Consciousness and Cognition 105 (2022) 103412

Contents lists available at ScienceDirect

Consciousness and Cognition

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

Depressive traits are associated with a reduced effect of choice on intentional binding

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A R T I C L E I N F O

Keywords:
Sense of agency
Depression
Psychosis
Valence
Retrospective
Choice

A B S T R A C T

A sense of agency (SoA) over wilful actions is thought to be dependent on the level of choice and the nature of the outcome. In a preregistered study, we manipulated choice and valence of outcome to assess the relationship between SoA across the depression and psychosis continuum. Participants ($N = 151$) completed a Libet Clock task, in which they had either a free or forced choice to press one of two buttons and received either a rewarding or punishing outcome. Participants also completed questionnaires on depressive and psychosis-like traits. Rewarding outcomes increased intentional binding. The evidence favoured no effect of choice on average, but this was influenced by inter-individual differences. Individuals reporting more depressive traits had less of a difference in intentional binding between free and forced choice conditions. We show that implicit SoA is sensitive to outcome valence and the effect of choice differs across the depression continuum.

1. Introduction

Understanding how actions and their subsequent outcomes are accompanied by a sense of agency (SoA) is of foundational importance for understanding the human condition. SoA is commonly studied using temporal compression between events. For example, the perception of a temporal delay between pressing a light switch and the light turning on, is commonly shorter than the objective temporal delay. This phenomenon is known as temporal binding, or intentional binding when involving a wilful or intentional act. A SoA helps distinguish between actions and events initiated or caused by oneself and those caused by an external source (Balconi, 2010; Dewey & Knoblich, 2014; Frith, 2005). Studying this *feeling of agency,* has been a strong focus of studies interested in human consciousness (David et al., 2008), but little is known about how this differs across the depressive and psychosis continuums.

SoA is conceptualised as two separable processes, consisting of an explicit *judgement of agency* and an implicit *feeling of agency* (Saito et al., 2015; Synofzik et al., 2008). Explicit SoA reflects a higher-level and conscious interpretation of our actions (Moore et al., 2012; Synofzik et al., 2013) and is often measured by directly asking an individual to reflect on the degree of control they experienced over their actions (Haggard & Chambon, 2012; Metcalfe & Greene, 2007). However, such measures are susceptible to both response and social desirability biases (Moore, 2016; Wegner, 2003). This results in a tendency for individuals to overestimate or even misattribute agency for their actions (Tsakiris & Haggard, 2005; Wegner & Wheatley, 1999). An implicit *feeling of agency* is thought to emerge from the sensorimotor processes required to execute an action. This aspect of SoA is considered implicit as it is pre-reflective and occurs

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https://doi.org/10.1016/j.concog.2022.103412
Received 16 February 2022; Received in revised form 10 August 2022; Accepted 30 August 2022
Available online 7 September 2022
1053-8100/

outside of conscious awareness (Gallagher, 2012; Moore, 2016). The most robust and frequently used implicit SoA measure is the intentional binding paradigm (Balconi, 2010; Moore & Obhi, 2012). This paradigm relies on the phenomenon of temporal binding, whereby the brain groups separate events into a coherent and meaningful event sequence. The perceptual attraction of distinct events is thought to reflect the neural mechanisms of sensory awareness, a proposed requirement for short-term memory and thus accessible to consciousness (Crick & Koch, 1990). A relationship between binding and consciousness has also been suggested by Damasio (1989), with conscious recall of sensory contents requires the binding of information from distinct cortical regions. The link between temporal binding and agency has received empirical support from studies measuring temporal compression between an action and a subsequent outcome. Crucially, temporal binding can be enhanced when a person makes an intentional action, a phenomenon known as intentional binding (Haggard et al., 2002; Haggard & Clark, 2003). Intentional binding is considered a proxy for implicit SoA (Moore & Haggard, 2008; Saito et al., 2015). However, this theoretical positional has not gone unchallenged. For example, several studies have suggested that intentional binding may simply be a form of causal binding (Buehner, 2012; Buehner & Humphreys, 2009; Fereday et al., 2019; Hoerl et al., 2020), thus having little to do with intention or agency. It is therefore crucial to control for causality between events to test whether an intentional act has any effect on temporal binding over and above that observed when two events are causally related.

Intentional binding is commonly measured using a Libet Clock Task. Developed by Benjamin Libet in the 1980′s, the Libet clock experiment was designed to understand human volition (initiating an action based on an internal motivation, rather than an external stimulus; Haggard & Lau, 2013). Here, participants perform a voluntary action (usually a button press), and using a “Libet clock”, estimate the perceived time of this action or its subsequent outcome. When doing so, the participant’s time perception between the action and outcome, is shifted towards each other. This compression is referred to as the Intentional Binding effect, where greater intentional binding is indicative of greater SoA (Ebert & Wegner, 2010). Research using intentional binding paradigms have significantly informed our theoretical understanding of implicit SoA (Wolpe & Rowe, 2014). Both prospective and retrospective factors are involved in SoA (Moore & Obhi, 2012). The prospective component is thought to emerge from the motor system in the form of an efference copy to predict the sensory consequences of the voluntary action (Wolpert et al., 1995; Zaadnoordijk et al., 2019). Detailed within the comparator model of SoA (Frith et al., 2000), the predicted sensory input is compared with the actual sensory feedback resulting from the action, and greater similarity between the two results in a stronger SoA (Gallagher, 2000; Jeannerod, 2009; Wolpert & Ghahramani, 2000).

One prospective factor that theoretically should influence our SoA, is the ability to choose a course of action. Agency and freedom are closely associated and agency is thought to be greatest when humans are presented with an “environment of opportunities” in which to act (Pettit, 2001). It could be argued that being instructed to act diminishes or removes any opportunity of agency. Previous empirical work supports this theoretical position. For example, free choice over which action to perform has been show to increase judgements of agency (Wenke et al., 2010). Subsequent research has focused on implicit measures of agency including intentional binding. For example, using a Libet Clock, Barlas and Obhi (2013a) demonstrated greater intentional binding when participants had a greater choice of actions.

