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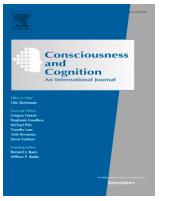

Sense of agency during and following recovery from anorexia nervosa

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ABSTRACT

The need to feel in control is central to anorexia nervosa (AN). The sense of control in AN has only been studied through self-report. This study investigated whether implicit sense of control (sense of agency; SoA) differs across AN patients, recovered AN (RAN) patients and healthy controls (HC). Furthermore, we assessed whether state anxiety is influenced by negative emotional states. SoA was measured with the intentional binding task (IB) and state-anxiety levels through a questionnaire. We did not find any evidence of differences in SoA between groups. Furthermore, state anxiety was not a significant predictor of SoA. Further research into SoA in AN should focus on other features of the SoA that are not targeted by the IB task.

1. Introduction

Many people have experienced loss of control, for example, in a relationship or at work, or over their thoughts and emotions. Less common, however, is the experience of losing control over actions such as switching on the light – 'was it me who turned on the light?' The latter refers to a more implicit experience of control that is called *sense of agency* (SoA) (Haggard, 2017; but cf. Synofzik et al., 2008 for a distinction between different components of agency). Several psychiatric groups, such as those with obsessive–compulsive disorder and schizophrenia, struggle with respect to experiencing control as well as SoA (Haggard et al., 2003; Oren et al., 2019). A disorder in which SoA has not been investigated yet, but in which the need for control is a central component, is anorexia nervosa (AN) (Fairburn et al., 2003; Froreich et al., 2016; Horesh et al., 2000).

AN is classified by the DSM-V (American Psychiatric Association, 2013) as an intense fear of gaining weight, restriction of energy intake leading to a significantly low body weight, and a false experience of body weight or shape. Clinical characteristics associated with AN are negative body image, lack of self-confidence, impulsivity, perfectionism, fear of failure (performance anxiety), and self-criticism (Noordenbos & Lammers, 2018). Even though the need for control is not a direct diagnostic symptom in AN, it is a central aspect of the disorder and found to be a contributory factor to the development of AN (Slade, 1982). How control can be intertwined with someone's eating disorder (ED) is best reflected in the following description from a patient:

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> *I think of my ed [eating disorder] as a sanctuary from the pain that I've lived through. I have control over myself when I restrict, and I have control over my body when I purge and that is what has got me through the hard times in my life, the times when there was no control or stability in sight.* (Fox et al., 2005, p. 958).

This patient describes that when she faces difficult situations in life, over which she experiences no control, she turns to her ED to fulfil her need for control. It has indeed been suggested that an ED is an attempt to compensate for the lack of control that patients with AN experience over their lives (Bruch, 1974; Oldershaw et al., 2015; Serpell et al., 1999; Tan et al., 2006). The ED provides a strong feeling of self-confidence and a strong sense of self, which contributes to a more positive identity and a sense of control (Noordenbos, 2007, p. 46). In other words, in AN patients (unhealthy) dieting behaviour leads to a feeling of being in control, which is experienced as extremely positive.

At first, the dieting behaviour might seem functional to AN patients, as it alleviates distress and provides them with a sense of control. However, this sense of control is not permanent as AN patients need to continue and enhance these dietary behaviours, as not doing so leads to a perceived *loss* of control which in turn often results in feelings of extreme anxiety (Fairburn et al., 1999). Over time, these controlling behaviours can become habitual (Walsh, 2013). The paradox is that, in AN patients, restrictive and/or compensative behaviour to lose weight starts off as behaviour that increases the feeling of being in control. As the disease progresses, however, the ED will often take control over the patient, as is reflected in this patient's report:

> *It takes control of you, but it can also feel very safe. It's a very confusing illness, because at the moment it's probably got a lot of control over me, in certain ways, and I just want to get away from it, I'm just sick and tired and I'm exhausted, but then it kinds of protects you as well, I think, from coping with other things… It distracts you so completely about things you don't want to think about, to lose that is quite scary.* (Tan et al., 2006, p. 12).

During ED treatment patients are taught healthy ways to experience control without needing the ED behaviours to accomplish this. Indeed, several studies show that, after recovery, patients show an increase in the feeling of control (e.g. Jenkins & Ogden, 2012). However, the work described above has mainly focused on the self-reported experience of control in AN, and how this experience of control relates to recovery (Fairburn et al., 1999; Noordenbos, 2007; Surgenor et al., 2003; Tan et al., 2006). A more implicit sense of control, such as the SoA, has not yet been studied in AN or in patients who are recovered from AN (RAN). Given the clinical relevance of this experienced lack of control and how it is intertwined with ED symptomology, it is important to fully understand all aspects of the sense of control. Focusing on mechanisms of implicit SoA may help to illuminate the underlying cause of experienced loss of self-control in AN, and how this implicit feeling of self-control is related to recovery from AN. Furthermore, adopting implicit measures can help to avoid some of the classic issues related to explicit self-report measures (e.g. demand characteristics), a much debated issue within research into AN (Engel et al., 2021).

SoA is defined by Haggard (2017) as the association between a voluntary action and outcome – e.g. flipping the switch (voluntary action) that turns on the light (outcome). Haggard (2017) described two key mechanisms that are necessary for the SoA to arise, ownership ('my body moved') and volition ('I voluntary made it move') (For a more detailed reading on neurological and cognitive mechanisms involved in the SoA see e.g., Haggard, 2017; Moore & Haggard, 2008; Moore & Obhi, 2012; Wen & Haggard, 2020). SoA is often measured with the intentional binding (IB) task (Haggard et al., 2002; Moore & Obhi, 2012). This task is an adapted version of the Libet clock method (Libet et al., 1993) and measures the perceived time of action (e.g. a key press) and a sensory outcome (e.g. auditory tone). When participants are under the impression that they cause the tone, a temporal binding occurs, and participants estimate the time of action and the occurrence of the tone as closer together (Haggard, 2017).

Targeting the SoA might be a useful way in which to explore an implicit component of the sense of control. Consistent with this hypothesis, the SoA has been found to be disturbed in a variety of psychiatric and neurological disorders associated with deficits in the explicit sense of control, e.g. schizophrenia (Haggard et al., 2003; Hauser et al., 2011; Synofzik & Voss, 2010), (Jenkinson et al., 2015), obsessive-compulsive disorder (Oren et al., 2019), Parkinson's disease (Saito et al., 2017), and autism spectrum disorder (Sperduti et al., 2014). These findings support the possibility that the lack of control that AN patients experience may be associated with a reduced SoA.

