Cognition 162 (2017) 54–60

Contents lists available at ScienceDirect

Cognition

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

Brief article

Having control over the external world increases the implicit sense of agency

Brianna Beck, Steven Di Costa, Patrick Haggard *

Institute of Cognitive Neuroscience, University College London, Alexandra House, 17 Queen Square, WC1N 3AZ London, United Kingdom

A R T I C L E I N F O

Article history:
Received 16 June 2016
Revised 1 February 2017
Accepted 5 February 2017

Keywords:
Action selection
Intentional binding
Pain
Sense of agency
Sensory attenuation

A B S T R A C T

The sense of agency refers to the feeling of control over one's actions, and, through them, over external events. One proposed marker of implicit sense of agency is 'intentional binding'—the tendency to perceive voluntary actions and their outcomes as close in time. Another is attenuation of the sensory consequences of a voluntary action. Here we show that the ability to choose an outcome through action selection contributes to implicit sense of agency. We measured intentional binding and stimulus intensity ratings using painful and non-painful somatosensory outcomes. In one condition, participants chose between two actions with different probabilities of producing high or low intensity outcomes, so action choices were meaningful. In another condition, action selection was meaningless with respect to the outcome. Having control over the outcome increased binding, especially when outcomes were painful. Greater sensory attenuation also tended to be associated with stronger binding of the outcome towards the action that produced it. Previous studies have emphasised the link between sense of agency and *initiation* of voluntary motor actions. Our study shows that the ability to control outcomes by discriminative action selection is another key element of implicit sense of agency. It also investigates, for the first time, the relation between binding and sensory attenuation for the same events.

1. Introduction

The sense of agency refers to the feeling of controlling one's own actions and, through them, events in the outside world. It is a ubiquitous and familiar experience, but has proved difficult to study experimentally, in part because of a 'self-serving bias' that associates more positive outcomes to one's own agency (Bradley, 1978; Greenberg, Pyszczynski, Burling, & Tibbs, 1992). Implicit measures of sense of agency may address these issues. The 'intentional binding' measure involves a compression of the perceived interval between voluntary actions and their outcomes, relative to passive movements and their outcomes (Haggard & Clark, 2003; Haggard, Clark, & Kalogeras, 2002). Attenuation of the sensory consequences of a voluntary action has also been proposed as a measure of implicit sense of agency (Blakemore, Frith, & Wolpert, 1999). However, it remains unclear whether both measures reflect a single underlying cognitive construct, or distinct cognitive processes. Dewey and Knoblich (2014) found no association between them across participants, but the two measures were obtained from separate tasks. The relation between sensory attenuation and intentional binding might become clearer if both measures are obtained for the same action-outcome events.

Another key aspect of the concept of agency, besides motoric action control, is the ability to influence events in the world. However, it is not yet known whether the *implicit* sense of agency is sensitive to the degree of control one has over the outcomes of one's actions. Intentional binding studies generally pair one or more possible actions with a *single* outcome. One showed stronger binding when an action was more likely to produce an outcome (Moore & Haggard, 2008). Another found that intentional binding increased with the number of alternative actions producing the same outcome (Barlas & Obhi, 2013). In everyday life, however, people choose between alternative actions based on their anticipated consequences. Accordingly, Desantis, Hughes, and Waszak (2012) asked participants to press one of two keys, producing either a high or a low tone. They found no difference in binding between a condition where the key predicted the pitch of the tone, and a condition where the pitch was unpredictable. This suggests that intentional binding is insensitive to control over *which* outcome is produced. Yet, no study has investigated intentional binding in the everyday situation of choosing between alternative actions based on the *value* of their likely outcomes. Here we investigated whether implicit sense of agency reflects the degree

* Corresponding author.
E-mail address: p.haggard@ucl.ac.uk (P. Haggard).

http://dx.doi.org/10.1016/j.cognition.2017.02.002
0010-0277/

of voluntary control over outcomes that are meaningful to the agent.

One such meaningful outcome is pain. Some have reported a reduction in intentional binding with negative action outcomes (Christensen, Yoshie, Di Costa, & Haggard, 2016; Takahata et al., 2012; Yoshie & Haggard, 2013). On the other hand, pain is a powerful learning signal, guiding future action to avoid injury and further pain. The importance of associating one's actions with harmful consequences might suggest an *increased* sense of agency for actions with painful outcomes, as long as one can minimise pain level through action selection. Thus, control over pain level should increase binding. Such a finding would demonstrate that the implicit sense of agency reflects three components of volition: the capacity to choose between alternative actions, sensitivity to their consequences, and the motivational value of those consequences.

In this study, we used intentional binding and stimulus intensity ratings to investigate implicit sense of agency for painful outcomes. Participants selected between two alternative actions. For half the participants, the outcome of their action was either a high intensity or a low intensity heat-pain stimulus. For the other half, the outcome was either a high intensity or a low intensity electrocutaneous stimulus, which was never perceived as painful. In both groups, we compared blocks where participants could control outcome intensity through their action selection with blocks where they could not. Participants reported either the time of their action or the time of the outcome (Fig. 1). We predicted greater intentional binding (i.e. stronger implicit sense of agency) when participants could learn to minimise pain by selecting the appropriate action. We also asked our participants to rate outcome stimulus intensity after each trial. Since both sensory attenuation and intentional binding have been proposed as implicit measures of sense of agency, we investigated whether lower intensity ratings (i.e. sensory attenuation) would be associated with greater intentional binding across trials.