Retrospective influences on SoA have also been manipulated by varying the valence of the outcome. It has previously been demonstrated that SoA is subject to a self-serving bias (Yoshie & Haggard, 2013), with positive outcomes associated with self-agency to a greater extent than negative outcomes (Barlas & Obhi, 2014; Takahata et al., 2012). However, this has been shown to depend on the predictability of an outcome occurring. When outcomes are unpredictable, positive outcomes enhanced the retrospective component of intentional binding, whereas when an outcome was predictable, no retrospective effect was found (Christensen et al., 2016). Further research provided evidence that retrospective effects on intentional binding were dependent on the ability to predict the valence of the outcome, rather than the mere occurrence of a specific outcome (Yoshie & Haggard, 2017). In addition to predictability, the ability to choose an action has been shown to influence the effect of valence, with greatest binding for freely chosen actions resulting in positive outcomes (Barlas et al., 2018). It should be noted that contrary evidence showing no effect of outcome valence on temporal binding, including a non-replication of the Yoshie and Haggard (2013) study, has also been documented (Moreton et al., 2017). In the present study, we will further investigate how choice and outcome valence influence intentional binding.

Understanding the contribution of prospective and retrospective factors on SoA is important for understanding psychiatric conditions associated with self-disturbances. The most frequently studied psychiatric conditions, in terms of SoA differences, are those associated with psychosis (Franck et al., 2001; Frith, 2000; Jeannerod, 2009; Jones & Fernyhough, 2007). Across the psychosis continuum, consistent evidence points to a reduced prospective effect on SoA (Maeda et al., 2013; Synofzik et al., 2013). In terms of the comparator model (Frith et al., 2000), this may emerge due to a discrepancy between the executed motor commands and the corollary discharge or efference copy. This theoretical approach has encouraged studies focused on prospective factors such as making a self-initiated voluntary action or motor movement (Hauser et al., 2011; Synofzik et al., 2010; Voss et al., 2010). However, to date, research is lacking on the effect of action choice on SoA across the psychosis continuum. Previous research has shown that patients with chronic schizophrenia show an attenuated intentional binding, especially for the prospective aspect of SoA (Synofzik et al., 2010; Synofzik & Voss, 2010; Voss et al., 2010). Yet, it is interesting to note that greater intentional binding has also been identified in patients with schizophrenia (Haggard & Clark, 2003) and in the prodromal stage of illness (Hauser et al., 2011). As psychosis is thought to exist on a continuum, with conditions such as schizophrenia representing the extreme end of a normal distribution of psychosis-like experiences (van Os & Reininghaus, 2016; Verdoux & van Os, 2002), it is important to assess SoA differences across the psychosis continuum. Moreover, this approach avoids confounds such as medications, effects of stigmatisation, and hospitalisations, whilst allowing for larger sample sizes avoiding issues surrounding limited statistical power in clinical research (David, 2010; DeRosse & Karlsgodt, 2015). Larger sample sizes are also important for detecting effects in individuals with less severe expressions of psychosis (or other psychiatric-relevant trait), as the effect size may be smaller.

Altered SoA across the depression continuum has received considerably less focus. This is surprising considering the strong evidence for self-referential processing differences experienced in clinically diagnosed depression (Obhi et al., 2013). Moreover, several symptoms characteristic of depression, such as learned helplessness or hopelessness, point to an altered SoA to affect change in their lives. Depression is associated with a tendency to selectively ascribe actions to factors outside self-control, leading to a loss of motivation (Bandura, 2002). Seligman (1989) outlined the theory of learned helplessness showcasing how these agency perceptions in depression can be sustained. Seligman suggested that persistent exposure to uncontrollable events can lead to an expectation that we have little agency and therefore, prompt individuals to make fewer attempts in changing their behaviours resulting in disengagement and maintenance of depression in a self-perpetuating cycle. Understanding and improving explicit agency over an individual's life forms a key component of several therapeutic approaches such as Cognitive Behavioural Therapy (CBT) in treating depression as modifying maladaptive cognitions regarding our own SoA can strengthen agency and foster more pro-active behaviours to hinder the cycle of low agency, disengagement, and depression maintenance (Keeton et al., 2008). Despite the clear theoretical link and clinical awareness of the importance of explicit agency in depression, no research has investigated altered implicit SoA across the depression continuum. Although, explicit and implicit SoA may represent unique cognitive processes (Dewey & Knoblich, 2014; Haggard, 2017), an altered implicit SoA may also be altered in those with depression. For example, depressed patients show a reduced self-serving bias (Alloy & Abramson, 1982) which has not been assessed using intentional binding paradigms. Likewise, an external locus of control is commonly associated with depression. Locus of control is defined as the degree to which a person expects an outcome of their behaviour is contingent on their own behaviour, rather than a function of luck or fate (Rotter, 1966). An external locus of control is commonly associated with depressive disorders (Dimitrovsky et al., 1987; Richardson et al., 2012; Wiersma et al., 2011) which may manifest in altered SoA when choice is manipulated. Moreover, depressed individuals may experience less feeling of control over events and subsequently a reduced effect of choice on intentional binding tasks.

In the current study we adopt a continuum approach to assess the relationship between intentional binding and both depression and psychosis continuums using a Libet Clock task that manipulates both choice and valence outcome. We predicted that 1) temporal compression would be greater when an action preceded an outcome, demonstrating intentional binding 2) Individuals would exhibit greater intentional binding when they had a choice compared to no choice in their actions. 3) Greater intentional binding when the outcome was rewarding. We also predicted that 4) intentional binding would be greatest when individuals had both a choice and received a rewarding outcome. Given that schizophrenia is associated with a reduced effect of prospective factors on SoA (Synofzik et al., 2010; Synofzik & Voss, 2010; Voss et al., 2010), we expected that 5) individuals displaying more psychosis-like traits would exhibit a reduced effect of choice on intentional binding. We also predicted that because depressed individuals are generally less sensitive to positive feedback, 6) those with a greater number of depressive traits would show a reduced effect of a rewarding outcome on SoA.