In sum, the feeling of control is central to AN and has mostly been investigated through self-report. The current study was set up to investigate the implicit sense of control, the SoA, in AN and RAN patients. The RAN group is included to investigate if the SoA changes after a successful completion of treatment, as previous research has shown that the sense of control is an important factor in recovery (Fairburn et al., 1999; Noordenbos, 2007; Surgenor et al., 2003). We expected that AN patients would have a lower SoA compared to healthy controls (HC).

Research on healthy subjects has found that emotional states, such as fear and anger, reduce the SoA (Christensen et al., 2019). A recent study showed higher state anxiety in AN prior to an experimental task (Hasenack et al., 2021). It is plausible that higher states of anxiety lower the SoA in AN, given the evidence that emotional states reduce the SoA. In light of this, we included state anxiety in our design. We hypothesize that higher state anxiety predicts a lower SoA, and we expect this to be most prominent in the AN group.

2. Method

2.1. Ethics statement

The ethics committee of the Utrecht University, Faculty of Social and Behavioural Sciences, Experimental Psychology approved the current study. The study adhered to the tenets of the Declaration of Helsinki (2013). Participants were informed about the study; they

received oral and written information on the purpose and procedure. Informed consent forms were signed before taking part in the study.

2.2. Participants

To our knowledge a study on the SoA in AN and RAN has not been conducted before and we were unable to conduct a power analysis. Therefore, we based our sample size on the Central Limit Theorem and aimed for 30 participants in each group. However, due to time restrictions we were unable to recruit our last 8 participants in the AN group. A total of 89 females participated in this study, of whom 8 people were excluded from analysis on the account of having bulimia nervosa or binge eating disorder diagnoses. In total, 81 participants were included for the analysis: 22 AN patients, 30 RAN patients, and 29 HC. See Table 1 for demographic and clinical characteristics of the AN patients, RAN patients and HC. All AN and RAN reported diagnoses were checked with the SCID-IV, part H. RAN patients were considered recovered when they successfully completed their ED treatment. Inclusion criteria for HC were no past or present ED.

AN patients and RAN patients were recruited from the Leontienhuis and treatment centre GGZ Rivierduinen Eetstoornissen Ursula, both located in the Netherlands. Leontienhuis is a non-treatment institution where help and support is provided by people recovered from an ED. For more information see https://www.leontienhuis.nl. HC were volunteers from the Leontienhuis and undergraduate students, who were recruited from Utrecht University. Students received course credit for participation.

2.3. Materials and procedure

After providing signed informed consent, participants took part in the interview, filled out the questionnaires, and participated in the IB task in the order as presented below. Gorilla Experiment Builder (https://www.gorilla.sc) was used to create and host the questionnaires (Anwyl-Irvine et al., 2020).

2.3.1. Structured and clinical interview for DSM (SCID) IV-I part H

Part H (Eating Disorders) of the SCID IV-I interview (First, 1997) was used to check the diagnostic criteria for the presence of an acute or past ED diagnosis in participants.

2.3.2. Self-Control Scale

The Self-Control Scale (SCS) is a trait measure of self-control (Tangney et al., 2004). It's a validated scale that shows good internal consistency (alpha = 0.89) and retest reliability (alpha = 0.89). It consists of 36 statements that are scored on a 5-point scale ranging from 1 "not at all" to 5 "very much", from which a total score is calculated. The questionnaire was used for a demographic description of the sample.

2.3.3. State-Trait anxiety scale

The State-Trait Anxiety Scale (STAI) measures state and trait anxiety (Spielberger et al., 1970). The STAI consists of 40 statements that are scored on a 4 point scale ranging from 1 "almost never" to 4 "almost always". The first 20 items evaluate state anxiety and the other 20 evaluate trait anxiety. For this study, only the state version (STAI-S) was administered. The internal consistency of the STAI-S is good (alpha = 0.94) (van der Bij et al., 2003). The sum of the first 20 items was calculated.

2.3.4. Intentional binding task

An adapted version of the intentional binding task designed by Haggard, Clark and Kalogeras (2002) was used in this study. A 13-inch screen was used where the stimuli, followed by an answering box, were presented in a fixed order, they were both presented on a

Table 1
Descriptive and inferential statistics of the demographic and clinical characteristics for the sample.

Descriptives				Inferential statistics			
	HC	RAN	AN	*DF*	*F*	*p*	η_p^2
Age	30.3 ± 14.0 (18–55)	32.5 ± 10.6 (19–56)	29.9 ± 10.6 (19–63)	2, 78	0.392	0.677	0.010
BMI	22.0 ± 2.72 (18.0–28.3)	20.2 ± 2.42 (14.9–25.4)	19.0 ± 2.46 (14.0–22.7)	2, 55	6.057	0.004	0.181
Illness duration in Years	–	7.21 ± 5.00 (2–20)	5.85 ± 3.69 (2–15)				
Time since completion ED treatment in years	–	5.68 ± 6.75 (0–28)	–				
Self-Control Scale	119.59 ± 14.24	120.00 ± 15.95	111.09 ±17.73	2, 79	2.428	0.095	0.058
STAI-S	35.9 ± 8.26	48.1 ± 13.1	59.5 ± 10.9	2, 79	29.4	0.001	0.43

Note. HC = Healthy Control, AN = Anorexia Nervosa, RAN = Recovered AN, BMI = Body Mass Index, STAI-S = State/Trait Anxiety Scale – State (Spielberger et al., 1970).

white background. The stimuli consisted of a clock, centred on the screen with a rotating clock hand, see Fig. 1. The hand rotated with a speed of 2560 ms per revolution. The starting location of the dot was determined randomly for every trial. The clock hand stopped rotating between 1500 ms and 2500 ms after a keypress (spacebar) or auditory tone (1,000 Hz, 100 ms duration). The answer screen appeared with a request to report the time of the keypress and tone and an answer box, which only logged numbers between 0 and 60.

