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# “Not my fault!” “All thanks to me!”: Studying Agency, Satisfaction and Self-Serving Attributional Bias with Rigged Archery in Virtual Reality

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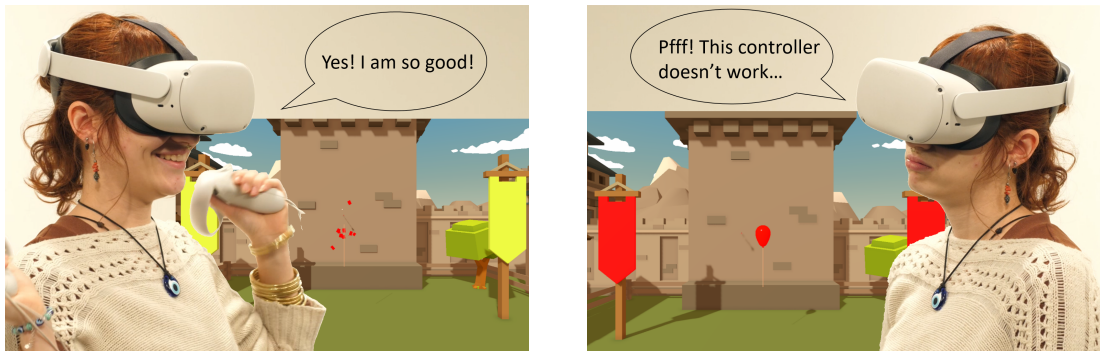


Figure 1: Example of Self-Serving Attributional Bias happening during immersion in the virtual environment.

## ABSTRACT

User’s experience in virtual reality includes different cognitive, emotional, and behavioural factors. One key factor that characterises the interaction between humans and their environment is the sense of Agency. In virtual reality, the sense of Agency is defined as the sensation of having a virtual body which moves and acts accordingly to one’s intentions. However, it is usually measured with self-assessed questionnaires, focusing mainly on motor control within the virtual environment. We designed an experiment based on a game of rigged archery, manipulating avatar control and distant consequences of user’s actions. This allowed us to separately study both dimensions of Agency: the Feeling of Agency and the Judgement of Agency. Through this, we studied how they are linked with other psychological factors such as Locus of Control, Satisfaction and Self-Serving Attributional Bias. Our results suggest an influence of Internal Locus of Control on the Feeling of Agency. We observed that participant’s satisfaction levels was correlated with their assessment of Agency, and more prominently their Judgement of Agency. In addition, our results show that Feeling of Agency and Judgement of Agency can be understood as two distinct parameters of one’s subjective experience in virtual reality. Lastly, we observed that participants immersed in our virtual environment did show a Self-Serving Attributional Bias, as in real life. Indeed, they tended to claim authorship on successful actions while blaming failure on external factors. We believe that these results offer a better understanding of the different factors that could impact the sense of Agency in virtual reality.

**Index Terms:** Computing methodologies—Computer graphics—

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## 1 INTRODUCTION

In today’s increasingly digitised world, virtual environments are becoming integrated into various aspects of human life. In this context, the concept of Agency becomes increasingly significant for exploring interactions and decision making within these environments. For example, virtual training for physical tasks is gaining popularity. Focusing on learning precise gesture and reducing mistakes in manipulation, the trainee needs to gain ownership over technical movements and their consequences in the virtual environment. In these learning situations, the concept of Agency in Virtual Reality (VR) takes primordial importance. Moreover, moral scenarios such as virtual courtrooms, where individuals may stand trial or participate in legal proceedings, are starting to appear. In those scenarios, where interactions may lack the immediacy and tangibility of real-world experiences, the acknowledgment of one’s actions and their consequences becomes even more critical for establishing trust, credibility, and legitimacy [39]. Beyond legal contexts, the acknowledgment of one’s actions and their consequences carries profound implications, not only at the individual level but also at the broader level of societal norms and values. In virtual social platforms, such as VRChat [2] or Sensar [3], individuals engage in diverse types of social interactions, ranging from casual conversations to collaborative projects, in which the attribution of actions and their outcomes shapes interpersonal relationships and community dynamics.