2. Materials and methods

2.1. Participants

We used the software program G*Power to conduct a power analysis. Our goal was to obtain 0.90 power to detect a medium effect size of 0.30 at 0.016 alpha error probability (Bonferroni corrected for 3 correlation analyses). This returned a sample size of 140. We collected additional data to ensure that any exclusions due to non-task compliance or extreme scores, did not result in a reduced cohort. 181 participants returned complete datasets; 25 failed the quality control check as they did not respond with sufficient accuracy (>80 %) to the forced choice condition and were excluded and four were excluded as the relevant intentional binding scores were outside 3SDs of the mean (i.e., difference in intentional binding for the choice or outcome conditions). It should be noted that the inclusion of outliers made no difference to the conclusions of the study. Therefore, the study comprised a final total of 151 healthy adults (126F:25 M), aged 18–30 ($M = 19.30$, $SD = 1.71$). Participants were all undergraduate psychology students, recruited through The University of Kent Psychology Research Participation Scheme and reflect the broader student population in terms of ethnicity and socioeconomic backgrounds. Participants reported no history of neurological or psychiatric diagnoses prior to participation, and normal or corrected-to-normal vision. Upon completion, all participants received course credit for their time.

2.2. Ethical considerations

Full ethical approval was granted by the University of Kent Psychology Ethics Committee [Ethics ID: 202016044826956677]. All participants gave full informed consent prior to participation and had the right to withdraw at any point. Participants were made aware of the sensitive nature of the questionnaires prior to consenting to the study.

2.3. Equipment

The study was completed online using Qualtrics Survey Software (https://www.qualtrics.com) to present the study information to the participant and acquire consent. Demographic information and questionnaire data were also collected. The cognitive task (Libet clock) was presented using Pavlovia (https://pavlovia.org).

2.4. Sense of agency task

A Libet clock paradigm was used to assess temporal binding (see Fig. 1). Temporal binding can be measured by measuring the temporal shift of the action towards an outcome (action binding), or the temporal shift of the outcome towards an action (outcome binding). Action and outcome binding are often conceptualized as a reflection of a unitary temporal binding process. However, recent evidence suggests no correlation between the two temporal compressions (Tonn et al., 2021). We decided to focus on outcome binding as it permits a baseline condition that has a greater control over causality. We presented the same outcome stimuli (rewarding or punishing sound) and also the prompts to press a button, but crucially, without the participant pressing the button. This allows for baseline variables for each of the conditions (free/forced prompts and rewarding/punishing sounds). Using action binding with the same paradigm would result in only two baseline scores as an outcome sound could not be presented.

Participants were presented with a clockface (labelled at 5-minute intervals from 0 to 55). In each trial, a smaller circle rotated continuously around the clockface indicating the time on the clock, with a complete revolution lasting 2000 ms. The centre of the clock had a fixation cross and after a random interval between 750 and 2000 ms, was replaced with an arrow cue ("<", ">", or "< >") that remained on the screen for 500 ms, before returning to a fixation cross for the remainder of the trial. All conditions were fixed in number but presented in a random manner within each block.

2.5. Baseline condition

In baseline blocks, participants were instructed to focus their attention on the fixation cross in the centre of the clock, before being presented one of three arrow cues ("<", ">", "<>"). A sound (cash register or klaxon) would occur at a random interval of 400–1400 ms after the action cue. Participants were instructed to wait for a sound and were then prompted to provide the time on the clock that the sound occurred. Therefore, the baseline was identical to the operant condition except for the requirement to press a button. Each participant completed two baseline blocks; the first presented at the start of the study, with a total of 32 trials – the first four of which were considered practice trials and excluded.

2.6. Operant condition

In operant blocks, participants were informed that they now had to select an action when prompted and that their key press would

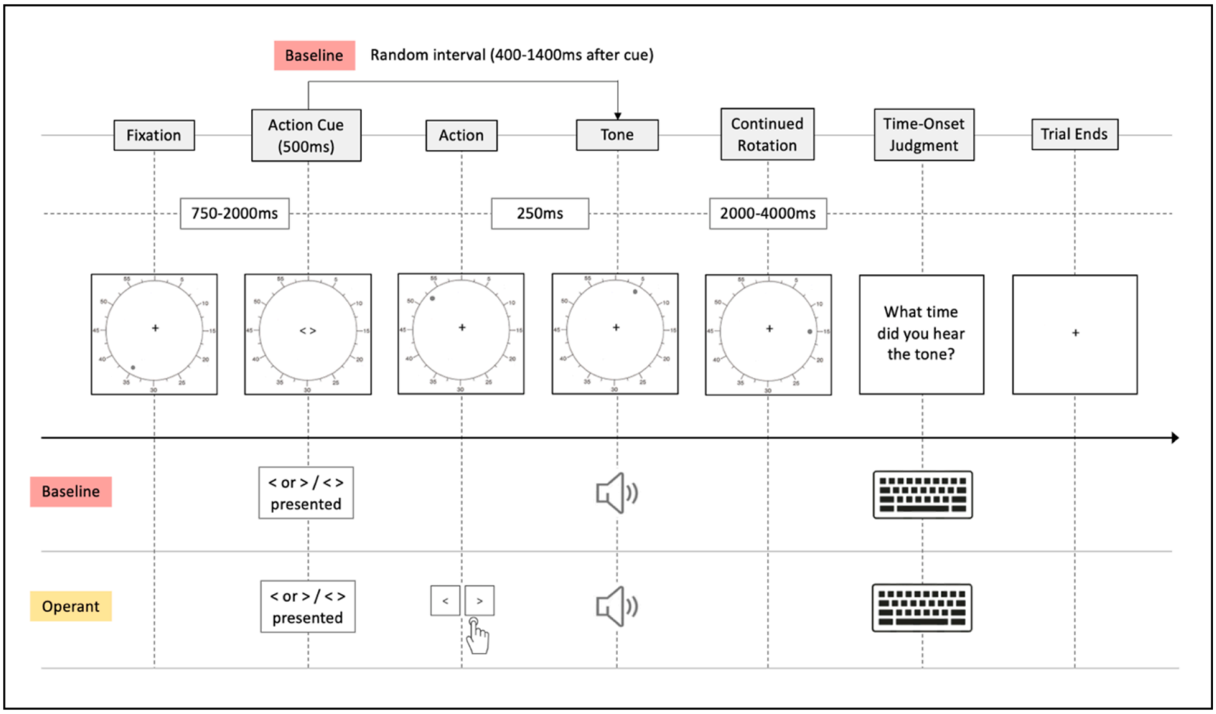

Fig. 1. Schematic Illustration of the Sense of Agency Libet Clock Task. *Note*. Schematic illustration for both baseline and operant blocks of the Sense of Agency Task. In operant blocks, participants watched a Libet clock-hand rotation and made an action ("<" or ">" key press). This action produced a rewarding or punishing auditory sound after a 250 ms interval, of which they would report the perceived time-onset that this sound occurred on the position of the clock. In baseline blocks, participants made no action, and were only required to indicate the time of which the rewarding or punishing sound occurred.