In the IB task, participants judged the subjective time of a simple voluntary action (keypress) or an auditory tone. Participants were asked to sit approximately 30 cm from the screen and fixate on the fixation dot in the centre, while the clock hand rotated until the trial was completed. The task consisted of 4 conditions (2 baseline, and 2 operant conditions) with 28 trials in each. The first 3 trials were considered practice trials, the last 25 trials were used for analysis. Note that the trials were shortened for this study, in the original 40 trials per condition are used. This was done to keep the experiment short due to the low attention span of AN patients.

In the Baseline Tone condition, participants were presented with an auditory tone and were asked to judge the time when they heard the tone. In the Baseline Action condition, participants were asked to press the spacebar at a moment of their choosing and were asked to judge the time at which they pressed the spacebar (action judgement). In the two operant conditions, the participants were asked to press the spacebar, which was followed by the auditory tone. Participants were asked to make a judgement of the time of the tone (Operant Tone) and a judgement of the time of action (Operant Action). In the operant conditions, the auditory tone was presented with a fixed temporal window, 250 ms after the spacebar was pressed. The conditions were randomly presented for each participant. See Fig. 2 for an overview of conditions.

2.4. Statistical analysis

All data were analysed in *R* (v3.6.3; R Core team, 2020). The SCS and STAI-S scores were derived by summing item scores.

For the IB task, the variables of interest were the timing errors in judgement for each condition. To calculate the IB, the judgement errors were transformed into milliseconds by dividing the time of a complete rotation (which is 2560 ms) by 60. Next, the action-shift, tone-shift and IB were calculated with the following formulas:

$$\text{action} - \text{shift} = Operant_{Action} - Baseline_{Action}$$

$$\text{tone} - \text{shift} = Baseline_{Tone} - Operant_{Tone}$$

$$IB = action - shift + tone - shift$$

A higher IB value reflects a stronger IB, which in turn reflects a stronger SoA (Haggard, 2017; Moore & Obhi, 2012).

A one-way ANOVA was used to calculate differences between Group (AN, RAN, HC) for the STAI-S scores. A mixed ANOVA was used to analyse differences in judgement errors with Group (AN, RAN, HC) as between subjects variable and Condition (Baseline, Operant) and Event (Action, Tone) as within-subjects variables. Planned comparisons were Tukey corrected. Partial eta-square (η_p^2) was used to indicate effect sizes. A η_p^2 of 0.01 is considered a small effect, 0.06 a medium effect, and 0.14 a large effect.

Three regression analyses were conducted with IB scores, action-shift, and tone-shift as the dependent variables and STAI-S scores and Group as independent variables. For Group, we coded HC as the reference level.

The assumption of normality was assessed with the Shapiro-Wilks test and data plots. Homogeneity of variance was assessed with the Levine's test.

We checked for correlations of all agency measurements with, 'age', 'BMI', 'SCS', 'duration ED', 'duration ED treatment', and 'time since completion ED treatment', as described in Table 1. There were some significant correlations, but they did not survive the Bonferroni correction (critical $p = .007$; all p's > 0.035) and were therefore not used as covariates in analyses.

On the account of a null result, a Bayes Factor (BF) was calculated to determine whether the data provided evidence for the null hypothesis. To calculate the BF, the *R* package Bain was used (Gu et al., 2021). A BF of 0–1 is interpreted as no evidence, 1–3 is anecdotal evidence, 3–10 is moderate support, and BF > 10 is strong support (Hoijtink et al., 2019).

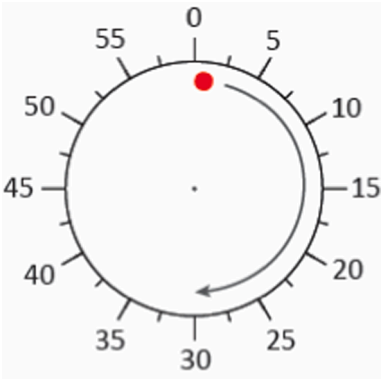

Fig. 1. Schematic overview of clock presented during experiment, with clockwise rotating hand.