2. Materials and methods

2.1. Participants

Fifty healthy adults participated. Half had painful heat stimuli as outcomes (17 female, 18–35 years old, M_{age} = 25.28 years, SD_{age} = ±4.86 years). The other half had non-painful electrocutaneous stimuli as outcomes (16 female, 19–39 years old, M_{age} = 26.56 years, SD_{age} = ±4.93 years). All gave written informed consent, and were paid £7.50/hr. The experiment was approved by the UCL Research Ethics Committee, and carried out in accordance with the Declaration of Helsinki.

2.2. Apparatus and materials

A computer running Labview 2012 (National Instruments, Austin, TX, USA) displayed the clock, triggered the stimuli, and

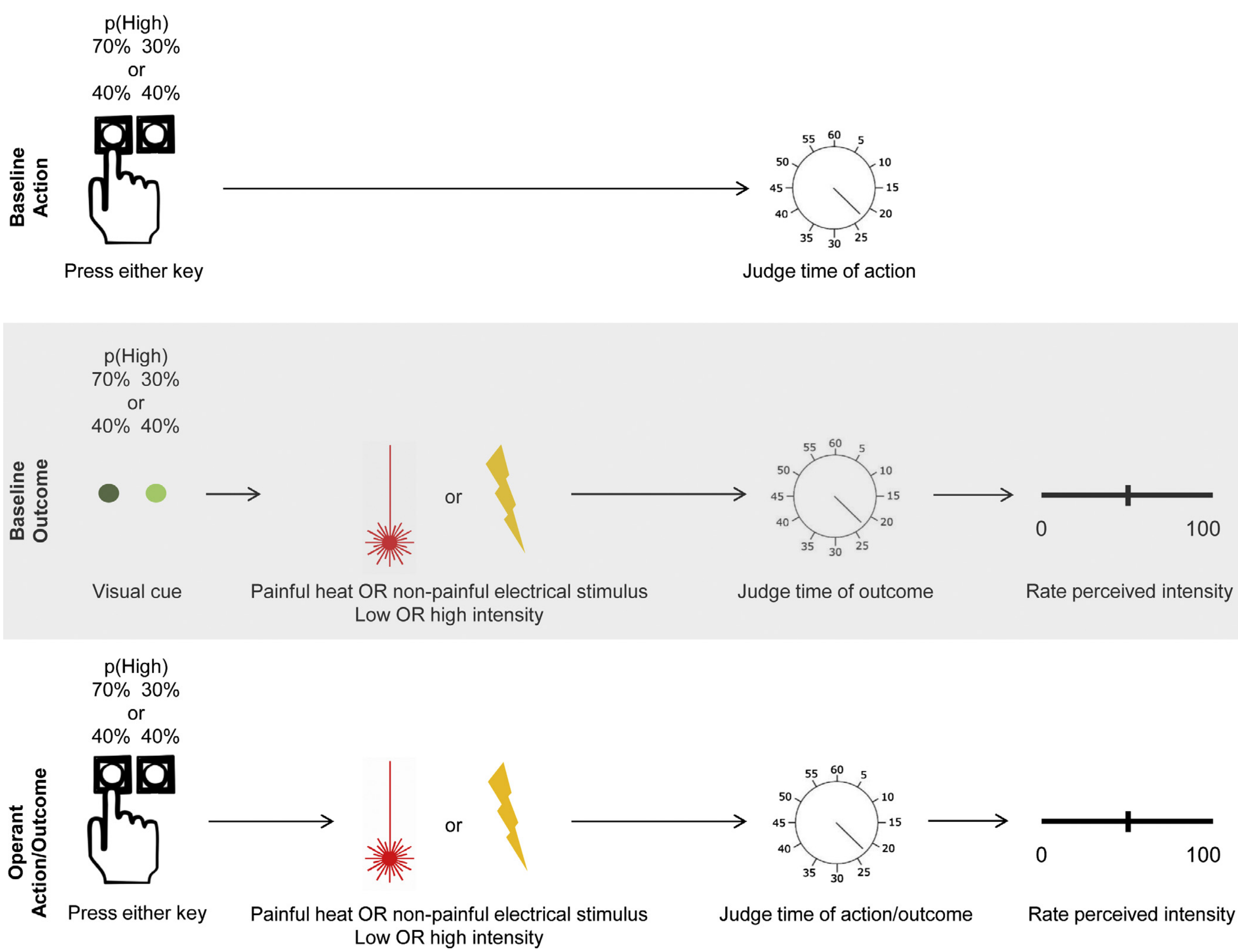

Fig. 1. Trial timelines for baseline action judgement blocks, baseline outcome judgement blocks, and operant action/outcome judgement blocks.

collected responses. Radiant heat stimuli were delivered to the left hand dorsum with a CO_2 laser stimulation device (SIFEC, Ferrières, Belgium). Each laser stimulus lasted 100 ms, including temperature ramp-up and plateau. Electro-cutaneous stimuli, lasting 5 ms, were delivered with a DS5 constant current stimulator (Digitimer, Welwyn Garden City, UK) connected to self-adhesive stimulation electrodes (BIOPAC, Goleta, CA, USA) affixed to the left hand dorsum.