initiate a point gain or loss – represented through a rewarding or punishing sound respectively (cash machine or klaxon sound, as used in the baseline condition). The cue instructed each participant to press either the corresponding “<” or “>” key, or they were given a choice between the two buttons if presented with “< >”. After each key press, one of these sounds was randomly presented after 250 ms interval. Participants were informed that their responses would be recorded for a total score and that they would be rewarded with an extra credit if they finished in the top 25 % of participants. However, this was simply to motivate attention and effort and as the sounds were randomly allocated across trials, every participant received this extra credit. After the sound during both baseline and operant blocks, the clock disappeared after a random interval between 2000 and 4000 ms, and participants reported the perceived onset-time of the sound by typing a number into the response window.

The following seven operant blocks each consisted of 24 trials (6 for each condition in a randomized fashion), with a brief break offered between blocks if the participant required. Following the operant blocks, the second baseline block was presented and consisted of 28 trials. Therefore, a total of 144 operant trials (36 for each condition) and 56 baseline trials were presented. Reliability of the intentional binding index (difference between operant and baseline temporal binding) was calculated using the *splithalf* package in R, following a permutation based splithalf approach (Parsons, 2021; Parsons et al., 2019) with 5000 random splits.

2.7. Psychosis-like traits

To measure the participants’ psychosis-like traits, the Prodromal Questionnaire (PQB; Loewy et al., 2011) was administered. The PQ-B is a condensed 21-question self-report screening measure for psychosis-like traits. This identified the number of positive-oriented psychosis-like symptoms the participant had felt over the past month. The PQ-B is shown to be a valid and efficient measure for use in adolescents, young adults (Savill et al., 2018) and representative samples of nonclinical adolescents (Fonseca-Pedrero et al., 2018) with good internal consistency ($\alpha = 0.95$) and test–retest reliability ($r = 0.81$; Kline et al., 2012, 2015). A total score for each participant ranged from 0 to 21, with greater scores representing greater number of psychosis-like symptoms. This score was then used in the analyses. PQ-B scores ranged from 0 to 19 with a mean score of 6.37 (SD = 4.56).

2.8. Depressive traits

Depressive symptoms were measured using the Beck Depression Inventory (BDI-II; Beck et al., 1996). The BDI-II consists of 21 questions on a 4-point scale. The BDI-II measures depressive symptoms experienced over the previous two weeks. The BDI-II is well validated for use in a healthy, university-aged sample, with high internal consistency ($\alpha = 0.91$) and test–retest reliability ($r = 0.93$; Beck et al., 1996; Sprinkle et al., 2002; Storch et al., 2004). A total score for each participant ranged from 0 to 63, with greater scores representing greater number of depressive traits. The total score was used in all analyses. BDI-II scores ranged from 0 to 53 with 92 reporting minimal depressive traits (BDI-II range: 0–13), 25 mild (BDI-II range: 14–19), 18 moderate (BDI-II range 20–28), and 20 severe (BDI-II range: 29–63). The mean score of the cohort was 13.15 (SD = 11.20).

2.9. Procedure

All participants completed the study on a personal computer or laptop. Upon signing up for the study, participants followed a link directing them to the Qualtrics page. Here, they were provided information about the study, the requirements of the study, and the risks of participation. All participants gave full informed consent, before providing their basic demographic details. Subsequently, participants completed the PQ-B and BDI questionnaires before being directed to complete the second part of the study via Pavlovia. On Pavlovia, participants performed a soundcheck to ensure they could sufficiently hear the stimuli. Participants were then presented with the instructions for the Libet Clock task, before performing the first baseline block, the seven operant blocks, followed by the second and final baseline block. After completion, participants were each debriefed and provided the full details of the study’s aims. The entire study took approximately 90-minutes to complete.

2.10. Statistical analyses

2.10.1. Intentional binding

To compute intentional binding, the mean baseline judgement error was subtracted from the mean operant judgement error for each condition (free reward, free punish, forced reward, forced punish; see Supplementary Data). It should be noted that the judgement error during the baseline condition was based on the identical prompt used in the operant condition but crucially, without the requirement for the participant to press a button. Using this method, we produced a baseline condition that matched the operant condition and the difference between the two provided a measure of intentional binding. These perceptual shift values are indicative of the intentional binding scores – i.e., a shift in time of the outcome towards the action. Greater negative values therefore represent greater intentional binding, indicating a greater temporal compression between the action and outcome.

To assess the prospective and retrospective effects on SoA, the intentional binding scores were included in a 2 × 2 repeated-measures analysis of variance (RM-ANOVA), with both choice (free or forced) and outcome valence (rewarding or punishing) as within-subject factors. Effect sizes are provided in the form of partial eta-squared (η_p^2). We also provide Bayesian alongside frequentist statistics computed in JASP v0.14.1 (JASP Team, 2022). For the Bayesian analyses we adopted the default Cauchy priors as recommended (*t*-test: $r = 0.707$; ANOVA: $r_{fixed} = 1$, $r_{random} = 0.5$) and for the correlation analyses, a default stretched beta prior (width = 1) Wagenmakers et al., 2018). We also conducted analyses across a range of stretched beta priors to assess the robustness of any supported correlations across a range of stretched beta priors (κ). A Bayes factor (BF) quantifies the evidence for a particular model. For example, a BF_{10} of 8 equates to data that is 8 times as likely from the alternate model as from the null model. Evidence for the alternate model is interpreted in a linear scale but for the ease of interpretation we conclude $BF_{10} = 1–3$ as inconclusive or preliminary evidence, 3–10 as moderate evidence, and > 10 as strong evidence for the alternate model. Likewise, a BF_{10} between 0.33 and 1 should be considered inconclusive or preliminary evidence, between 0.1 and 0.33 as moderate evidence, and <0.1 as strong evidence for the null model.