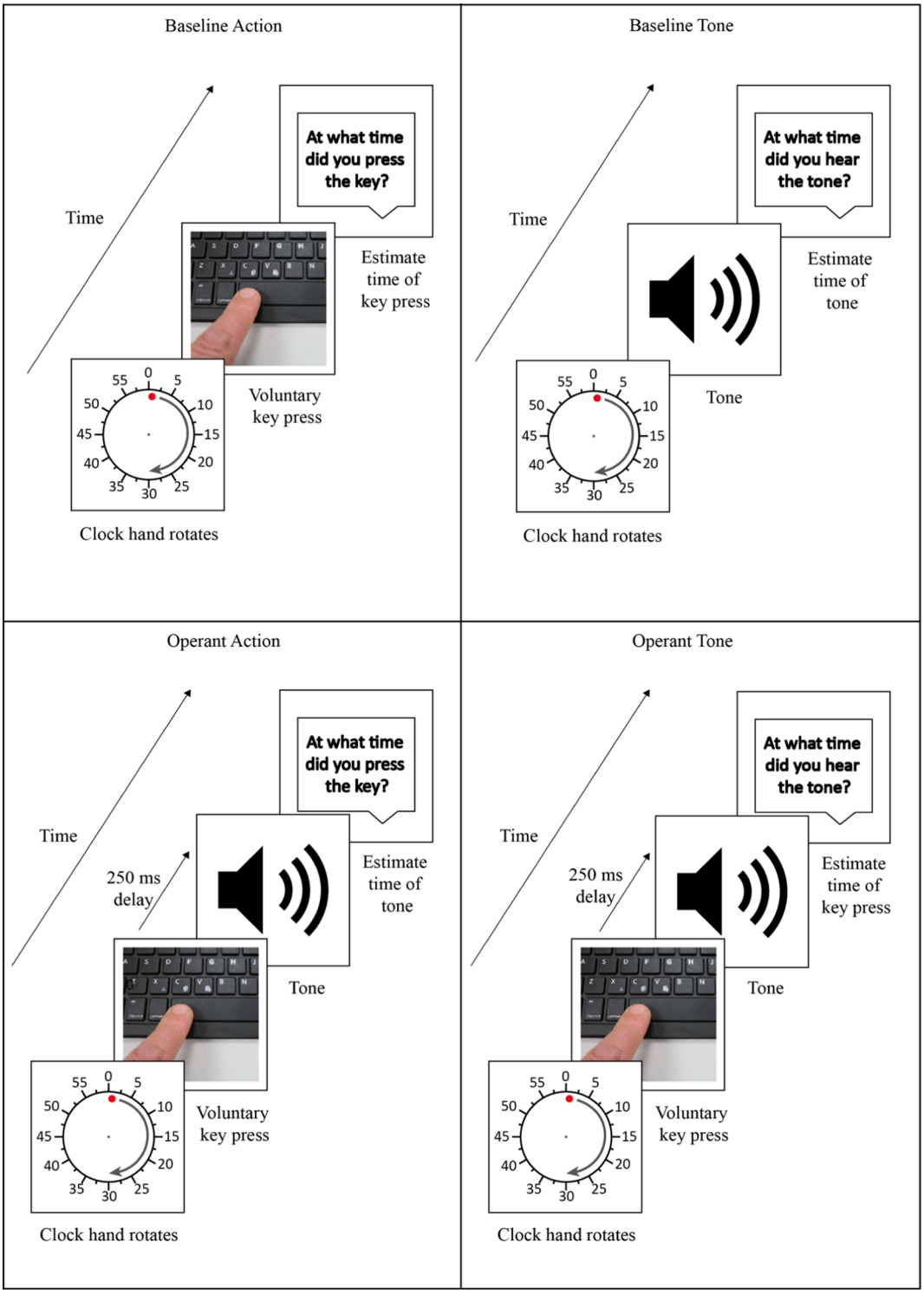

Fig. 2. IB task with Baseline and Operant conditions.

3. Results

BMI was significantly different between groups, see Table 1 for inferential statistics. Tukey pairwise comparison revealed that AN patients had a significant lower BMI compared to HC (p =.009). A significant lower BMI was also found for RAN patients compared to

HC (p =.038). No significant difference was found in BMI between RAN and AN (p =.49). Results showed no difference in age between groups, see Table 1 for statistics.

A one-way ANOVA revealed no differences on the SCS, indicating that groups did not differ in the explicit sense of control, see Table 1 for statistics. A one-way ANOVA showed significant differences between Group for state anxiety, $F(2,79) = 29.4$, $p < .001$, $\eta_p^2 = 0.43$. AN patients showed higher STAI-S scores compared to RAN patients (p =.001) and HC (p <.001). RAN patients have higher STAI-S scores compared to HC (p <.001), see Table 1 and Fig. 3.

3.1. IB

The results of the mixed ANOVA revealed a significant main effect of Event and a significant interaction effect of Condition by Event. This interaction effect indicates a temporal binding in the Operant Conditions, see Fig. 4. In contrast to our expectations, we did not find a main effect of Group. See Table 2 and 3 and Fig. 4 for means in judgement error per Condition and inferential statistics.

To further test for evidence for the null hypothesis (no differences between group) Bayesian ANOVAs were conducted. Results revealed a BF_{IB} of 3.677 (anecdotal evidence), a $BF_{action\text{-}shift}$ of 24.365 (strong support), and a $BF_{tone\text{-}shift}$ of 3.292 (anecdotal evidence).

3.2. STAI-S and IB

In contrast to expectations, the results of the regression indicated that STAI-S scores did not significantly predict IB scores (R^2 = 0.01, $F(5,75) = 1.09$, p =.37, $BF = 32.208$ (strong support for H_0)), nor action-shift (R^2 = -0.03, $F(5,75) = 0.62$, p =.69, $BF = 17.838$ (strong support for H_0)) or tone-shift ($R^2 = 0.02$, $F(5,75) = 1.28$, p =.28, $BF = 17.860$ (strong support for H_0)). See Tables 4, 5 and 6 for the model summaries.

3.3. Explicit control and implicit control

To further explore whether the explicit feeling of control is related to the implicit SoA, multiple Pearson's correlations were conducted between SCS and action-shift, SCS and tone-shift, and SCS and IB. After FDR correction, the Pearson's correlations showed a significant association between SCS and tone-shift for RAN patients ($r(28)$ = -0.43, p =.037). All other correlations were non-significant (p >.371).

3.4. Explicit control and state anxiety

In addition, we explored whether the explicit feeling of control is related to state anxiety, multiple Pearson's correlations were conducted between SCS and STAI-S. After FDR correction, the Pearson's correlations showed a significant association between SCS and STAI-S for HC ($r(27)$ = -0.54, p =.002) and RAN patients ($r(28)$ = -0.37, p =.045). The correlation in AN patients was not significant ($r(20)$ = -0.01, p =.664).

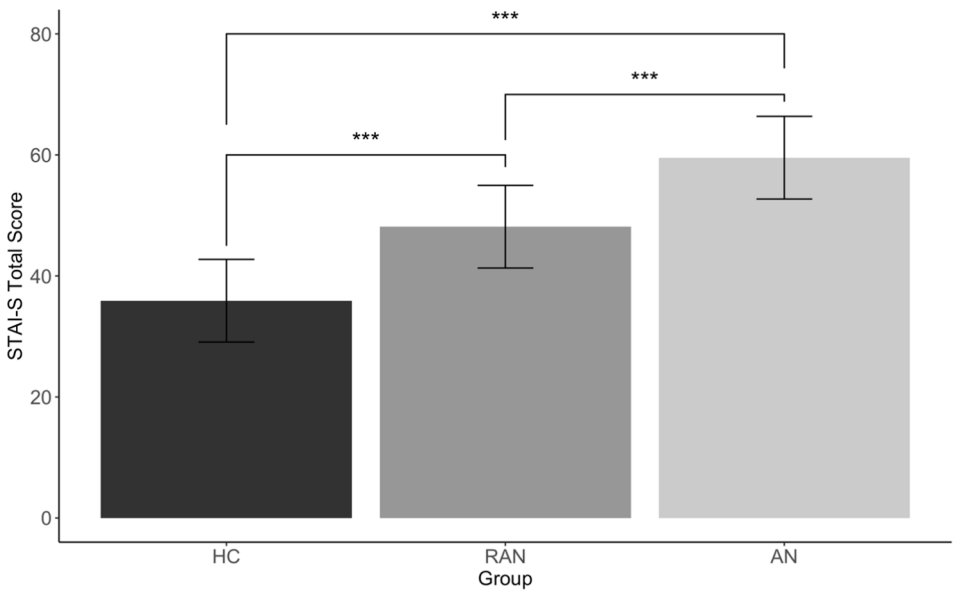

Fig. 3. *STAI-State scores of HC, RAN and AN. Note.* ***p <.001 Error bars depict SE. STAI-S = State/Trait Anxiety Scale – State (Spielberger et al., 1970). HC = healthy control, AN = anorexia nervosa, RAN = recovered AN.

