

## **UC Merced**

# **Proceedings of the Annual Meeting of the Cognitive Science Society**

### **Title**

Action and outcome predictability impact sense of agency

### **Permalink**

<https://escholarship.org/uc/item/26h670hk>

### **Journal**

Proceedings of the Annual Meeting of the Cognitive Science Society, 46(0)

### **Authors**

Saad, Laura

McCurry, J. Malcolm

Trafton, Greg

### **Publication Date**

2024

Peer reviewed

# Action and outcome predictability impact sense of agency

**Laura Saad (laura.s.saad.ctr@us.navy.mil)**  
Naval Research Laboratory, Washington, D.C. USA

**J. Malcolm McCurry (john.mccurry@arcfield.com)**  
Arcfield, Chantilly, VA USA

**J. Gregory Trafton (greg.j.trafton.civ@us.navy.mil)**  
Naval Research Laboratory, Washington, D.C. USA

## Abstract

The sense of agency (SoA) represents the everyday experience of control over our actions and their outcomes. We posit a new framework that defines SoA as consisting of three main components: sense of control of self, sense of control of the environment, and the presence of a goal. Across five experiments, we test this framework by altering participants' SoA over their actions and outcomes by manipulating the predictability of each. Results suggest that both actions and outcomes affect participants' SoA. We also report, contrary to previous theoretical predictions, that unpredictable outcomes lead to the lowest SoA as compared to actions. Additionally, results from explicit measures suggest that participants do not discriminate between control over actions and outcomes and that this remains true regardless of experimental design or explicit agency question type. Taken together, these results suggest that both actions and outcomes are vital to the experience of control.

**Keywords:** sense of agency; sense of control

## Introduction

You press a button and the television switches on, click a computer mouse and open a document, wave to a friend and they smile at you. Each of these actions are associated with a feeling that we are in control of the desired outcome. This feeling of control, often referred to the sense of agency (SoA), is a fundamental aspect of daily life.

There are two theories that attempt to explain SoA. First, the comparator model (CM) (Frith, Blakemore, & Wolpert, 2000) describes a mechanism by which action control is established via a process that compares predicted and actual feedback from a motor action. "Feedback" in this context refers to motor or sensory feedback received from actions (e.g., the feel of the button depressing beneath our finger) via the motor system.

Second, the theory of apparent mental causation (TAMC) (Wegner & Wheatley, 1999) explains the process by which SoA is experienced through the explicit linkage between thoughts and actions. The theory states there exists three criteria that must be met in order for an individual to consciously determine agency over their action: priority (i.e., the thought came shortly before the action), exclusivity (i.e., the thought was the only apparent cause of the action), and consistency (i.e., the thought was consistent with the action).

Note that both the CM and the TAMC focus on the role of **actions** in the sense of agency: if an individual's actions are disturbed, they should feel a weakening of their SoA.

However, there is reason to believe that the **outcomes**<sup>1</sup> also may impact a person's SoA. For example the predictability (Tobias-Webb et al., 2017; Ma, Hommel, & Chen, 2019), congruence (Hughes, 2018; Ebert & Wegner, 2010), and timing (Kawabe, Roseboom, & Nishida, 2013; Walsh & Haggard, 2013; Damen, Van Baaren, Brass, Aarts, & Dijksterhuis, 2015) of an outcome have all been shown to affect explicit reports of SoA. The predictions of both CM and TAMC are clear, however: disrupting actions are more impactful to SoA than disrupting the outcomes of their actions.

The aim of this paper is two-fold. First, we propose a new framework of SoA that more clearly defines the concept in terms of goals, actions, and outcomes. Second, we test aspects of this new framework across a series of experiments in an effort to investigate the role of actions and outcome predictability on reports of SoA. To do this we develop a preliminary set of explicit questions (cf. (Gutzeit, Weller, Kürten, & Huestegge, 2023; Kong, Aberkane, Desoche, Farne, & Vermet, 2023) as a means for measuring this experience.

Across five experiments, we alter participants' SoA over their actions and outcomes by manipulating the predictability of each and in turn provide evidence that both aspects affect participants reported experiences of control. Additionally, results suggest that participants do not clearly discriminate between control over their actions and outcomes and that this finding remains true regardless of the type of explicit question used. We also report, contrary to previous theoretical predictions, that unpredictable outcomes lead to the lowest reported SoA. Taken together, these results suggest that both actions and outcomes are vital to SoA, though the ability to explicitly discriminate the influence of each on our conscious experience may be limited.