In VR, the Sense of Agency (SoA) is centered on manipulating and navigating one’s virtual body inside the virtual environment, focusing on mastering and embodying this digital identity [27]. A very commonly used model of Agency is the multi-factorial two-step account from Synofzik et al. in 2008 [40]. It separates Agency in two sub components, the Feeling of Agency (FoA) and the Judgement of Agency (JoA). FoA is relying on sensory input and motor control, while JoA is a retrospective cognitive process, related to action

attribution and causal role. It has been shown that this Agency model functions as well to describe the Sense of Agency in VR [24]. An important question raised when studying the sense of Agency is how to measure it. Subjective questionnaires assess Agency in VR but they seem to overlook at one's JoA over their action's outcome in the virtual environment. In order to measure JoA, implicit methods have been used, but they can lead to complications such as cognitive overload during a VR experiment. Explicit measurement of JoA would be ideal but a commonly known psychological bias, the Self-Serving Attributional Bias (SSAB) would probably interfere with this measure. Indeed, to protect their self-esteem and well being, people tend to claim authorship of actions and consequences that are considered successful, and distance themselves from actions with negative outcomes [23]. To our knowledge, this work is one of the first attempt to verify if this bias can be observed in a virtual environment. Our objective is to evaluate the user's subjective SoA during a VR experiment. We explore how FoA and JoA are subject to the SSAB, as well as their interaction with other factors such as Motor Control, Action Outcome, Locus of Control and Satisfaction.

To this end, we propose an experimental protocol with different conditions for Motor Control during a rigged game of archery in VR. This experiment was conducted with 30 participants and our results suggest that, as in real life, users tend to claim more authorship of an action when its outcome is successful. On the contrary, in the case of a failure, we observed that participants tended to take less responsibility for the outcome of their action, and to blame external factors. Furthermore, we found a positive correlation between the user's Locus of Control profile and their Sense of Agency, more precisely between Internal Locus of Control and FoA, but we found no interaction between LoC and JoA. Lastly, our results suggest that participant's level of satisfaction had a positive effect on the level of JoA they experienced.

In this paper, we present the related works in section 2 with inherent hypothesis, the experimental setup description and the used questionnaires in section 3. We present the results with their statistical description and analysis in section 4, we discuss them in section 5 and we conclude with future works in section 6.

## 2 RELATED WORKS

One of the key concepts used to study human behaviour in VR is the Sense of Presence, which is defined as the subjective feeling of "being there" in the virtual environment [38]. Another key concept is the Sense of Embodiment according to which, users perceive their virtual body as if it would be their own body. One dimension of the Sense of Embodiment is the Sense of Agency, defined as the sensation of having a virtual body which moves and acts accordingly to one's intentions [27]. Finally, emotions play a pivotal role in shaping users' subjective experiences in VR, encompassing a diverse range of affective and behavioural reactions elicited by virtual stimuli. It is well known that emotions, felt during immersion in VR, can contribute positively and significantly to other factors such as presence [25] or embodiment [14].

In this context, the concept of Agency in VR becomes central for understanding user's interactions with their virtual environment. At first, Agency started to be explained from a cognitive perspective with the comparator model. This model, also called the central monitoring theory, implies a comparison between the prediction and the outcome of an action. If they match, one attributes the Agency of that action to oneself. This model was used to explain schizophrenia [16] or the inefficacy of self-tickling [6]. Another model explained Agency as the experience of conscious will, coming from three sources: priority, consistency and exclusivity of a thought about an action. The thought should occur before the action, be consistent with the action, and not be accompanied by other potential causes [43]. More recently, another model gained popularity as it explains Agency from both sensorimotor and cognitive perspectives,

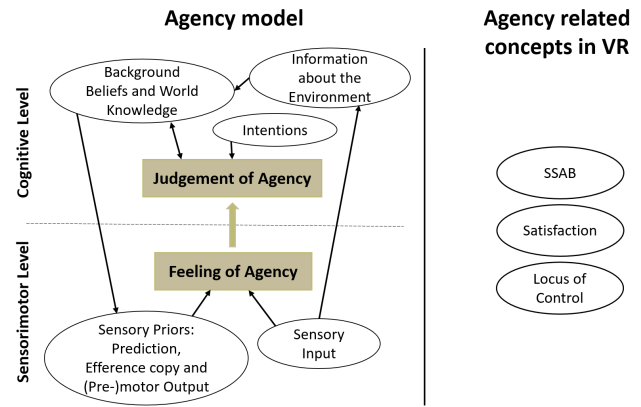


Figure 2: Representation of Agency based on the two-step account of Agency theory (inspired by Synofzik et al. [40,41]) and Agency related concepts in VR.

the two-step account of Agency [40]. As stated earlier, it describes two distinct, yet interconnected, dimensions: the Feeling of Agency (FoA) and the Judgment of Agency (JoA). Those dimensions are central to understand human control over actions and events, delving into these concepts requires a consideration of both bottom-up (sensory-driven) and top-down (cognitively driven) processes (see Figure 2).