2.3. Procedure

In the heat-pain group, each participant's nociceptive threshold was determined using a reaction time (RT) staircase. Participants pressed a key with their right hand as soon as they detected any sensation on their left hand. Starting at 38 °C, laser temperature increased by 4 °C until RT fell below 650 ms, then decreased by 2 °C until RT rose above 650 ms, and finally increased by 1 °C until RT was below 650 ms on 3 out of 4 repetitions. The final temperature was taken as the threshold. The 650-ms cutoff provides a valid measure of Aδ activation (Churyukanov, Plaghki, Legrain, & Mouraux, 2012; Mouraux, Guérit, & Plaghki, 2003). Low heat-pain stimuli were set to 2 °C above threshold (M_{thr} = 48.68 °C, SD_{thr} = ±1.38 °C), and high heat-pain stimuli were set to 8 °C above threshold.

In the electro-cutaneous group, each participant's tactile detection threshold was determined using a yes/no staircase. Starting at 0.4 mA, the intensity increased by 0.4 mA until it was detected, then decreased by 0.2 mA until it was no longer detected, and finally increased by 0.1 mA until it was detected on 3 out of 4 repetitions. To match the substantial variability in the perceived intensity of a nociceptive heat stimulus (e.g. Kong et al., 2006; Kupers, Faymonville, & Laureys, 2005), low and high ranges of electro-cutaneous stimulation were used rather than two fixed intensities. The low stimulus ranged from 0.75 to 1.25 mA above detection threshold (M_{thr} = 0.58 mA, SD_{thr} = ±0.20 mA). The high intensity stimulus ranged from 2.75 to 3.25 mA above threshold. All participants reported that the electro-cutaneous stimuli were not painful.

The low and high stimuli were each demonstrated twice. Participants then completed six practice trials in which they rated stimulus intensity on a visual analogue scale (VAS) from 0 to 100. To anchor use of the scale, they were instructed to consider the average perceived intensity of the low stimulus demonstrations a '25', and the average perceived intensity of the high stimulus demonstrations a '75'.

Next, participants completed the main experiment, consisting of 2 baseline action judgement blocks, 4 baseline outcome judgement blocks, 4 operant action judgement blocks, and 4 operant outcome judgement blocks (Fig. 2). Half the participants completed the baseline blocks first, and the other half completed the operant blocks first. Within the baseline and operant conditions, block order was ABBA counterbalanced. Each block contained 10 trials.

2.3.1. Baseline action judgements

Participants fixated a rotating clock marked from 0 to 60 in increments of 5. At a time of their own free choice, they pressed a key with their right hand. They were told that they could press either F3 or F4, but to use both keys. Participants were instructed not to choose a time to press the key in advance. The clock stopped 1500–2500 ms after the key press. Participants reported where the clock hand was when they pressed the key, being as precise as possible.

2.3.2. Baseline outcome judgements

Participants fixated the same clock, but did not make an action. After a random delay, one of two green lights on either side of the clock flashed. After 250 ms, a high or low heat-pain or electro-cutaneous stimulus was delivered to their left hand. Participants reported where the clock hand was when they felt the stimulus, and then used the VAS to rate stimulus intensity.

In two of the blocks, one of the lights preceded a low intensity stimulus 70% of the time. The other light preceded a low intensity stimulus 30% of the time. Before these blocks, the participant was told that one of the lights would be more likely to precede a low intensity stimulus, and they should report which light it was at the end of the block. The position of this light varied randomly between blocks.