## A Framework of the Sense of Agency

Here we propose a new framework of SoA. In contrast to previous theories, we propose that both actions and outcomes impact an individual's SoA. Individuals do not act in a bubble, and so their own experience of agency is inherently tied to their ability to affect change in their environment. Therefore, the SoA we refer to here refers to the experience of con-

<sup>1</sup>Here, the term "outcome" refers to events that happen in the environment that can be perceived as being a result of our actions. This term can also sometimes, confusingly, be used to refer to motor feedback or in reference solely to actions (Haggard, 2017).

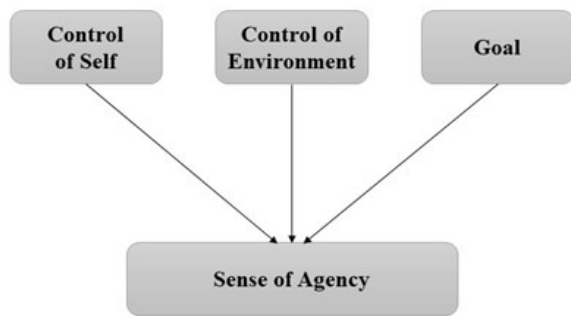


Figure 1: A framework of the sense of agency.

trol of our actions and their outcomes in the current context, where the current context refers to events that occur on a relatively short time-scale. A typical example would be the SoA one might experience after interacting with a mouse attached to a computer. This is different from the general agency one might feel in the process of applying for a job or in their ability to make decisions throughout the course of their own life. The definition we propose here stems from theories of action control (Pacherie, 2007; Frith et al., 2000) as well as causal inference (Wegner & Wheatley, 1999; Desantis, Roussel, & Waszak, 2011) that are typically applied to the same type of SoA investigated in the current set of experiments.

Our framework proposes that SoA in the current context consists of three main components: sense of control of self, sense of control of the environment, and the presence of a goal (Figure 1). To experience a sense of control of the self, the action an individual takes must be completed as expected (e.g., in the case of the mouse and computer, no issues with the desk, mouse, or mouse pad) and must be processed as expected (e.g., the participant can feel the mouse beneath their hand at all times). To experience a sense of control of the environment, the outcome associated with our action must be perceived to occur as predicted, perceived to be caused by the action, and be causally plausible. Importantly for outcomes, this framework specifies that the true causal link between the action and outcome doesn't matter; what is important is the perception of the causal link between an individual's action and the outcome. If that is present, then this theory predicts individuals should experience SoA over the outcome. Additionally, it is important the individual has a goal. We assume that goals are hierarchical and can exist at multiple levels of abstraction (Altmann & Trafton, 2002). Goals can also be self-directed (e.g., "I want to move the mouse to turn on my laptop") or externally-generated (e.g., "The experimenter told me to move my mouse on the screen").

## Experiment 1

To manipulate SoA over actions and outcomes we designed an experiment where participants interacted with a virtual shopping cart. Participants added items to their cart by click-

ing and dragging them over the image of the empty cart on screen. On each trial participants were presented with images of three grocery items to choose from and an image of an empty grocery cart at the bottom-center of their screen. Participants were instructed to choose the item they wanted most by clicking on the image and dragging it to the shopping cart. Once the item was in the shopping cart, the empty cart changed to an image of a "full" cart, or a shopping cart with an item in it. In this design, the action refers to the entire process of clicking on the item, dragging it to the cart, and releasing it into the virtual shopping cart. The outcome refers to the change from the empty cart to the full one.

In the *predictable action predictable outcome* (PAPO) condition participants were able to click and drag the item they wanted into the cart on the first try. In the *predictable action unpredictable outcome* (PAUO) condition the participants were able to click and drag the item into the cart on the first try but instead, a different item than the one they had chosen ended up in the grocery cart. Lastly, in the *unpredictable action predictable outcome* (UAPO) the drag and drop action did not work on the first try (i.e., once the item was released over the cart it "failed" and went back to its original place on the screen). The number of failures varied depending on the trial (see Procedure for more details).

Based on our framework, SoA should be negatively impacted both by the unpredictability of the action and of the outcome in our task. This should result in lower SoA during both the unpredictable action (UAPO) and unpredictable outcome (PAUO) conditions, compared to the control condition (PAPO), respectively. If we see no difference in SoA between the conditions, then that suggests that the predictability of the action or the outcome may not play a large role in SoA.