2.10.2. Relationship with depression and psychosis

The second analysis assessed the relationship between depression and psychosis and the calculated effects of choice ($IB_{Choice} = IB_{Free\ Choice} - IB_{Forced\ Choice}$) and outcome ($IB_{Outcome} = IB_{Reward} - IB_{Punish}$) where IB refers to intentional binding. Therefore, a greater negative value for IB_{Choice} indicates a greater difference in intentional binding when presented with a free choice compared with a forced choice. Likewise, a greater negative value for $IB_{Outcome}$ indicates a greater difference in intentional binding when presented with a rewarding outcome compared with a punishing outcome. Pearson's correlations were conducted to examine the relationship between depression and psychosis-like traits and IB_{Choice} and $IB_{Outcome}$.

Both inverted raincloud plots (Allen et al., 2019) and scatterplots were computed using ggplot2 in R (R Core Team, 2020). The project was preregistered and all data is available online [https://osf.io/27qwj/]. We made one small adjustment to the outlier criteria as we felt the preregistered cut-off of 1.5 SD above or below the mean was too conservative. Again, it should be noted that the overall results did not differ when using the preregistered outlier cut-off. We preregistered a sample size of 140, but due to the parallel nature of data collection online and the need to collect more data than necessary to factor in exclusions, the final sample size was 151. We decided that it was transparent to include the complete dataset rather than the preregistered sample size of 140.

3. Results

3.1. Reliability of questionnaires

Within the current sample, both the psychosis PQ-B (α = 0.85) and the BDI-II had good internal consistency (α = 0.93). It should be noted that the BDI-II is not a clinically diagnostic tool and although some participants scored at clinically relevant levels, all participants included in the study reported no diagnosis of depression or any other psychiatric condition.

3.2. Reliability of intentional binding task

The (Spearman-Brown corrected) splithalf internal consistency for intentional binding scores was $r_{SB} = 0.88$, 95 % CI [0.83, 0.92]. We also computed internal consistency for each condition. For Free Choice Rewarding the internal consistency was $r_{SB} = 0.71$, 95 % CI [0.58, 0.80], Free Choice Punishing, $r_{SB} = 0.61$, 95 % CI [0.42, 0.74], Forced Choice Rewarding, $r_{SB} = 0.73$, 95 % CI [0.61, 0.81], and Forced Choice Punishing, $r_{SB} = 0.57$, 95 % CI [0.38, 0.70].

3.3. Intentional binding

To assess the first hypothesis, we analyzed whether temporal compression was greater during the operant (i.e. action required) than the baseline (i.e. no action required) conditions. Temporal compression was greater during the operant condition (M = −31.95, sd = 141.34) than the baseline condition (M = 52.17, sd = 103.15), providing strong evidence for a difference, t(150) = 10.57, p < 0.001 [BF_{10} = 6.76e + 16].

To assess hypotheses two to four, we analyzed the effects of choice available (free v forced) and subsequent outcome (reward v punish).

Both means and standard deviations of intentional binding for the prospective (choice; free or forced) and retrospective factors (outcome valence; rewarding or punishing) are presented in Table 1.

A main effect of outcome valence was identified, $F(1, 150) = 43.61$, $p < .001$, [BF_{10} = 3.02e + 10], $\eta_p^2 = .23$, with greater intentional binding after receiving the rewarding ($M = -101.95$, $SE = 8.40$), compared to the punishing outcome ($M = -66.30$, $SE = 8.40$). A null effect of choice was identified, $F(1, 150) = 1.72$, $p = .19$, [$BF_{10} = 0.16$] $\eta_p^2 = .01$. The interaction between both choice and outcome on intentional binding was also not supported, $F(1, 150) = 0.84$, $p = .36$, [$BF_{10} = 0.19$] $\eta_p^2 = .01$.

For the Bayesian analyses, we assessed the sensitivity of the analysis to the specification of the prior. We identified comparable

Table 1
Means and standard deviations of intentional binding (ms) for both choice and outcome valence.

Outcome Valence	Choice			
	Free		Forced	
	M	*SD*	*M*	*SD*
Rewarding	−107.02	115.68	−96.87	123.52
Punishing	−66.67	104.25	−65.92	98.53

Note: M and SD represent mean and standard deviation, respectively. Negative numbers reflect greater shift of the sound towards the action.

effects with a wider prior (i.e. r = 2) and a narrower prior (i.e. r = 0.1). The results from both these analyses are not qualitatively different from the initial analysis. Full details of the models are provided in Supplementary Table 1.

To summarise, our findings reveal strong evidence for an effect of outcome, moderate evidence for a null effect of choice on intentional binding (see Fig. 2), and moderate evidence for no interaction between choice and outcome. The results were robust across prior specification. Therefore, hypothesis three was supported but hypotheses two and four were not.

3.4. Relationship between SoA and depression and psychosis

We calculated correlations between both psychosis and depressive traits with the difference scores for both choice and outcome. IB_{Choice} is the difference in intentional binding for free and forced choice trials, and $IB_{Outcome}$ is the difference in intentional binding between reward ing and punishing outcomes. Strong evidence for a correlation between IB_{Choice} and depressive traits was identified, $r(149) = 0.25$ [95 % CI: 0.10–0.40], $p = .002$ [$BF_{10} = 12.34$] (see Fig. 3) and this was consistent across a range of prior distributions (see Fig. 4). However, no such relationship was identified for psychosis-like traits, $r(149) = 0.13$ [95 % CI: −0.03 – 0.29], $p = .11$ [$BF_{10} = 0.37$], not supporting hypothesis 5, although the evidence only weakly supported the null model. Regarding $IB_{Outcome}$, we demonstrate moderate evidence supporting the null model for both depressive-traits, $r(149) = 0.04$ [95 % CI: −0.12 – 0.20], $p = .61$ [$BF_{10} = 0.12$] and psychosis-like traits, $r(149) = -0.03$ [95 % CI: −0.19 – 0.13], $p = .68$ [$BF_{10} = 0.11$]. Therefore, hypothesis six was not supported. We also examined the correlation between psychosis and depressive traits and intentional binding in general. Moderate evidence in favour of the null model was demonstrated for both psychosis, $r(149) = 0.08$ [95 % CI: −0.08 – 0.24], $p = .31$ [$BF_{10} = 0.17$] and depressive traits, $r(149) = 0.06$ [95 % CI: −0.10 – 0.22], $p = .48$ [$BF_{10} = 0.13$].