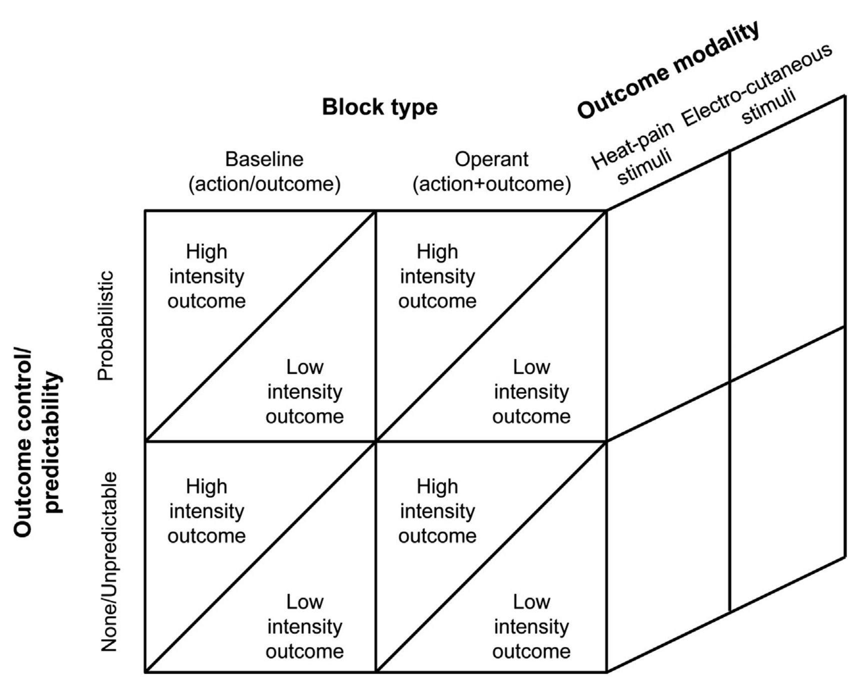

Fig. 2. Schematic representation of the experimental design.

Table 1
Summary of fixed effects in linear mixed effects model of action binding.

Fixed effect	Coefficient (ms)[a]		DF	t	p
	Mean	SEM			
Outcome modality (heat-pain vs electro-cutaneous)	17.90	±19.72	48	0.91	0.369
Outcome control (probabilistic vs no control)	28.67	±9.11	1931	3.15	0.002
Intensity rating	0.32	±0.33	1931	0.98	0.329
Outcome modality × Outcome control	3.31	±12.84	1931	0.26	0.797
Outcome modality × Intensity rating	−0.07	±0.43	1931	−0.16	0.873
Outcome control × Intensity rating	−0.69	±0.42	1931	−1.65	0.099
Outcome modality × Outcome control × Intensity rating	0.72	±0.56	1931	1.28	0.202

[a] Positive coefficients indicate greater action binding.

In the other two blocks, both lights preceded a low intensity stimulus 60% of the time. Before these blocks, participants were told that the light that flashed would have nothing to do with the intensity of the stimulus they would receive.

2.3.3. Operant action judgements

Participants pressed either F3 or F4 with their right hand at a time of their own free choice, and, 250 ms later, a high or low heat-pain or electro-cutaneous stimulus was delivered to their left hand. Participants reported where the clock hand was *when they pressed the key*, and then rated stimulus intensity on the VAS.

In the two 'probabilistic control' blocks, one of the keys produced a low intensity stimulus 70% of the time. The other key produced a low intensity stimulus 30% of the time. Before these blocks, the participant was told that pressing one of the keys would be more likely to give them a low intensity stimulus, and they should report which key it was at the end of the block. The identity of this key varied randomly between blocks.

In the two 'no control' blocks, both keys produced a low intensity stimulus 60% of the time. This probability was chosen to balance the number of high and low intensity outcomes in the 'probabilistic control' and 'no control' blocks, assuming that participants would try to avoid high intensity outcomes when possible. Before the 'no control' blocks, participants were told that the key they pressed would have nothing to do with the stimulus intensity they would receive.

2.3.4. Operant outcome judgements

These blocks were the same as the operant action judgment blocks, except that participants reported where the clock hand was *when they felt the stimulus.*

3. Results

3.1. Action binding

Action binding is the difference in the perceived time of the action when it is followed by an outcome (operant action judgement condition), compared to when it is not (baseline action judgement condition; Table S1). A linear mixed effects model with random intercepts by participant was used to find predictors of action binding across trials. The fixed effects were outcome modality (painful heat or innocuous electro-cutaneous stimuli), outcome control (probabilistic control or no control), subjective intensity rating (mean-centred), and their 2- and 3-way interaction terms. Wald tests of the marginal significance of each predictor showed that outcome control was the only significant predictor of action binding, $t(1931) = 3.15$, $p = 0.002$ ($\beta = 28.67$ ms, SE = ±9.11 ms; Table 1). There was greater action binding when participants had probabilistic control over stimulus intensity than when they had no control (Fig. 3a).

3.2. Outcome binding

Outcome binding is the difference in the perceived time of the outcome when it is caused by the participant's action (operant outcome judgement condition), compared to when it is not (baseline outcome judgement condition; Table S2). A linear mixed effects model was used to find predictors of outcome binding across trials. Wald tests showed that the interaction between outcome control and outcome modality was a significant predictor of outcome binding, $t(1931) = -2.68$, $p = 0.008$ ($\beta = -44.64$ ms, SE = ±16.66 ms). There was also a non-significant trend towards lower stimulus intensity ratings predicting greater outcome binding (i.e. a more negative binding value), $t(1931) = 1.82$, $p = 0.069$ ($\beta = 0.77$ ms, SE = ±0.42 ms; Table 2).

To follow up the interaction, we ran separate mixed effects models for the groups that received heat-pain and electro-cutaneous stimulation. Probabilistic control over heat-pain level predicted greater outcome binding, $t(964) = -4.93$, $p < 0.0001$ ($\beta = -60.40$, SE = ±12.25). Control over electro-cutaneous intensity did not predict outcome binding, $t(971) = -1.08$, $p = 0.282$ ($\beta = -11.70$, SE = ±10.86) (see Fig. 3b).