## Methods

**Participants** We recruited 45 total participants through Cloud Research and paid \$0.25 per minute for participation in the study (approximately \$1.50 per participant). This sample size was based on an a priori power calculation with a medium effect size ( $d = 0.50$ ),  $\alpha = 0.05$  and a power = 0.80 to be adequately powered to conduct a one-way repeated measures analysis of variance (ANOVA) with one group and three within-subjects measures (conditions: PAPO, PAUO, UAPO). We removed 2 participants for failing an attention check leaving a total of 43 participants for analysis. The average age of this final sample was 40.95 (SD = 9.13) years old. 24 identified as male and 19 identified as female.

**Materials** Participants were given the choice of three common grocery items that were presented on the top of the experimental screen. Some examples of these items are ice cream, a pineapple, cookies, milk, etc. Participants saw a set of three items sampled from a total set of 45 grocery items on each trial. The grocery cart, which was empty at the start of every trial was presented beneath the grocery items and in the center of the screen.

To assess participants' experience of agency in the current

context we used explicit agency questions presented at the end of every 1st and 5th trial. Participants used a 6 point (1 = "no control" to 6 = "total control") Likert scale to report their feelings of control over their **actions** ("How much control did you feel over your action putting the item in the cart?"), **outcomes** ("How much control did you feel over which item went into the cart?"), and their **overall** experience ("How much control did you feel over the entire shopping trip?"). These items were designed to measure each component of our framework: SoA of self, SoA of environment, and overall control, respectively. Notably, our measure of overall control represents a standard measure used in typical SoA experiments (Kawabe et al., 2013; Kulakova, Khalighinejad, & Haggard, 2017; Stephenson, Edwards, Howard, & Bayliss, 2018; Barlas, Hockley, & Obhi, 2018).

**Procedure** After entering in demographic information, participants were given instructions that informed them they would be going on a series of shopping trips where during each trip their goal was to add the grocery item they liked best to their virtual shopping cart. They were also informed that they would occasionally be asked some questions about their experience. Next, they completed five PAPO practice trials where the item they chose was successfully dropped into the grocery cart on the first try of every trial. Detailed task instructions were repeated on the first practice trial.

After completing training, participants proceeded to the main experiment where they completed three blocks of five trials of the three experimental conditions (PAPO, PAUO, and UAPO) for a total of 15 trials. Order of presentation of the blocks was counterbalanced between participants. During the UAPO trials, on the 1st and 5th trial of the block the participants experienced two failures (i.e., item did not drop into the empty cart and reverted back to its original location) before the item was correctly added to the cart. To increase the unpredictability, on trials 2-4 of the block the number of failures was shuffled (0, 1, or 2 times) so that participants did not experience the same amount of failures on every trial. Regardless of experimental condition, at the end of trials 1 and 5 of each block, participants were presented with the explicit agency questions.

## Results

A one-way repeated measures ANOVA (3 condition x action control question) revealed an overall difference between conditions,  $F(2,84) = 41.22, p < 0.01, \eta^2 = 0.32$  (leftmost bars in Figure 2). Reports of control were higher in the PAPO condition compared to the UAPO (Bonferonni post hoc,  $t = 5.43, p < 0.01$ ) and PAUO conditions (Bonferonni post hoc,  $t = 8.61, p < 0.01$ ). There was also more reported control in the UAPO condition compared to the PAUO condition (Bonferonni post hoc,  $t = -3.98, p < 0.01$ ).

This pattern of results was replicated when evaluating reports of outcome control,  $F(2,84) = 107.43, p < 0.01, \eta^2 = 0.54$  (middle bars in Figure 2). Reports of control were higher in the PAPO condition compared to the UAPO (Bonferonni

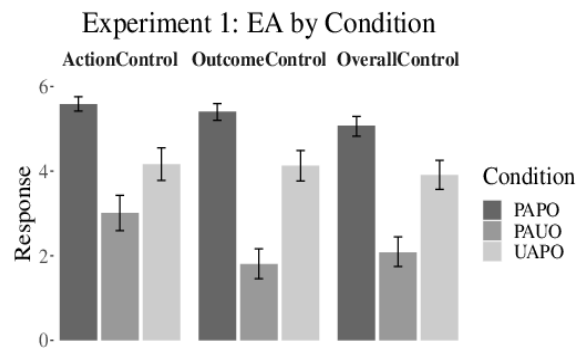


Figure 2: Bar plots of responses to explicit agency questions by condition. Error bars represent 95% confidence interval.

post hoc,  $t = 5.96, p < 0.01$ ) and PAUO conditions (Bonferonni post hoc,  $t = 14.20, p < 0.01$ ). There was also more reported control in the UAPO condition compared to the PAUO condition (Bonferonni post hoc,  $t = -8.45, p < 0.01$ ).