In sum, at the lower end of the depression continuum, greater intentional binding was demonstrated for trials consisting of a free choice. The effect diminished with increasing number of depressive traits (see Fig. 3).

4. Discussion

We manipulated action choice and outcome valence to assess prospective and retrospective effects on implicit SoA and explore differences across the psychosis and depression continuums. Intentional binding was demonstrated and was greater when the outcomes were rewarding, evidencing a strong retrospective effect of valence. No overall effect of choice on intentional binding was found but this was dependent on inter-individual differences. Individuals reporting more depressive traits had less of a difference in intentional binding between free and forced choice conditions.

Several symptoms characteristic of depression indicate an altered SoA. For example, a depressed individual may state that they feel helpless to change their current situation or hopeless regarding the outcome of their actions. Despite clear theoretical links with

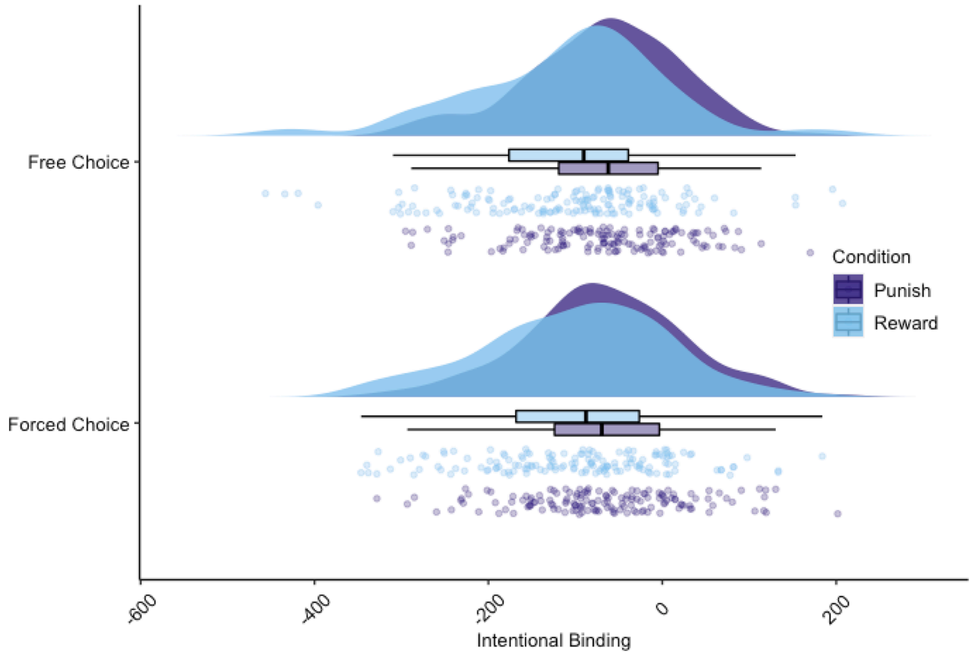

Fig. 2. Raincloud Plot Displaying the Distribution of Intentional Binding for Both Free and Forced Choice and Punishing and Rewarding Outcomes. *Note*. Raincloud plots depicting the distribution of participants' Intentional Binding scores (msecs) for both prospective (choice; free or forced) and retrospective factors (outcome valence; rewarding or punishing) of the SoA task. Greater negative values correspond to greater intentional binding. Each dot corresponds to an individual participant. Boxplots display the mean and the interquartile range with error bars extending to the furthest datapoint within 1.5 standard deviations from the mean. Distribution of Intentional Binding scores are also provided.