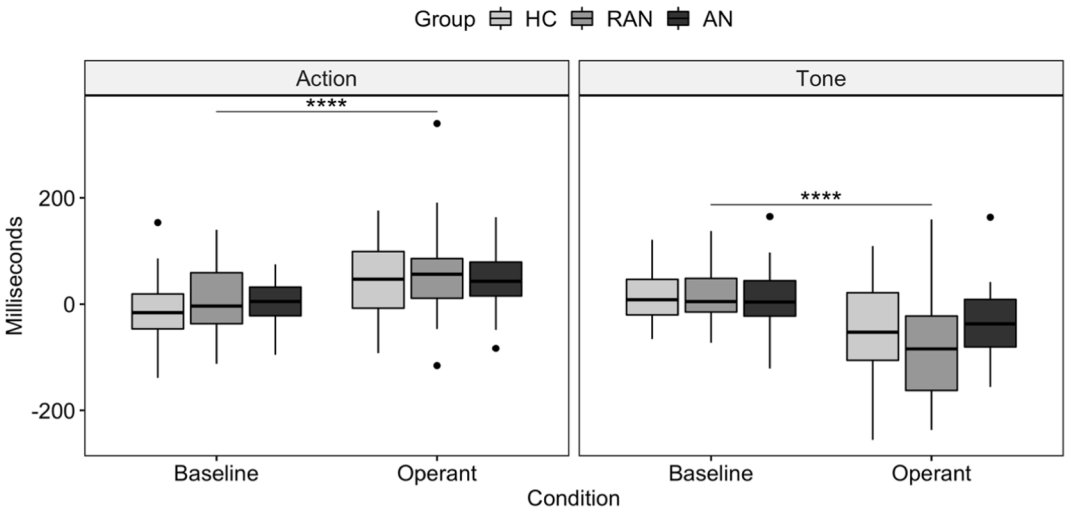

Fig. 4. Means in judgement errors for Baseline Action and Operant Action (left) and Baseline Tone and Operant Tone (right) Note. ****p <.0001.

Table 2
Descriptive statistics of the Baseline and Operant Action and Tone and Action Shift and Tone Shift by group.

Event	Group	Baseline		Operant		Shift	
		M (ms)	*SE (ms)*	*M (ms)*	*SE (ms)*	*M (ms)*	*SE (ms)*
Action	HC	−12.7	11.8	49.3	13.9	62	10.8
	RAN	7.44	11.4	62.8	16.2	55.4	12.2
	AN	5.25	8.43	50.8	14.2	45.6	9.43
Tone	HC	13.4	9.47	−57.9	16.9	71.3	17.6
	RAN	15.9	9.39	−85.9	17.4	102	15.1
	AN	10.6	12.8	−36.2	15.6	46.8	19
		M	*SE*				
IB	HC	133.3	21.1				
	RAN	157.4	19.0				
	AN	92.4	21.0				

Note. HC = healthy control, AN =anorexia nervosa, RAN = recovered AN, IB = Intentional Binding.

Table 3
Results of the mixed ANOVA for the IB task.

Effect	*DF*	*F*	*p*	η_p^2
Group	2,78	0.238	0.79	0.006
Event	**1,78**	**50.235**	**<0.001**	**0.392**
Condition	2,78	2.508	0.12	0.031
Group:Event	2,78	2.028	0.14	0.049
Group:Condition	2,78	1.405	0.25	0.035
Event:Condition	**1,78**	**115.057**	**<0.001**	**0.596**
Group:Event:Condition	2,78	2.385	0.10	0.058

Note. DF = Degrees of Freedom.

Table 4
Model summary IB.

	Beta	*Std. Error*	*t*	*p*
Intercept	177.72	90.60	1.96	0.05
STAI-S	−1.24	2.46	−0.50	0.62
RAN	−20.08	117.55	−0.17	0.86
AN	12.54	158.81	0.08	0.94
STAI-S:RAN	1.23	2.89	0.43	0.67
STAI-S:AN	−0.41	3.27	−0.12	0.90

Note. STAI-S = State/Trait Anxiety Scale – State (Spielberger et al., 1970), AN = anorexia nervosa, RAN = recovered AN.

Table 5
Model summary Action Shift.

	Beta	*Std. Error*	*t*	*p*
Intercept	41.50	49.53	0.84	0.41
STAI-S	0.57	1.35	0.43	0.67
RAN	59.29	64.26	0.92	0.36
AN	59.18	86.82	0.68	0.50
STAI-S:RAN	−1.82	1.58	−1.00	0.34
STAI-S:AN	−1.50	1.79	−0.84	0.41

Note. STAI-S = State/Trait Anxiety Scale – State (Spielberger et al., 1970), AN = anorexia nervosa, RAN = recovered AN.

Table 6
Model summary Tone Shift.

	Beta	*Std. Error*	*t*	*p*
Intercept	136.23	75.63	1.80	0.08
STAI-S	−1.81	2.06	−0.88	0.38
RAN	−79.37	98.13	−0.81	0.42
AN	−46.65	132.58	−0.35	0.73
STAI-S:RAN	2.74	2.41	1.14	0.26
STAI-S:AN	1.09	2.73	0.40	0.69

Note. STAI-S = State/Trait Anxiety Scale – State (Spielberger et al., 1970), AN = anorexia nervosa, RAN = recovered AN.

4. Discussion

The present study was designed to determine whether an implicit sense of control, the SoA, differs between AN patients, RAN patients, and HC, and if state anxiety would be a predictor of the SoA. In contrast to expectations, our results did not show any group differences on the IB task, indicating that SoA is not different between AN patients, RAN patients and HC. Evidence for the null finding was supported by the Bayesian analysis, with strong evidence for the action-shift but only anecdotal evidence for tone-shift and total IB score. Interestingly, state anxiety was not a significant predictor of the IB. This finding was supported by the Bayesian analysis with strong evidence. In other words, in contrast to our expectations, we found that state anxiety does not appear to influence the SoA.