Lastly, the same pattern of results was replicated for reports of overall control,  $F(2,84) = 68.40, p < 0.01, \eta^2 = 0.45$  (rightmost bars in Figure 2). Again, reports of control were higher in the PAPO condition compared to the UAPO (Bonferonni post hoc,  $t = 5.30, p < 0.01$ ) and PAUO conditions (Bonferonni post hoc,  $t = 10.70, p < 0.01$ ). There was also more reported control in the UAPO condition compared to the PAUO condition (Bonferonni post hoc,  $t = -6.73, p < 0.01$ ).

## Discussion

Participants reported the most amount of control in the predictable condition (PAPO) and the least amount of control in the unpredictable outcome condition (PAUO). Reports of control in the unpredictable action condition (UAPO) fell between the two other conditions. This pattern was consistently present regardless of which type of control (i.e., for actions, outcomes, or overall) that participants were reporting. Based on theoretical predictions from the CM or TAMC, the unpredictable action condition should have affected overall control more negatively than the unpredictable outcome, but our results display evidence for the opposite pattern. We found support for the importance of outcome predictability in the experience of control and for its inclusion in our framework of SoA. These results provide evidence to suggest that both action and outcome predictability impact SoA.

The lack of discrimination between reports of control across the different questions was unexpected. If participants were able to discriminate between control of the self and control of the environment then the pattern of results should have indicated a difference in responses across the different questions. More specifically, reports of control for actions in the UAPO condition should have been lower compared to the PAPO and PAUO conditions. However, what we saw was that reports of control in the PAUO condition were lowest, regardless of whether the question was about the self (action)

or the environment (outcome). One possibility is that participants are not able to differentiate between the role of action and outcome in their overall experience of control. We investigate this hypothesis further in the next set of experiments.

### Experiments 2a-c

To investigate whether participants' inability to discriminate the role of action and outcome in their overall experience of control we conducted 3 experiments where participants in each experiment only saw and responded to one of the three explicit agency questions: action, outcome, or overall. These questions were included at the end of trials 1 and 5 during each block. In experiment 2a participants responded to the action control question, in 2b the outcome control question, and in 2c the overall control question. All other aspects of the task were the same as in experiment 1.

If the role of outcomes is an essential component in the experience of control, we should see the same pattern of results as was present in experiment 1. Additionally, if the lack of differentiation between explicit agency questions is due to a true limitation in ability, then the pattern of results should remain consistent even when the participants are asked about one event in isolation. If participants are able to differentiate the role of actions and outcomes in their experience of control then we should expect lower reports of control for actions (control of self) in the UAPO condition compared to the PAUO and PAPO conditions and lower reports of control for outcomes (control of environment) in the PAUO condition compared to the PAPO and UAPO conditions.

### Methods

**Participants** We recruited 51 participants for experiment 2a, 50 for experiment 2b, and 46 for experiment 2c. The power calculation and payment for participation used the same methods as as experiment 1. We removed 1 participant for failing an attention check ("Please respond with the number 3 for this question.") and 15 participants who did not respond to the experimental feedback question leaving a total of 131 participants for analysis. The average age of this final sample was 41.40 (SD = 12.43) years old. 73 identified as male, 54 identified as female, 1 as "other", and 3 were not recorded. This left 46 participants in experiment 2a, 43 in experiment 2b, and 42 in experiment 2c.

### Results

**Experiment 2a** A one-way repeated measures ANOVA (3 condition x action control question) revealed an overall difference between conditions,  $F(2,84) = 41.22, p < 0.01, \eta^2 = 0.40$  (leftmost bars in Figure 3). Reports of control were higher in the PAPO condition compared to the UAPO (Bonferonni post hoc,  $t = 5.23, p < 0.01$ ) and PAUO conditions (Bonferonni post hoc,  $t = 10.60, p < 0.01$ ). There was also more reported control in the UAPO condition compared to the PAUO condition (Bonferonni post hoc,  $t = -5.78, p < 0.01$ ).