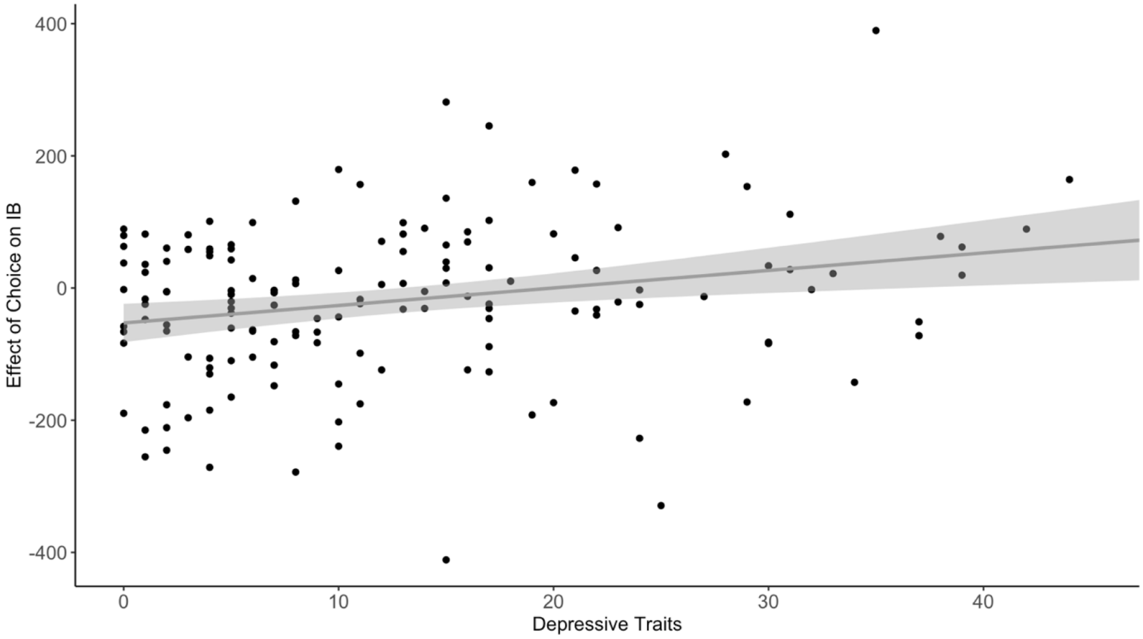

Fig. 3. Relationship Between the Effect of Choice on Intentional Binding and Depressive Traits. *Note*. A positive correlation between the effect of choice on intentional binding with depressive traits was identified. Effect of choice on intentional binding represents the difference between the effect of free and forced choice. A greater negative number reflects a greater effect of free choice on intentional binding. The scatterplots provide a graphical representation of the relationship between the effect of choice on intentional binding with depressive traits with the grey line representing the line of best fit and the shaded area representing the 95% confidence interval.

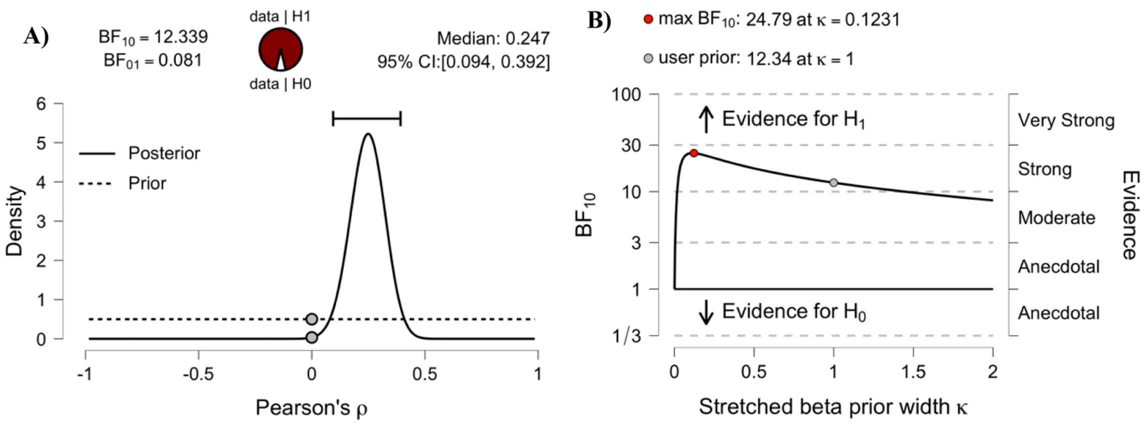

Fig. 4. Evidence for robustness of results for the Bayesian correlation between IB $_{Choice}$ and depressive traits. *Note*. A) Prior and posterior distribution and B) Strength of evidence across a range of alternate priors, for the correlation between depressive traits and IB $_{Choice}$. Strong evidence was demonstrated in favour of a correlation, and this was consistent across a range of prior distributions.

agency, this is the first study to demonstrate altered implicit SoA in relation to depressive traits. The reduced effect of choice, coupled with no effect of outcome, did not support our hypothesis. Therefore, although cognitive biases related to sensitivity to rewards have been implicated in depression (Halahakoon et al., 2020), we provide evidence that this does not extend to valence effects on an implicit SoA with random rewarding outcomes. Future research is warranted to assess the relationship between depressive traits and retrospective factors on SoA using alternative paradigms, especially those where participants can learn that one choice is associated with a superior outcome (Di Costa et al., 2018; Majchrowicz et al., 2020). The implicit SoA task used in the present study required the participant to make a choice between competing actions, but this had no influence on the valence of the subsequent outcome. Therefore, a SoA may only emerge if the individual falsely perceives they have some control of the nature of the outcome. It is possible that depressed individuals do not show this cognitive bias and do not display an illusion of control. The results tentatively support previous findings of reduced illusion of control in depressed individuals (Moore & Fresco, 2012). As with the self-serving bias, such cognitive biases may well be protective, allowing a greater feeling of control and self-determination in circumstances where control is lacking.

Enactive theorists claim an intimate relationship between emotion and action. Rather than an action being a consequence of an emotion, they claim that the action itself may be constitutive of the emotion. In other words, emotions can be understood as specific modifications of our active engagement with the world rather than mental states that are separate from action or behaviour (Hutto, 2012; Kyselo, 2014). Under this framework, depression has been characterized by an altered basic form of goal-pursuit, resulting in passivity and reduced agency (Slaby et al., 2013). The reduced effect of choice on implicit SoA, identified in the present study, may reflect greater passivity in simple actions in those with greater depressive symptoms and should encourage future research addressing enactive accounts of depression and the integrated role of emotion and action.

Psychosis has been linked with altered SoA across a range of tasks and stages of illness (Synofzik et al., 2013). Under a comparator model framework (Frith et al., 2000), consistent evidence has identified altered prospective factors amongst patients with chronic schizophrenia (Haggard et al., 2003; Synofzik et al., 2010; Synofzik & Voss, 2010; Voss et al., 2010), early psychosis (Hauser et al., 2011), and in subclinical psychosis (Di Plinio et al., 2019). The results from the present study support no association between increased psychosis-like traits and a decreased effect of choice on implicit SoA. Although this is inconsistent with previous research (Di Plinio et al., 2019) it should be noted that the evidence for the null was only weakly supported in the present study. Despite clear diagnostic overlap between psychosis and mood disorders such as depression (Wigman et al., 2011), no research to date has explored the role of negative mood on the relationship between psychosis and an altered SoA. If the present results extend to those with clinically diagnosed psychosis-related conditions, it demonstrates that mood symptoms, rather than psychosis, may be the crucial factor in terms of distortions to implicit SoA. However, although psychosis is considered to exist on a continuum, with diagnosed conditions such as schizophrenia simply reflecting the extreme end, the relationship with SoA may not follow a simple linear relationship. Therefore, the current results provide evidence that challenges differences in SoA across the psychosis continuum, but further research is required to determine whether this extends across the entire psychosis continuum. Future research could also include questionnaires with a greater focus on specific agency-related symptoms that may show a greater association with implicit measures of SoA such as intentional binding tasks.

