are mediated by mentalizing and reward networks. *Journal of Cognitive Neuroscience, 23*(9), 2197–2210.
Filevich, E., Kühn, S., & Haggard, P. (2012). Intentional inhibition in human action: The power of 'no'. *Neuroscience and Biobehavioral Reviews, 36*(4), 1107–1118.
Glimcher, P. W., Kable, J., & Louie, K. (2007). Neuroeconomic studies of impulsivity: Now or just as soon as possible? *The American Economic Review, 97*(2), 142–147.
Guitart-Masip, M., Fuentemilla, L., Bach, D. R., Huys, Q. J. M., Dayan, P., Dolan, R. J., et al. (2011). Action dominates valence in anticipatory representations in the human striatum and dopaminergic midbrain. *Journal of Neuroscience, 31*(21), 7867–7875.
Kleiner, M., Brainard, D. H., & Pelli, D. G. (2007). What's new in Psychtoolbox-3. *Perception, 36*, 14.
Kühn, S., Haggard, P., & Brass, M. (2009). Intentional inhibition: How the "veto-area" exerts control. *Human Brain Mapping, 30*(9), 2834–2843.
Libet, B., Gleason, C. A., Wright, E., & Pearl, D. (1983). Time of conscious intention to act in relation to onset of cerebral-activity (readiness-potential): The unconscious initiation of a freely voluntary act. *Brain, 106*, 623–642.
Logan, G. D., Cowan, W. B., & Davis, K. A. (1984). On the ability to inhibit simple and choice reaction time responses: A model and a method. *Journal of Experimental Psychology-Human Perception and Performance, 10*(2), 276–291.
McFarland, D. J., & Sibly, R. M. (1975). The behavioural final common path. *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences, 270*(907), 265–293.

Muraven, M., & Baumeister, R. F. (2000). Self-regulation and depletion of limited resources: Does self-control resemble a muscle. *Psychological Bulletin, 126*(2), 247–259.
Olds, J., & Milner, P. (1954). Positive reinforcement produced by electrical stimulation of septal area and other regions of rat brain. *Journal of Comparative and Physiological Psychology, 47*(6), 419–427.
Passingham, R. E., Bengtsson, S. L., & Lau, H. C. (2010). Medial frontal cortex: From self-generated action to reflection on one's own performance. *Trends in Cognitive Sciences, 14*(1), 16–21.
Pelli, D. G. (1996). The VideoToolbox software for visual psychophysics: Transforming numbers into movies. *Spatial Vision, 10*(4), 437–442.
Platt, M. L., & Glimcher, P. W. (1999). Neural correlates of decision variables in parietal cortex. *Nature, 400*(6741), 233–238.
Ramautar, J. R., Slagter, H. A., Kok, A., & Ridderinkhof, K. R. (2006). Probability effects in the stop-signal paradigm: The insula and the significance of failed inhibition. *Brain Research, 1105*(1), 143–154.
Remijnse, P. L., Nielen, M. M. A., Uylings, H. B. M., & Veltman, D. J. (2005). Neural correlates of a reversal learning task with an affectively neutral baseline: An event-related fMRI study. *NeuroImage, 26*(2), 609–618.
Richmond, B. J., & Optican, L. M. (1990). Temporal encoding of 2-dimensional patterns by single units in primate primary visual-cortex. 2. Information-transmission. *Journal of Neurophysiology, 64*(2), 370–380.
Schmeichel, B. J., & Vohs, K. (2009). Self-affirmation and self-control: Affirming core values counteracts ego depletion. *Journal of Personality and Social Psychology, 96*(4), 770–782.
Steiger, J. J. (1980). Tests for comparing elements of a correlation matrix. *Psychological Bulletin, 87*(2), 245–251.
Tricomi, E. M., Delgado, M. R., & Fiez, J. A. (2004). Modulation of caudate activity by action contingency. *Neuron, 41*(2), 281–292.
Verbruggen, F., & Logan, G. (2008). Response inhibition in the stop-signal paradigm. *Trends in Cognitive Sciences, 12*(11), 418–424.
Williams, E. J. ( (1959). The comparison of regression variables. *Journal of the Royal Statistical Society. Series B (Methodological)*, 396–399.
Zajonc, R. B. (1968). Attitudinal effects of mere exposure. *Journal of Personality and Social Psychology, 9*(2), 1–27.