We also ran a linear mixed effects model of timing judgement errors in the baseline outcome judgement blocks alone, to determine whether the effect of outcome control might have come from differences between conditions in the baseline blocks. In baseline blocks the outcome stimulus was not controlled, but was predictable to the same extent as in the corresponding operant blocks, because visual cues preceded the stimuli. Outcome predictability did not predict baseline outcome judgement errors (Table S3).

3.3. Intensity ratings

Intensity ratings were submitted to an analysis of variance (ANOVA) with the between-subjects factor 'outcome modality' (painful heat or innocuous electro-cutaneous stimuli) and the within-subjects factors 'outcome intensity' (high or low), 'block type' (baseline outcome judgements, operant outcome judgements, or operant action judgements), and 'outcome predictability' (probabilistic or unpredictable). There were main effects of outcome intensity, $F(1,48) = 455.63$, $p = <0.00001$, $\eta_p^2 = 0.905$, and outcome modality, $F(1,48) = 10.98$, $p = 0.002$, $\eta_p^2 = 0.186$. Participants perceived the high intensity stimuli (M = 55.35, SEM = ±1.96) as stronger than the low intensity stimuli (M = 24.62, SEM = ±1.24), and the heat-pain stimuli (M = 44.42, SEM = ±1.44) as more intense than the electro-cutaneous stimuli (M = 35.55, SEM = ±2.26).

Additionally, there was a main effect of outcome predictability, $F(1,48) = 5.74$, $p = 0.020$, $\eta_p^2 = 0.107$, a two-way interaction between outcome intensity and predictability, $F(1,48) = 6.06$, $p = 0.017$, $\eta_p^2 = 0.112$, and a three-way interaction between outcome intensity, predictability, and modality, $F(1,48) = 20.35$, $p = 0.00004$, $\eta_p^2 = 0.298$. Paired samples t-tests with a Bonferroni correction (α_{adj}=0.05/[8(8 − 1)/2] = 0.002) showed that high heat-

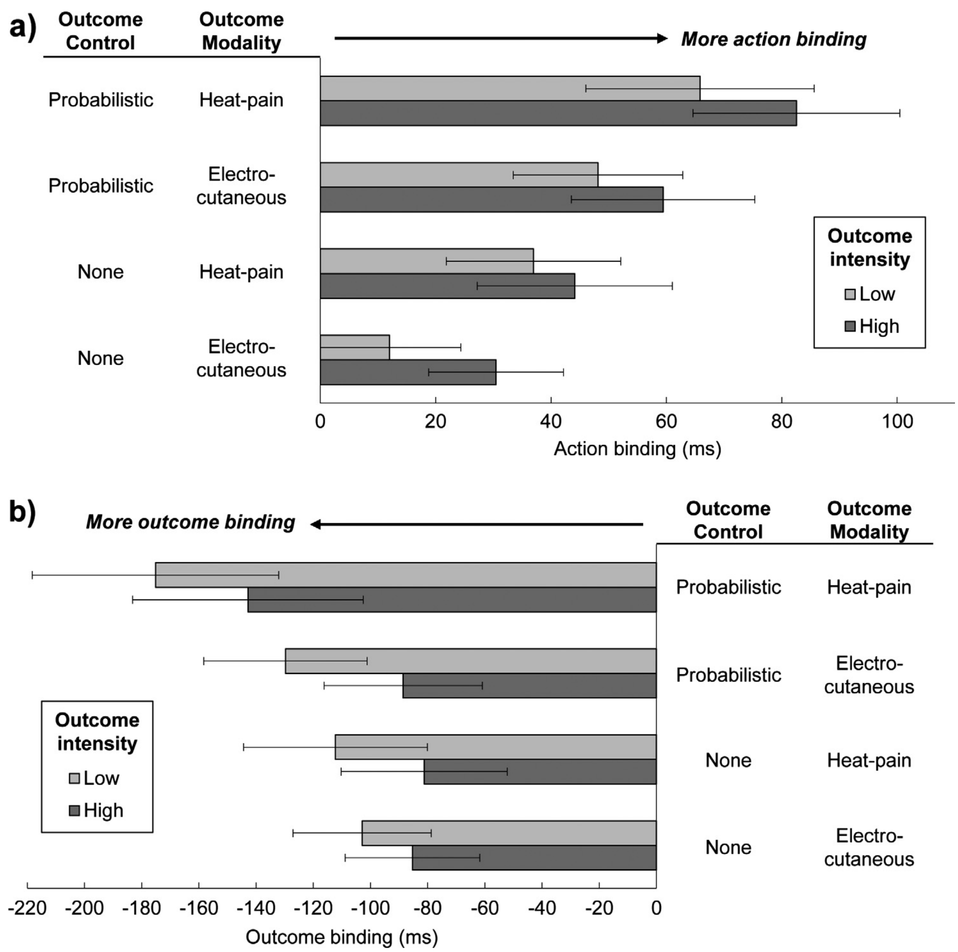

Fig. 3. Mean (±SEM) intentional binding values in each experimental condition, shown separately for (a) action binding, and (b) outcome binding. For visual simplicity, actual stimulus intensities (high or low) are shown here, but participants' subjective intensity ratings were used in the mixed effects models of action and outcome binding.