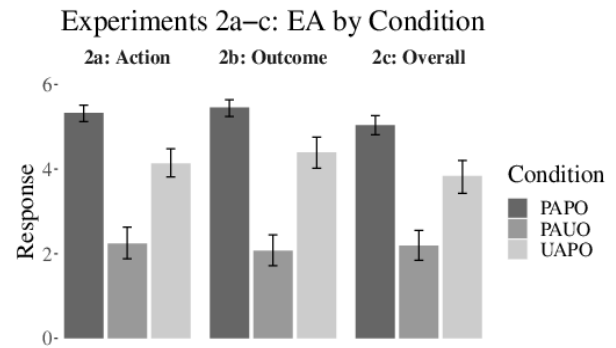


Figure 3: Bar plots of average responses to explicit agency questions by experiment and condition. Error bars represent 95% confidence interval.

**Experiment 2b** A one-way repeated measures ANOVA (3 condition x outcome control question) revealed an overall difference between conditions,  $F(2,84) = 107.43, p < 0.01, \eta^2 = 0.45$  (middle bars in Figure 3). Reports of control were higher in the PAPO condition compared to the UAPO (Bonferonni post hoc,  $t = 4.20, p < 0.01$ ) and PAUO conditions (Bonferonni post hoc,  $t = 12.60, p < 0.01$ ). There was also more reported control in the UAPO condition compared to the PAUO condition (Bonferonni post hoc,  $t = -7.57, p < 0.01$ ).

**Experiment 2c** A one-way repeated measures ANOVA (3 condition x overall control question) revealed an overall difference between conditions,  $F(2,84) = 68.40, p < 0.01, \eta^2 = 0.37$  (rightmost bars in Figure 3). Again, reports of control were higher in the PAPO condition compared to the UAPO (Bonferonni post hoc,  $t = 5.12, p < 0.01$ ) and PAUO conditions (Bonferonni post hoc,  $t = 10.70, p < 0.01$ ). There was also more reported control in the UAPO condition compared to the PAUO condition (Bonferonni post hoc,  $t = -5.72, p < 0.01$ ).

### Discussion

The pattern of results from experiment 1 was replicated in experiments 2a-c. First, this provides further evidence to support the importance of outcomes, as well as actions, in the experience of control. Additionally, the consistent pattern across explicit agency question type suggests that participants may be limited in their ability to discriminate between actions and outcomes when explicitly reporting their experience of control.

Recall that experiments 1 and 2a-c used a standard measure of SoA (i.e., the overall control question) (Barlas et al., 2018; Kawabe et al., 2013; Stephenson et al., 2018). However, there exists a validated scale of SoA that contains both a "positive" and "negative" SoA measure (Tapal, Oren, Dar, & Eitam, 2017). Experiment 3 will use this more comprehensive measure of SoA.

Table 1: Modified (Tapal et al., 2017) SoAS Items

Positive Items
1. Things I did were subject only to my free will.
2. My behavior was planned by me from the very beginning to the very end.
3. The decision whether and when to act was within my hands.
4. I was completely responsible for everything that resulted from my actions.
5. I was in full control of what I did.
Negative Items
6. My actions just happened without my intention.
7. I was just an instrument in the hands of somebody or something else.
8. The outcomes of my actions generally surprised me.
9. While I was in action, I felt like I was a remote controlled robot.
10. My movements were automatic-my body simply made them.
11. Nothing I did was actually voluntary.

### Experiment 3

To further investigate the role of action and outcome predictability on participants' SoA, we incorporated a modified version of a validated measure of SoA: The Sense of Agency Scale (SoAS) (Tapal et al., 2017). SoAS contains 11 items that are aimed at capturing the global experience of agency (i.e., context independent experience of control) and includes items such as "I am in full control of what I do" and "I am the author of my actions". To implement the scale in this study, where we explicitly ask participants to think about the current context, each item in the SoAS was modified slightly. For example, "I am in full control of what I do" was modified to "I was in full control of what I did." See Table 1 for a complete list of the included items organized by subscale. Importantly, SoAS asks participants to report on their experience of control over both actions and outcomes. The order of the items was counterbalanced across participants.