To summarise this model, the Feeling of Agency reflects the immediate, subjective experience of initiating and doing actions, it is influenced by both sensory and cognitive factors. In contrast, Judgment of Agency involves a deliberate cognitive assessment influenced by higher-level cognitive processes over causality perception and understanding. Individuals consciously evaluate their role in the consequences of their action on their surrounding environment. This cognitive assessment is based on one's knowledge and beliefs about one's environment and on one's intentions. In this representation, the information one receives from their environment is coming from the sensory input, shaping one's world knowledge and background beliefs, creating predictions and sensory priors. This model is also coherent with the model of predictive coding [15]. Judgment of Agency is defined more precisely as the explicit conceptual attributions of whether one did or did not make an action or cause an effect [22]. This definition involves the ability to predict the outcome of one's action in the environment, to match one's intention as in the comparator model, and to have a sense of authorship and responsibility over this action and its consequences. In the same line, Gentsch & Schütz-Bosbach propose a definition of SoA as the ability to recognize oneself in voluntary actions and the experience of causing one's own actions and their sensory consequences [18].

In the field of VR studies, a commonly used definition of SoA comes from Kilteni et al. [27], following the definition of Blanke and Metzinger: "global motor control, including the subjective experience of action, control, intention, motor selection, and the conscious experience of will." [7]. We can observe that, in VR, the most commonly measured dimension of Agency is the FoA. Indeed, two commonly used questionnaires in the VR community, the Peck and Gonzalez-Franco [31] or the Roth and Latoschik [33] embodiment questionnaires, focus mainly on motor control aspects. Even new VR questionnaires on embodiment and SoA [12], revolve around motor control over the virtual body. Those questionnaires do not measure user's intentions over their actions in VR. In addition, the consequences of these actions in the virtual environment are often not taken into account. It has been shown that both efferent information and prior thoughts about one's action consequences can provide important cues for a prereflective form of the experience

of being the agent of that action [18]. A recent state of the art on the sense of embodiment and its assessment methods developed even further those definitions of Agency [19]. In this work, authors present both implicit and explicit measurements that could be used for assessing JoA in virtual reality.

One of the proxy used for implicit measurement of JoA is the intentional binding effect [21]. To summarize this effect, people tend to have a time shift perception between an action and its consequence. They tend to underestimate this time when they feel a sense of Agency over the outcome of that action, and to overestimate it when they do not. This paradigm has already been tested in VR and shows that the level of SoA, experienced when being embodied in a virtual body, is comparable to the one experienced in real life [28]. To use this paradigm during a virtual reality experiment, Cornelio et al. proposed different ways of inducing intentional binding in a virtual environment, like audio or tactile feedback [30]. Another way of assessing implicit JoA is sensory attenuation. Coming from the comparator model of Blakemore et al., sensory attenuation is a reduction of the perceived intensity of haptic [5], auditory [44] or visual [18] stimuli, when one feels a sense of Agency over an action. The perceived intensity is lower when one is the agent of the action rather than when this action is done by another agent. Lastly we could cite the Biased Sensory Feedback, involving distorted sensory information about one's actions and their outcomes. Observation of brain areas associated with Agency using EEG or fMRI helps to identify the neural bases of the SoA experienced over one's actions. For example, Jeunet et al. in 2018 [24] conducted an experiment with EEG, where they observed a modification of the SoA perceived by the participants, by modulating the priority, consistency and exclusivity principles [43]. Those assessment methods could end up being too complex for being used as measurements of SoA in VR. Thus, the need for using explicit measures arises, akin to those used for embodiment.

Explicit JoA could be assessed with questions like "Did you do that?" [20]. In psychology, studies that use explicit measures of JoA are subject to a cognitive bias called the Self-serving Attributional Bias (SSAB). As previously explained in the introduction, humans are prone to alter their perception of causality in order to protect or enhance their self-esteem. They tend to attribute success to their own dispositions, and failure to external forces [23]. To our knowledge, this bias is well-known in psychology and has been studied in the context of action performance in VR [11]. It has been observed in the context of consequences appreciation in HCI [10, 45] but never in VR. In their work, Jeunet et al. [24] assessed Agency by asking the question: "How much did you feel in control?". Interestingly, they found a correlation between the answers to this question and the participant's Internal Locus of Control. Locus of Control is defined as the extent to which one believes that their action influences life events. Those with an Internal Locus of Control tend to believe that events are caused by their own actions; while those with an External Locus of Control tend to believe that events happen because of external forces that are beyond their influence and control [34]. However, the approach of Jeunet et al. did not permit to distinguish between FoA and JoA with the question they used, therefore their results show only a positive correlation between general SoA and Internal LoC.