One reason for why this study found no difference in IB scores between groups might simply be that the specific mechanisms underlying the IB task are not impaired or altered in AN patients (in contrast to schizophrenic patients, for example, who show an enhanced retrospective binding (Synofzik & Voss, 2010; Voss et al., 2010)). Consequently, the deficit in control associated with AN may be best conceptualised in terms of negative attitudes towards themselves and their ambitions – for example, "despair over defining or becoming the person they want to be" (Bers et al., 2004) – rather than the feeling of control over action and sensory outcome, which is targeted by the IB. Instead, dieting as a means to gain control may be triggered by negative affect and serve as a method to cope or avoid emotional distress (Noordenbos, 2007).

Nevertheless, agency is a complex construct and the IB task only measures binding over an action and fixed sensory outcome and is a relatively predictable task. Therefore, it might only tap into some aspects of agency, and our findings might not necessarily generalise to all aspects of agency. For example, it has been suggested that IB only relies on stimulus anticipation, rather than a voluntary action (Hughes et al., 2013).

Beyond volition, it has been claimed that ownership is needed for the SoA to arise (Haggard, 2017). However, it has been found that the IB effect arises without ownership of the agent (Zapparoli et al., 2022). While the IB task used in our study did not show differences in stimulus anticipation in our sample, the task might not pick up on differences in ownership (Zopf et al., 2018). This possibility could be especially likely since differences in ownership over a rubber hand have been previously found in AN (Keizer et al., 2014).

Given the above-mentioned limitations on the IB task, future studies might incorporate different paradigms that tap into implicit agency in AN patients (e.g. sensory attenuation (Blakemore et al., 1999) or control feedback (Eitam et al., 2013). A recent study of Perrykkad et al (2021) investigated the predictive processing account of agency, which situates agency in a broader scheme of action and policy selection. Here the authors incorporate different degrees of uncertainty and showed that uncertainty over actions negatively influenced the SoA (for a detailed overview of this study see Perrykkad et al., 2021). Such paradigms, which modulate uncertainty, might be more informative of the SoA in AN, as AN patients experience higher anxiety and higher need for control in uncertain situations (Sternheim et al., 2011).

This study did not find an influence of state-anxiety on the SoA. Previous studies have found that negative emotional states, such as fear and anger, reduce the SoA in the IB task (Christensen et al., 2019). Although anxiety and fear share the same underlying brain and behavioural mechanisms, they are distinct processes; fear is a directional state while anxiety is more diffuse (Barlow, 2004). Therefore, fear – as opposed to anxiety – might have an influence on temporal binding. For example, Christensen et al. (2019), used painful shocks during some trials of the IB, where they manipulated their paradigm in such a way that fear was directly related to the task. Our study did not specifically manipulate emotional states, but only measured the level of state-anxiety between groups before the experiment. However, further studies on anxiety and SoA are needed to investigate the precise relation between fear, anxiety, and SoA.

Another interesting task for future studies is to investigate the difference between AN subtypes (i.e. restrictive and binge-purge).

Restrictive patients may gain control through inhibitory behaviour whereas binge-purge patients might gain control through action (purging) (Weller et al., 2020). Unfortunately, our sample size was too small for statistical analysis per subtype. Future research should be undertaken to investigate differences in SoA between restrictive and binge-purge AN patients.

Lastly, we conducted two exploratory analyses. First, we explored the relationship between explicit sense of control and the SoA. Here, we found a negative relationship between tone-shift and the explicit sense of control for RAN patients. This finding was surprising, as previous studies have not found a relationship between explicit measures and SoA (Dewey & Knoblich, 2014; Saito et al., 2015). We currently have no ready explanation why this (negative) relationship was found for RAN patients alone. Future research should be undertaken to elucidate this finding.

Second, we explored the relationship between the explicit sense of control and state anxiety. We found an inverse relationship between explicit sense of control and state anxiety for HC and RAN patients. Interestingly, we did not find a significant relationship for AN patients. This finding is in direct contrast to previous literature where it is suggested that control and (state) anxiety in AN is linked (Fairburn et al., 1999; Noordenbos, 2013, p. 7). However, both correlation analyses were conducted on a small sample and might not be reliable (Bujang et al., 2016). Replication studies with an adequate sample size are needed before drawing conclusions.

In conclusion, the aim of this study was to investigate an implicit sense of control (SoA) in AN and RAN patients through an objective measure (IB task). We did not find any evidence of altered SoA, as assessed by the IB task, in AN and RAN patients. We also did not find state anxiety to be a predictor for the SoA. Further research into SoA in AN, should investigate other features of the SoA in AN patients that are not targeted by the IB task.

CRediT authorship contribution statement

Manja M. Engel: Conceptualization, Data curation, Formal analysis, Investigation, Writing – original draft, Writing – review & editing, Visualization, Project administration. **Vivien Ainley:** Software, Resources, Writing – review & editing. **Manos Tsakiris:** Conceptualization, Methodology, Software, Resources, Writing – review & editing, Supervision. **H. Chris Dijkerman:** Writing – review & editing, Supervision. **Anouk Keizer:** Conceptualization, Writing – review & editing, Supervision, Project administration.

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.

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References

American Psychiatric Association. (2013). *Diagnostic and Statistical Manual of Mental Disorders* (5th ed.). American Psychiatric Publishing.

Anwyl-Irvine, A. L., Massonnié, J., Flitton, A., Kirkham, N., & Evershed, J. K. (2020). Gorilla in our midst: An online behavioral experiment builder. *Behavior Research Methods, 52*(1), 388–407. https://doi.org/10.3758/s13428-019-01237-x

Barlow, D. H. (2004). *Anxiety and its disorders: The nature and treatment of anxiety and panic (Second Edition)*. The Guilford Press.

Bers, S. A., Blatt, S. J., & Dolinsky, A. (2004). The sense of self in anorexia-nervosa patients: A psychoanalytically informed method for studying self-representation. In *Psychoanalytic Study of the Child* (Vol. 59, pp. 294–315). Yale University Press. https://doi.org/10.1080/00797308.2004.11800742.

Blakemore, S.-J., Frith, C. D., & Wolpert, D. M. (1999). *Spatio-Temporal Prediction Modulates the Perception of Self-Produced Stimuli*. http://mitprc.silverchair.com/jocn/article-pdf/11/5/551/1758604/089892999563607.pdf.