Table 2
Summary of fixed effects in linear mixed effects model of outcome binding.

Fixed effect	Coefficient (ms)[a]		DF	t	p
	Mean	SEM			
Outcome modality (heat-pain vs electro-cutaneous)	−8.67	±39.13	48	−0.22	0.826
Outcome control (probabilistic vs no control)	−13.96	±11.79	1931	−1.18	0.236
Intensity rating	0.77	±0.42	1931	1.82	0.069
Outcome modality × Outcome control	−44.64	±16.66	1931	−2.68	0.008
Outcome modality × Intensity rating	−0.22	±0.54	1931	−0.41	0.683
Outcome control × Intensity rating	−0.29	±0.54	1931	−0.54	0.588
Outcome modality × Outcome control × Intensity rating	−0.19	±0.73	1931	−0.27	0.790

[a] Negative coefficients indicate greater outcome binding.

pain stimuli were perceived as less intense when they were predictable (M = 58.66, SEM = ±1.67) than when they were unpredictable (M = 63.04, SEM = ±2.04), $t(24) = -5.06$, $p = 0.000036$ (Fig. 4a). Perception of low heat-pain stimuli did not vary with predictability, $t(24) = 0.90$, $p = 0.377$, nor did perception of electro-cutaneous stimuli (Fig. 4b), whether high, $t(24) = -0.02$, $p = 0.988$, or low, $t(24) = -2.06$, $p = 0.050$.

4. Discussion

We found that both action and outcome binding increased when participants had probabilistic control over outcome intensity. This shows that intentional binding reflects the degree of control over the consequences of one's actions. Because our measures were implicit, we know that the underlying experience of action was changed, rather than the evaluation of that experience.

Having control over outcomes only enhanced outcome binding when the outcomes were painful. The capacity for pain to motivate action is acknowledged by recent theories (Haggard, Iannetti, & Longo, 2013; Legrain, Iannetti, Plaghki, & Mouraux, 2011), and distinct from evoked withdrawal responses. Our finding indicates the sense of control over pain may reflect a basic form of adaptive behaviour.

Action and outcome binding may reflect qualitatively different processes, or just two measures of a common process related to the sense of agency. We found that the motivational value of the outcome influenced outcome binding, but not action binding. This may demonstrate an important difference between action and