Participants were given these instructions: "Please answer the following questions about the shopping trip you just completed:" and as in the original version of the scale, participants were given a 7 point Likert scale (1 = strongly disagree to 7 = strongly agree) to respond. These items replaced the explicit agency items (i.e., actions, outcome, overall) that were included in experiments 1 and 2a-c. Participants responded to these items once per block (on trial 5). All other aspects of the experimental design were the same as in experiment 1.

If both actions and outcomes impact SoA, as our framework predicts, then we should see the same pattern of results regarding reports of control ( $PAPO > UAPO > PAUO$ ) for the positive SoAS subscale, while the reverse pattern ( $PAPO < UAPO < PAUO$ ) should be observed for the negative SoAS subscale.

### Methods

**Participants** We recruited 59 total participants through Cloud Research. The power calculation and payment used the same methods as experiment 1. We removed 3 participants who did not respond to the experimental feedback question leaving a total of 56 participants for analysis. The average age was 39.59 (SD = 12.20) years old. 30 identified as male and 25 identified as female and 1 was not reported.

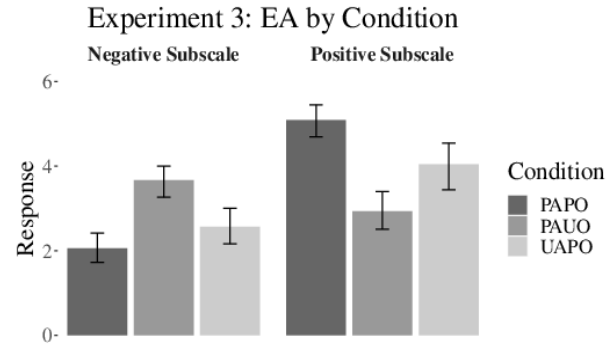


Figure 4: Bar plots of the average responses to the positive (right) and negative (left) subscales from the SoAS (Tapal et al., 2017). Error bars represent 95% confidence interval.

### Results

Reliability estimates were computed for both the positive and the negative subscales of the SoAS, separately to ensure that the modifications to the scale produced consistent results with the original version. Reliability was estimated at (McDonald's)  $\omega_r = 0.93$  and (Cronbach's)  $\alpha = 0.92$  for the positive subscale, and at (McDonald's)  $\omega_r = 0.91$  and (Cronbach's)  $\alpha = 0.88$  for the negative subscale indicating adequate levels of internal consistency of the measure.

A one-way repeated measures ANOVA (3 condition x 1 subscale) revealed a significant effect of experimental condition on responses to the SoAS positive subscale,  $F(2,110) = 35.41, p < 0.01, \eta^2 = 0.27$  (left bars in Figure 4). Higher levels of control were reported in the PAPO condition compared to the UAPO (Bonferonni post hoc,  $t = 4.23, p < 0.01$ ) and PAUO conditions (Bonferonni post hoc,  $t = 8.86, p < 0.01$ ). There was also more reported control in the UAPO condition compared to the PAUO condition (Bonferonni post hoc,  $t = -4.05, p < 0.01$ ).

A second one-way repeated measures ANOVA (3 condition x 1 subscale) revealed a significant effect of experimental condition on responses to the SoAS negative subscale  $F(2,110) = 30.35, p < 0.01, \eta^2 = 0.19$  (right bars in Figure 4). Lower levels of agreement (i.e., higher levels of control) were reported in the PAPO condition compared to the UAPO (Bonferonni post hoc,  $t = -3.31, p < 0.01$ ) and PAUO conditions (Bonferonni post hoc,  $t = -8.07, p < 0.01$ ). There was also less agreement (i.e., lower control) in the UAPO condition compared to the PAUO condition (Bonferonni post hoc,  $t = 4.25, p < 0.01$ ).

### Discussion

The pattern of results for the positive subscale of the SoAS replicated those from experiments 1 and 2a-c. Specifically, participants reported higher SoA (as indicated by more agreement to items in the positive subscale) in the control condition (PAPO) relative to the unpredictable action (UAPO) and unpredictable outcome (PAUO) conditions. Participants also

reported higher SoA in the UAPO condition relative to the PAUO condition. Importantly, this pattern of results was reversed for the negative items.

These results provide evidence in favor of the use of this previously validated measure of decontextualized SoA as a valid measure of SoA in the current context. Additionally, the consistency of the general pattern highlights the importance of both outcomes and actions in the experience of agency and provides evidence to suggest that the lack of sensitivity observed in experiments 1 and 2a-c may be due to a true limitation in participants abilities.