Bruch, H. (1974). *Eating disorders. Obesity, anorexia nervosa, and the person within*. Routledge & Kegan Paul.

Bujang, A. M., Baharum, N., Mara, T., & Alam, S. (2016). Sample Size Guideline for Correlation Analysis. In *World Journal of Social Science Research* (Vol. 3, Issue 1). www.scholink.org/ojs/index.php/wjssr.

Christensen, J. F., di Costa, S., Beck, B., & Haggard, P. (2019). I just lost it! Fear and anger reduce the sense of agency: A study using intentional binding. *Experimental Brain Research, 237*(5), 1205–1212. https://doi.org/10.1007/s00221-018-5461-6

Dewey, J. A., & Knoblich, G. (2014). Do Implicit and Explicit Measures of the Sense of Agency Measure the Same Thing? *PLOS ONE, 9*(10), Article e110118. https://doi.org/10.1371/JOURNAL.PONE.0110118

Eitam, B., Kennedy, P. M., & Higgins, · E Tory. (2013). Motivation from control. *Exp Brain Res*, *229*, 475–484. https://doi.org/10.1007/s00221-012-3370-7.

Engel, M. M., Gadsby, S., Corcoran, A. W., Keizer, A., Dijkerman, H. C., & Hohwy, J. (2021). *Waiting longer, feeling fatter: Effects of response delay on tactile distance estimation and confidence in females with anorexia nervosa*. https://doi.org/https://doi.org/10.31234/osf.io/gvr2h.

Fairburn, C. G., Cooper, Z., & Shafran, R. (2003). Cognitive behaviour therapy for eating disorders: A "transdiagnostic" theory and treatment. *In Behaviour Research and Therapy*. https://doi.org/10.1016/S0005-7967(02)00088-8

Fairburn, C. G., Shafran, R., & Cooper, Z. (1999). A cognitive behavioural theory of anorexia nervosa. *Behaviour Research and Therapy, 37*(1), 1–13. https://doi.org/10.1016/S0005-7967(98)00102-8

First, M.B. (1997). Structured clinical interview for the DSM-IV axis I disorders: SCID-I/P, version 2.0. New York: Biometrics Research Dept., New York State Psychiatric Institute.

Fox, N., Ward, K., & O'Rourke, A. (2005). Pro-anorexia, weight-loss drugs and the internet: An "anti-recovery" explanatory model of anorexia. *Sociology of Health and Illness, 27*(7), 944–971. https://doi.org/10.1111/j.1467-9566.2005.00465.x

Froreich, F. v., Vartanian, L. R., Grisham, J. R., & Touyz, S. W. (2016). Dimensions of control and their relation to disordered eating behaviours and obsessive-compulsive symptoms. *Journal of Eating Disorders*, *4*(1). https://doi.org/10.1186/s40337-016-0104-4.

Gu, X., Hoijtink, H., Mulder, J., & van Lissa, C. (2021). *bain: Bayes Factors for Informative Hypotheses* (R package version 0.2.8). https://CRAN.R-project.org/package=bain.

Haggard, P. (2017). Sense of agency in the human brain. *Nature Reviews Neuroscience, 18*(4), 197–208.

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

Haggard, P., Martin, F., Taylor-Clarke, M., Jeannerod, M., & Franck, N. (2003). Awareness of action in schizophrenia. *NeuroReport, 14*(7), 1081–1085. https://doi.org/10.1097/01.wnr.0000073684.00308.c0

Hasenack, B., Sternheim, L., Bijsterbosch, J., & Keizer, A. (2021). The link between anxiety and assessment of body attitudes and body size estimation in anorexia nervosa. *Journal of Experimental Psychopathology*, 1–8.

Hauser, M., Moore, J. W., de Millas, W., Gallinat, J., Heinz, A., Haggard, P., & Voss, M. (2011). Sense of agency is altered in patients with a putative psychotic prodrome. *Schizophrenia Research, 126*(1–3), 20–27. https://doi.org/10.1016/j.schres.2010.10.031

Hoijtink, H., Mulder, J., van Lissa, C., & Gu, X. (2019). A Tutorial on Testing Hypotheses Using the Bayes Factor. *Psychological Methods*. https://doi.org/10.1037/MET0000201

Horesh, N., Zalsman, G., & Apter, A. (2000). Internalized anger, self-control, and mastery experience in inpatient anorexic adolescents. *Journal of Psychosomatic Research, 49*(4), 247–253.

Hughes, G., Desantis, A., & Waszak, F. (2013). Mechanisms of intentional binding and sensory attenuation: The role of temporal prediction, temporal control, identity prediction, and motor prediction. *Psychological Bulletin, 139*(1), 133–151. https://doi.org/10.1037/a0028566

Jenkins, J., & Ogden, J. (2012). Becoming 'whole' again: A qualitative study of women's views of recovering from anorexia nervosa. *European Eating Disorders Review, 20*(1), e23–e31. https://doi.org/10.1002/ERV.1085

Jenkinson, P. M., Edelstyn, N. M. J., Preston, C., & Ellis, S. J. (2015). Anarchic hand with abnormal agency following right inferior parietal lobe damage: A case report. *Neurocase, 21*(4), 471–478. https://doi.org/10.1080/13554794.2014.925936

Keizer, A., Smeets, M. A. M., Postma, A., van Elburg, A., & Dijkerman, H. C. (2014). Does the experience of ownership over a rubber hand change body size perception in anorexia nervosa patients? *Neuropsychologia, 62*(1), 26–37. https://doi.org/10.1016/j.neuropsychologia.2014.07.003

Libet, B., Libet, B., Gleason, C. A., Wright, E. W., & Pearl, D. K. (1993). Time of Conscious Intention to Act in Relation to Onset of Cerebral Activity (Readiness-Potential). In *Neurophysiology of Consciousness* (pp. 249–268). Birkhäuser Boston. https://doi.org/10.1007/978-1-4612-0355-1_15.

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

Moore, J. W., & Obhi, S. S. (2012). Intentional binding and the sense of agency: A review. *Consciousness and Cognition, 21*(1), 546–561. https://doi.org/10.1016/j.concog.2011.12.002

Noordenbos, G. (2007). Gids voor herstel van eetstoornissen. *De Tijdstroom.*

Noordenbos, G. (2013). *Recovery from Eating Disorders: A Guide for Clinicians and Their Clients* ((1st ed.).). Wiley-Blackwell.