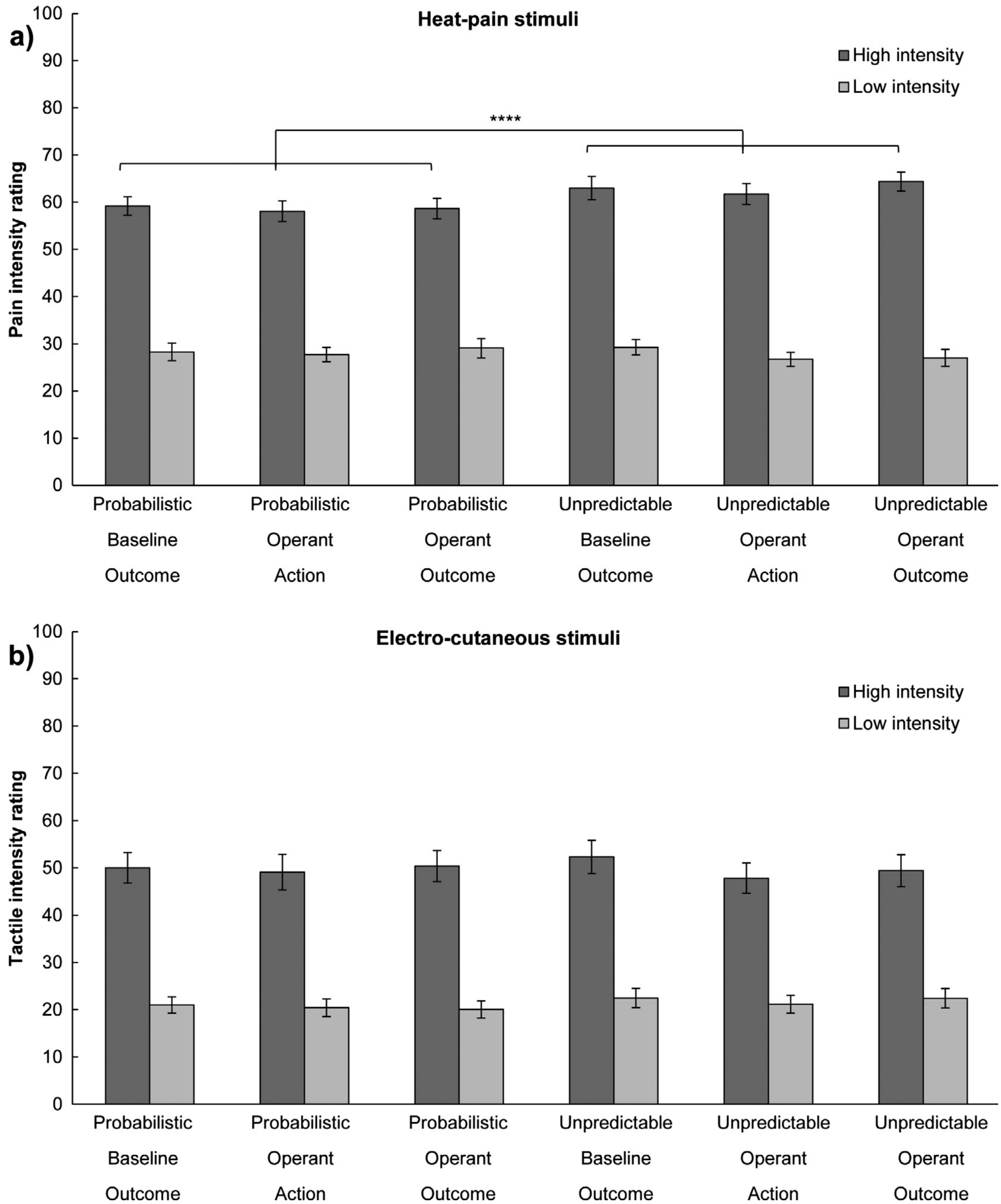

Fig. 4. Mean (±SEM) stimulus intensity ratings in each experimental condition for (a) painful radiant heat stimuli, and (b) non-painful electro-cutaneous stimuli. **** = $p < 0.0001$.

outcome binding, whereby the former reflects 'cold' statistical contingency, while the latter is sensitive to outcome valence.

In both baseline and operant blocks, predictable high heat-pain stimuli were perceived as less intense than unpredictable high heat-pain stimuli. Self-administration of painful stimuli is known to reduce perceived pain intensity relative to external administration (Kakigi & Shibasaki, 1992; Müller, 2012; Wang, Wang, & Luo, 2011). Our findings suggest that self-administration attenuates pain primarily because the action predicts the likely pain level. This is compatible with studies showing that painful stimuli feel less intense when they are cued than when they are unexpected (Carlsson et al., 2006; Crombez, Baeyens, & Eelen, 1994).

We also found a non-significant trend towards lower stimulus intensity ratings predicting greater outcome binding. Our finding suggests that sensory attenuation and outcome binding (but perhaps not action binding) may track a common underlying process related to sense of agency. However, this assertion should be treated with caution, for two reasons. First, the relation between these measures only approached the conventional boundary of statistical significance. Second, the association could reflect a domain-general mechanism of multisensory integration, in which the perception of action and outcome are combined in a way that is weighted by the reliability or the salience of each (Ernst & Banks, 2002). Future studies might further investigate whether this modest relation between perceived stimulus intensity and intentional binding is based on domain-general mechanisms such as multisensory cue integration, or an agency-specific process that has common effects on both intensity perception and time perception.

5. Conclusions

Our study shows that intentional binding is sensitive to the contingency structure of the environment, represented in our design by the contrast between blocks where participants had probabilistic control over outcome intensity and blocks where they had no such control. Moreover, the effect of control on outcome binding is modulated by the motivational significance of the action outcomes, represented by the contrast between painful and non-painful stimuli. Therefore, the implicit sense of agency, as measured by intentional binding, reflects the ability to choose between actions with different foreseeable and valenced consequences, providing a key link between volition, motivation, and responsibility.

Acknowledgements

The authors wish to thank Héloïse Théro for providing helpful comments on experimental design and data analysis. This research was supported by EU FP7 project VERE, WP1, award no. 257695 to PH, and by ERC Advanced Grant HUMVOL. SDC is supported by a UCL PhD demonstratorship. PH was also supported by an ESRC Professorial Fellowship (ES/J023140/1).

Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.cognition.2017.02.002.

References

Barlas, Z., & Obhi, S. S. (2013). Freedom, choice, and the sense of agency. *Frontiers in Human Neuroscience, 7*, 514. http://dx.doi.org/10.3389/fnhum.2013.00514.

Blakemore, S. J., Frith, C. D., & Wolpert, D. M. (1999). Spatio-temporal prediction modulates the perception of self-produced stimuli. *Journal of Cognitive Neuroscience, 11*(5), 551–559. http://dx.doi.org/10.1162/089892999563607.

Bradley, G. W. (1978). Self-serving bias in the attribution process: A reexamination of the fact or fiction question. *Journal of Personality and Social Psychology, 36*(1), 56–71. http://dx.doi.org/10.1037//0022-3514.36.1.56.

Carlsson, K., Andersson, J., Petrovic, P., Petersson, K. M., Öhman, A., & Ingvar, M. (2006). Predictability modulates the affective and sensory-discriminative neural processing of pain. *NeuroImage, 32*(4), 1804–1814. http://dx.doi.org/10.1016/j.neuroimage.2006.05.027.

Christensen, J. F., Yoshie, M., Di Costa, S., & Haggard, P. (2016). Emotional valence, sense of agency and responsibility: A study using intentional binding. *Consciousness and Cognition, 43*, 1–10. http://dx.doi.org/10.1016/j.concog.2016.02.016.