Although the focus of the paper was the relationship between implicit SoA and depression and psychosis continuums, the paper also extends our cognitive understanding of implicit SoA. The effect of outcome in the present study is consistent with a retrospective effect on intentional binding. Previous research has used a financial reward to show a similar effect (Takahata et al., 2012), and we extend this evidence to show that it is consistent across both choice and no-choice conditions. The results are consistent with a self-serving bias, whereby individuals attribute greater agency over positive compared with negative outcomes (Yoshie & Haggard, 2013). As the SoA task used in the present study was not predictable, in that the choice in which button to press had no effect on the outcome, the strong effect of outcome is consistent with the integrated cue theory (Lau et al., 2007; Moore & Fletcher, 2012; Synofzik et al., 2013; Wolpe et al., 2013). According to this model of SoA, prospective factors are sufficient for a SoA when they are reliable. When prospective factors are unreliable, SoA may rely more on retrospective factors such as whether the action resulted in a positive or rewarding outcome.

In the present study, the evidence favoured no effect of choice on SoA. This does not support previous research showing that SoA is greater for free compared with forced choice (Borhani et al., 2017; Caspar et al., 2016). However, the nature of the choice and the outcome may explain the difference in effect of choice. The study by Borhani, Beck, & Haggard (2017) showed an effect of choice when the outcome was a painful heat or electro-tactile stimulation which differed from the sound indicating a point gained or lossed in the present study. The study by Caspar et al (2016), used financial penalty or painful shock to another person as the outcome. Previous research, using a similar outcome variable as the present study, demonstrated that increasing the number of choices can influence SoA judgements (Barlas & Obhi, 2013b). Although the results from the present study do not support this effect, it should be noted that the evidence for a null effect of choice was inconclusive.

Participants were presented with a choice on certain trials, but the outcome remained random. Therefore, the task may have induced a sense of learned helplessness that may have affected SoA. Previous research has shown that deprivation of personal control can lead to learned helplessness and remove a SoA (Soral et al., 2021). Future research employing more meaningful choices and alternate outcome measures are required in order to fully understand the effect of choice on SoA. For example, retrospective cue integration processes also contribute to intentional binding (Lau et al., 2007; Moore & Fletcher, 2012; Synofzik et al., 2013; Wolpe et al., 2013). According to optimal cue integration theory, the brain integrates related sensory signals as a weighted average according to their reliability or precision, with more reliable signals given higher weighting in the resulting percept. For example, Ernst and Banks (2002) showed that haptic cues contribute more to object size perception when visual perception of the object is degraded. Similarly, using an intentional binding paradigm, Wolpe et al. (2013) showed that outcome binding increases when the sound is embedded in a background of noise, indicating that the more reliable action cue is driving the perceived time of the action-sound event. Prospective cues to SoA can also be accommodated within a cue integration account through a Bayesian cue integration framework that also considers the influence of prior information (predictions) on perception (Moore & Fletcher, 2012). Therefore, the fact that choice had no main effect or interaction with outcome valence in the present study, may be due to the lack of meaningful choice or predictability that a specific choice would increase the chance of a certain outcome.

The current study was limited to outcome binding to assess implicit SoA. Although intentional binding is often considered a unitary construct, some studies have questioned whether action and outcome binding may reflect unique processes (Borhani et al., 2017; Di Costa et al., 2018; Wolpe et al., 2013). Therefore, future research is required to assess the association between action-binding and mental health traits as well as assess the effects of choice and outcome valence manipulations. In the present study we control for simple binding between temporally related events by including a prompt to move and the subsequent outcome, without any need for the participant to press a button. Future studies could go further to control for simple causality effects on temporal binding. For example, a study using virtual and augmented reality demonstrated that a virtual hand that precisely tracked the participant's movements and a fake hand that did not require any movement from the participant resulted in the same magnitude of temporal binding following a button press (Suzuki et al., 2019). Observing a fake hand, especially as it was modelled on the participant's own movements, may engage sensorimotor processes similar to those when actually performing an action. In Suzuki et al (2019) they used an explicit rating of ownership to show that subjective feelings of agency were not comparable between the two conditions and thus could not explain the lack or a difference in intentional binding. However, explicit measures of agency do not correlate with implicit measures (Dewey & Knoblich, 2014) making the results difficult to interpret. Future research is required to assess whether intentionality increases binding over and above those observed due to causality. It should also be of note that the current project was conducted online during a global pandemic which may have influenced the results. Although the conditions of the online task were adhered to extremely well, with only a few cases excluded through the attention checks, future laboratory based experiements are required to confirm the results in more controlled conditions. For example, questionnaires administered before the cognitive task may have influenced the results and the order could be counterbalanced in future experiements. Although course credits are a valued reward for undergraduate psychology students, greater incentives, in the form of monetary rewards, may influence the results. More generally, the use of undergraduate psychology students attending a Western university will bias results due to being predominantly female and highly educated. Although participants with a diagnosis of depression (and other psychiatric conditions) were excluded, several of the participants reported depressive traits that may be clinically relevant. Although the BDI-II should not be used as a diagnostic tool, some participants may be clinically depressed without a formal diagnosis. Future research should extend the continuum approach to clinical samples to assess the effects of SoA across the entire continuum of depressive traits and explore whether a linear model remains the best fit.

In sum, we identified a strong effect of valence outcome on implicit SoA, supporting a strong influence of retrospective factors on SoA when a prospective factor is unreliable. The evidence favoured no effect of freedom of choice on average, but this was influenced by inter-individual differences. Individuals reporting more depressive traits had less of a difference in intentional binding between free and forced choice conditions.

Author contributions

NJS, MG, & AKM designed the study; NJS, MG analyzed the data; NJS, MG, BB, & AKM all wrote and edited the manuscript.

Funding

None to report.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

We acknowledge all participants for their time and effort. We would like to thank Frank Gasking for assistance with coding the task.

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.concog.2022.103412.

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