## General Discussion

In this paper, we proposed a new framework that defines SoA as consisting of a feeling of control over both actions and outcomes. To evaluate the assumptions within this framework, we manipulated the predictability of actions and outcomes and measured participants' sense of agency across five experiments. A remarkably consistent pattern emerged: participants experienced the most SoA when both actions and outcomes were predictable and the least amount of SoA in cases where the outcome was unpredictable. Participants' SoA was more negatively affected by unpredictable outcomes than by unpredictable actions: outcome predictability appears to be more critical to SoA than action predictability. This finding, that unexpected outcomes impact SoA, is in line with other empirical results (Majchrowicz & Wierzchoń, 2018; Sato & Yasuda, 2005). Importantly, however, these results contradict current theories of SoA which make the claim that the predictability of actions is the most important determinant of SoA.

Another theory of SoA not previously mentioned here is the cue integration theory (CIT). CIT is typically posited as an explanation for the temporal binding (TB) effect, a widely used implicit measure of SoA (Wolpe, Haggard, Siebner, & Rowe, 2013; Moore & Fletcher, 2012). Briefly, this theory suggests that temporal estimates in TB tasks are a result of the optimal integration of information from different sensory cues (e.g., internal or external) weighted by their reliability in an effort to reduce variability in estimation, where estimation is regarding the timings of events as is the case in TB. Information from internal cues is weighted more heavily than information from external cues due to prior experience. However, information from external cues can exert more influence when internal cues are unreliable.

If we expand this theory to account for our explicit SoA results we find that it does not provide an adequate explanation. For example, in PAUO, the internal/action cue provides strong sensory evidence in favor of SoA while the external/outcome cue does not. In this case, CIT would predict high levels of SoA due to the stronger weighting of the positive action cue. However, our data show the opposite pattern.

In the UAPO condition, the internal/action cue provides poor evidence of SoA while the external/outcome cue provides positive evidence of SoA. In this case, while CIT as-

sumes external cue evidence can override unreliable internal cue evidence leading to relatively high reports of control, we argue that the internal cue evidence in this case is not unreliable at all. In fact, it is a very salient and reliable source of information that the participant's actions are not being completed as they expect. Therefore, CIT would predict that this negative internal cue evidence for SoA should be more highly weighted compared to the positive external cue evidence, leading to low levels of reported SoA. However, again, we see the opposite pattern in our results; therefore CIT cannot account for the pattern of results observed here.

A consistent pattern that emerged was that participants' reports of control were consistent regardless of the type of explicit agency question participants responded to (i.e., action, outcome, or overall control). In other words, participants did not discriminate between actions and outcomes when reporting control. These results suggest a limitation in participants' ability to differentiate the role of actions and outcomes in their experience of control. We suggest that when reporting their experience of control, participants consider the experience as a whole rather than in discrete parts. Therefore, when someone experiences a loss of control of one aspect of a situation then this is likely to affect their perception of every other aspect of the situation, resulting in low reports of control.

The new framework posited here details what we believe to be the critical components underlying SoA. The series of experiments reported in this paper tested two main components of this framework: the sense of control of the self and of the environment. More specifically, we evaluated the influence of the perceived predictability of the action and the outcome. The results here indicate that these aspects of the framework are critical to participants' SoA and provides some preliminary evidence that each aspect plays a specific role in eliciting SoA such that the presence of goals and predictable outcomes impact SoA more than does predictable actions. There are other aspects of the framework that still must be tested. For example, one line of work might be to systematically evaluate how varying aspects of control over actions while maintaining a positive outcome affects participants' experience of agency. It may be the case that there is a threshold of this apparent bias in that if participants experience enough of a loss of control over the action, even in cases when the outcome goes as predicted, participants experience a decrease in agency.

In conclusion, SoA is impacted by both action and outcome predictability, consistent with our framework. The pattern of results observed replicated across differing experimental designs and different SoA measures. Importantly, contrary to theoretical predictions, unpredictable outcomes had the largest negative effect on overall reports of control providing even more support for the importance including outcomes as part of any theoretical framework aimed as explaining SoA. The mechanisms underlying SoA are still not well understood and our hope is that this framework can provide a useful starting point for future research in this domain.

## Acknowledgments

This work was supported by the Office of Naval Research (GT). The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Navy.