Churyukanov, M., Plaghki, L., Legrain, V., & Mouraux, A. (2012). Thermal detection thresholds of Aδ- and C-fibre afferents activated by brief CO_2 laser pulses applied onto the human hairy skin. *PLoS ONE, 7*(4), e35817. http://dx.doi.org/10.1371/journal.pone.0035817.

Crombez, G., Baeyens, F., & Eelen, P. (1994). Sensory and temporal information about impending pain: The influence of predictability on pain. *Behaviour Research and Therapy, 32*(6), 611–622. http://dx.doi.org/10.1016/0005-7967(94)90015-9.

Desantis, A., Hughes, G., & Waszak, F. (2012). Intentional binding is driven by the mere presence of an action and not by motor prediction. *PLoS ONE, 7*(1), e29557. http://dx.doi.org/10.1371/journal.pone.0029557.

Dewey, J. A., & Knoblich, G. (2014). Do implicit and explicit measures of the sense of agency measure the same thing? *PLoS ONE, 9*(10), e110118. http://dx.doi.org/10.1371/journal.pone.0110118.

Ernst, M. O., & Banks, M. S. (2002). Humans integrate visual and haptic information in a statistically optimal fashion. *Nature, 415*, 429–433. http://dx.doi.org/10.1038/415429a.

Greenberg, J., Pyszczynski, T., Burling, J., & Tibbs, K. (1992). Depression, self-focused attention, and the self-serving attributional bias. *Personality and Individual Differences, 13*(9), 959–965. http://dx.doi.org/10.1016/0191-8869(92)90129-D.

Haggard, P., & Clark, S. (2003). Intentional action: Conscious experience and neural prediction. *Consciousness and Cognition, 12*(4), 695–707. http://dx.doi.org/10.1016/S1053-8100(03)00052-7.

Haggard, P., Clark, S., & Kalogeras, J. (2002). Voluntary action and conscious awareness. *Nature Neuroscience, 5*(4), 382–385. http://dx.doi.org/10.1038/nn827.

Haggard, P., Iannetti, G. D., & Longo, M. R. (2013). Spatial sensory organization and body representation in pain perception. *Current Biology, 23*(4), R164–R176. http://dx.doi.org/10.1016/j.cub.2013.01.047.

Kakigi, R., & Shibasaki, H. (1992). Mechanisms of pain relief by vibration and movement. *Journal of Neurology, Neurosurgery, and Psychiatry, 55*(4), 282–286. http://dx.doi.org/10.1136/jnnp.55.4.282.

Kong, J., White, N. S., Kwong, K. K., Vangel, M. G., Rosman, I. S., Gracely, R. H., & Gollub, R. L. (2006). Using fMRI to dissociate sensory encoding from cognitive evaluation of heat pain intensity. *Human Brain Mapping, 27*(9), 715–721. http://dx.doi.org/10.1002/hbm.20213.

Kupers, R., Faymonville, M. E., & Laureys, S. (2005). The cognitive modulation of pain: Hypnosis- and placebo-induced analgesia. *Progress in Brain Research, 150*, 251–269. http://dx.doi.org/10.1016/S0079-6123(05)50019-0.

Legrain, V., Iannetti, G. D., Plaghki, L., & Mouraux, A. (2011). The pain matrix reloaded: A salience detection system for the body. *Progress in Neurobiology, 93*(1), 111–124. http://dx.doi.org/10.1016/j.pneurobio.2010.10.005.

Moore, J., & Haggard, P. (2008). Awareness of action: Inference and prediction. *Consciousness and Cognition, 17*(1), 136–144. http://dx.doi.org/10.1016/j.concog.2006.12.004.

Mouraux, A., Guérit, J. M., & Plaghki, L. (2003). Non-phase locked electroencephalogram (EEG) responses to CO_2 laser skin stimulations may reflect central interactions between Aδ- and C-fibre afferent volleys. *Clinical Neurophysiology, 114*(4), 710–722. http://dx.doi.org/10.1016/S1388-2457(03)00027-0.

Müller, M. J. (2012). Will it hurt less if I believe I can control it? Influence of actual and perceived control on perceived pain intensity in healthy male individuals: A randomized control study. *Journal of Behavioral Medicine, 35*(5), 529–537. http://dx.doi.org/10.1007/s10865-011-9382-0.

Takahata, K., Takahashi, H., Maeda, T., Umeda, S., Suhara, T., Mimura, M., & Kato, M. (2012). It's not my fault: Postdictive modulation of intentional binding by monetary gains and losses. *PLoS ONE, 7*(12), e53421. http://dx.doi.org/10.1371/journal.pone.0053421.

Wang, Y., Wang, J. Y., & Luo, F. (2011). Why self-induced pain feels less painful than externally generated pain: Distinct brain activation patterns in self- and externally generated pain. *PLoS ONE, 6*(8), e23536. http://dx.doi.org/10.1371/journal.pone.0023536.

Yoshie, M., & Haggard, P. (2013). Negative emotional outcomes attenuate sense of agency over voluntary actions. *Current Biology, 23*(20), 2028–2032. http://dx.doi.org/10.1016/j.cub.2013.08.034.