Noordenbos, G., & Lammers, M. (2018). Psychische achtergronden. In G. Noordenbos, & A. van Elburg (Eds.), *Handboek Eetstoornissen* ((3rd ed.,, pp. 99–108). De Tijdsstroom Uitgeverij.

Oldershaw, A., Lavender, T., Sallis, H., Stahl, D., & Schmidt, U. (2015). Emotion generation and regulation in anorexia nervosa: A systematic review and meta-analysis of self-report data. *Clinical Psychology Review, 39*, 83–95. https://doi.org/10.1016/j.cpr.2015.04.005

Oren, E., Eitam, B., & Dar, R. (2019). Intentional binding and obsessive-compulsive tendencies: A dissociation between indirect and direct measures of the sense of agency. *Journal of Obsessive-Compulsive and Related Disorders, 20*, 59–65. https://doi.org/10.1016/j.jocrd.2017.11.002

Perrykkad K, Lawson RP, Jamadar S, Hohwy J, 2021. The effect of uncertainty on prediction error in the action perception loop. Cognition 210:104598. doi:10.1016/j.cognition.2021.104598.

Saito, N., Takahata, K., Murai, T., & Takahashi, H. (2015). Discrepancy between explicit judgement of agency and implicit feeling of agency: Implications for sense of agency and its disorders. *Consciousness and Cognition, 37*, 1–7. https://doi.org/10.1016/J.CONCOG.2015.07.011

Saito, N., Takahata, K., Yamakado, H., Sawamoto, N., Saito, S., Takahashi, R., … Takahashi, H. (2017). Altered awareness of action in Parkinson's disease: Evaluations by explicit and implicit measures. *Scientific Reports, 7*(1). https://doi.org/10.1038/s41598-017-08482-0

Serpell, L., Treasure, J., Teasdale, J., & Sullivan, V. (1999). Anorexia nervosa: Friend or foe? *International Journal of Eating Disorders, 25*(2), 177–186. https://doi.org/10.1002/(SICI)1098-108X(199903)25:2<177::AID-EAT7>3.0.CO;2-D

Slade, P. (1982). Towards a functional analysis of anorexia nervosa and bulimia nervosa. *British Journal of Clinical Psychology, 21*(3), 167–179. https://doi.org/10.1111/j.2044-8260.1982.tb00549.x

Sperduti, M., Pieron, M., Leboyer, M., & Zalla, T. (2014). Altered pre-reflective sense of agency in autism spectrum disorders as revealed by reduced intentional binding. *Journal of Autism and Developmental Disorders, 44*(2), 343–352. https://doi.org/10.1007/s10803-013-1891-y

Spielberger, C. D., Gorsuch, R. L., & Lushene, R. E. (1970). *State-trait anxiety inventory (test manual)*. Consulting Psychologists Press.

Sternheim, L., Startup, H., & Schmidt, U. (2011). An experimental exploration of behavioral and cognitive-emotional aspects of intolerance of uncertainty in eating disorder patients. *Journal of Anxiety Disorders*. https://doi.org/10.1016/j.janxdis.2011.03.020

Surgenor, L. J., Horn, J., & Hudson, S. M. (2003). Empirical scrutiny of a familiar narrative: Sense of control in anorexia nervosa. *European Eating Disorders Review, 11*(4), 291–305. https://doi.org/10.1002/erv.499

Synofzik, M., Vosgerau, G., & Newen, A. (2008). Beyond the comparator model: A multifactorial two-step account of agency. *Consciousness and Cognition*. https://doi.org/10.1016/j.concog.2007.03.010

Synofzik, M., & Voss, M. (2010). Disturbances of the sense of agency in schizophrenia. In *Neuropsychology of the Sense of Agency: From Consciousness to Action* (pp. 145–155). Springer Milan. https://doi.org/10.1007/978-88-470-1587-6_8.

Tan, J. O. A., Hope, T., Stewart, A., & Fitzpatrick, R. (2006). Competence to make treatment decisions in anorexia nervosa: Thinking processes and values. *Philos Psychiatr Psychol, 13*(4), 267–282. https://doi.org/10.1038/mp.2011.182.doi

Tangney, J. P., Baumeister, R. F., & Boone, A. L. (2004). High self-control predicts good adjustment, less pathology, better grades, and interpersonal success. *J Pers*, *72*(2), 271–324. https://doi.org/https://doi.org/10.1111/j.0022-3506.2004.00263.x.

van der Bij, A. K., de Weerd, S., Cikot, R. J. L. M., Steegers, E. A. P., & Braspenning, J. C. C. (2003). Validation of the Dutch Short Form of the State Scale of the Spielberger State-Trait Anxiety Inventory: Considerations for Usage in Screening Outcomes. *Community Genetics, 6*(2), 84–87. https://doi.org/10.1159/000073003

Voss, M., Moore, J., Hauser, M., Gallinat, J., Heinz, A., & Haggard, P. (2010). Altered awareness of action in schizophrenia: A specific deficit in predicting action consequences. *Brain*. https://doi.org/10.1093/brain/awq152

Walsh, B. T. (2013). Reviews and Overviews The Enigmatic Persistence of Anorexia Nervosa. *American Journal of Psychiatry, 170*, 477–484.

Weller, L., Schwarz, K. A., Kunde, W., & Pfister, R. (2020). Something from nothing: Agency for deliberate nonactions. *Cognition, 196*, Article 104136. https://doi.org/10.1016/J.COGNITION.2019.104136

Wen, W., & Haggard, P. (2020). Prediction error and regularity detection underlie two dissociable mechanisms for computing the sense of agency. *Cognition, 195*. https://doi.org/10.1016/j.cognition.2019.104074

Zapparoli, L., Paulesu, E., Mariano, M., Ravani, A., & Sacheli, L. M. (2022). The sense of agency in joint actions: A theory-driven meta-analysis. *Cortex*. https://doi.org/10.1016/J.CORTEX.2022.01.002

Zopf, R., Polito, V., & Moore, J. (2018). Revisiting the link between body and agency: Visual movement congruency enhances intentional binding but is not body-specifics. *Scientific Reports, 8*(1), 1–9. https://doi.org/10.1038/s41598-017-18492-7