## References

- Altmann, E. M., & Trafton, J. G. (2002). Memory for goals: An activation-based model. *Cognitive science*, 26(1), 39–83.
- Barlas, Z., Hockley, W. E., & Obhi, S. S. (2018). Effects of free choice and outcome valence on the sense of agency: evidence from measures of intentional binding and feelings of control. *Experimental brain research*, 236, 129–139.
- Damen, T. G., Van Baaren, R. B., Brass, M., Aarts, H., & Dijksterhuis, A. (2015). Put your plan into action: The influence of action plans on agency and responsibility. *Journal of personality and social psychology*, 108(6), 850.
- Desantis, A., Roussel, C., & Waszak, F. (2011). On the influence of causal beliefs on the feeling of agency. *Consciousness and Cognition*, 20(4), 1211–1220.
- Ebert, J. P., & Wegner, D. M. (2010). Time warp: Authorship shapes the perceived timing of actions and events. *Consciousness and cognition*, 19(1), 481–489.
- Frith, C. D., Blakemore, S.-J., & Wolpert, D. M. (2000). Abnormalities in the awareness and control of action. *Philosophical Transactions of the Royal Society of London. Series B: Biological Sciences*, 355(1404), 1771–1788.
- Gutzeit, J., Weller, L., Kürten, J., & Huestegge, L. (2023). Intentional binding: Merely a procedural confound? *Journal of Experimental Psychology: Human Perception and Performance*, 49(6), 759.
- Haggard, P. (2017). Sense of agency in the human brain. *Nature Reviews Neuroscience*, 18(4), 196–207.
- Hughes, G. (2018). The role of the temporoparietal junction in implicit and explicit sense of agency. *Neuropsychologia*, 113, 1–5.
- Kawabe, T., Roseboom, W., & Nishida, S. (2013). The sense of agency is action–effect causality perception based on cross-modal grouping. *Proceedings of the Royal Society B: Biological Sciences*, 280(1763), 20130991.
- Kong, G., Aberkane, C., Desoche, C., Farne, A., & Vernet, M. (2023). No evidence in favour of the existence of ‘intentional’ binding. *bioRxiv*, 2023–02.
- Kulakova, E., Khalighinejad, N., & Haggard, P. (2017). I could have done otherwise: Availability of counterfactual comparisons informs the sense of agency. *Consciousness and cognition*, 49, 237–244.
- Ma, K., Hommel, B., & Chen, H. (2019). Context-induced contrast and assimilation effects in explicit and implicit measures of agency. *Scientific Reports*, 9(1), 3883.
- Majchrowicz, B., & Wierchoń, M. (2018). Unexpected action outcomes produce enhanced temporal binding but diminished judgement of agency. *Consciousness and cognition*, 65, 310–324.
- Moore, J. W., & Fletcher, P. C. (2012). Sense of agency in health and disease: a review of cue integration approaches. *Consciousness and cognition*, 21(1), 59–68.
- Pacherie, E. (2007). The sense of control and the sense of agency. *Psyche*, 13(1), 1–30.
- Sato, A., & Yasuda, A. (2005). Illusion of sense of self-agency: discrepancy between the predicted and actual sensory consequences of actions modulates the sense of self-agency, but not the sense of self-ownership. *Cognition*, 94(3), 241–255.
- Stephenson, L. J., Edwards, S. G., Howard, E. E., & Bayliss, A. P. (2018). Eyes that bind us: Gaze leading induces an implicit sense of agency. *Cognition*, 172, 124–133.
- Tapal, A., Oren, E., Dar, R., & Eitam, B. (2017). The sense of agency scale: A measure of consciously perceived control over one’s mind, body, and the immediate environment. *Frontiers in psychology*, 8, 1552.
- Tobias-Webb, J., Limbrick-Oldfield, E. H., Gillan, C. M., Moore, J. W., Aitken, M. R., & Clark, L. (2017). Let me take the wheel: Illusory control and sense of agency. *Quarterly Journal of Experimental Psychology*, 70(8), 1732–1746.
- Walsh, E., & Haggard, P. (2013). Action, prediction, and temporal awareness. *Acta psychologica*, 142(2), 220–229.
- Wegner, D. M., & Wheatley, T. (1999). Apparent mental causation: Sources of the experience of will. *American psychologist*, 54(7), 480.
- Wolpe, N., Haggard, P., Siebner, H. R., & Rowe, J. B. (2013). Cue integration and the perception of action in intentional binding. *Experimental brain research*, 229, 467–474.