The model of Agency proposed by Synofzik et al. in 2013, adds the influence of affective levels on sensory and cognitive levels. Indeed, according to these authors, value attribution, emotional appraisal and reward anticipation could influence FoA and JoA [41]. In VR, it has already been shown that emotions triggered in a virtual environment can modulate the sense of embodiment [14].

### 3 HYPOTHESES AND EXPERIMENTAL SETUP

In our exploration of the two dimensions of Agency within VR, we have formulated several hypotheses to guide our investigation.

First, we hypothesize that different motor control conditions, with different body postures and arm movements (body engagement), will induce different levels of Feeling of Agency. We also believe that rigging the outcome of one's action will not influence their Feeling of Agency but will influence their Judgement of Agency. Indeed, we anticipate that rigging the outcome of an action to match (or differ from) the user's intentions will generate a stronger (or weaker) Judgement of Agency. Those general hypotheses delve into the relationship between user's perceived control and the subjective evaluation of one's causal role in virtual actions. They will serve as control to assess the levels of FoA and JoA, thus setting the stage for the following specific hypotheses.

- $H_1$  A stronger body engagement in motor control over the virtual hands will generate a stronger Feeling of Agency (FoA), but will not affect the Judgement of Agency (JoA).
- $H_2$  Rigging the outcome of participant's actions will affect their Judgement of Agency (JoA) but will not affect their Feeling of Agency (FoA).

Furthermore, as explored in previous work [24], we expect a positive correlation between Locus of Control and Agency. Indeed, LoC is the tendency to assign action's outcome either to oneself or to external factors. Therefore, we hypothesize that both JoA and FoA could be affected by the user's LoC profile (Internal or External). In the context of the present study, we believe that the level of satisfaction, over an action or its outcome, could modulate both dimensions of Agency (FoA and JoA) as presented through the affective level in the Synofzik model [41].

- $H_3$  Levels of Locus of Control (LoC), assessed by participants, will be positively correlated with their Feeling of Agency (FoA).
- $H_{3Bis}$  Levels of Locus of Control (LoC), assessed by participants, will be positively correlated with their Judgement of Agency (JoA).
- $H_4$  Reported satisfaction levels over an action or its outcome, while completing a task in a virtual environment, will have a positive effect on the levels of both Feeling of Agency (FoA) and Judgement of Agency (JoA).

In addition to these hypotheses, we believe that the users will more easily claim ownership over an action with positive outcome than over an action with negative outcome. This assumption is in line with the psychological tendency of individuals to claim ownership over successful actions, thereby reinforcing their Agency, called Self-Serving Attributional Bias. Conversely, actions with negative outcomes will tend to be attributed to external factors (e.g. technical limitations of the VR system). By investigating this hypothesis alongside the others, we aim at understanding how the valence of an action's outcome can influence the subjective experience of Agency in VR.

- $H_5$  Successfully completing the task, regardless of the rigging condition, will generate a stronger Judgement of Agency, with users attributing the causality and responsibility of the successful results to themselves.

To validate those hypotheses, we designed a virtual environment representing an archery arena with two types of motor controls and three rigged archery conditions. We present the setup and the virtual environment in subsection 3.1, as well as the different experimental conditions for: Motor Control in subsection 3.2 and for Rigged Archery in subsection 3.3. We present the questionnaires we used in subsection 3.4.

### 3.1 Experimental setup

In pursuit of fostering a robust sense of presence, aiming at not disturbing Embodiment or Agency, we created a low-poly European medieval environment, depicted in Figure 3. We chose low poly as it has been shown that the realism of a virtual environment is not a critical factor for reaching high levels of plausibility illusion, and therefore high levels of presence [37]. The primary objective was to immerse participants in a competitive archery atmosphere upon entry. We deliberately avoided virtual spectators within the arena, as intense emotional responses stemming from stress or embarrassment could potentially disrupt the participants' sense of embodiment [14]. As well, there were no other competitors in the arena, preventing any potential additional stress coming from social comparison with others [35]. For the virtual representation of the body, visible in the right of Figure 3, we opted for a simplified avatar, featuring gender-neutral low-poly hands, facilitating self-identification for participants. This body was deemed enough for a minimal sense of embodiment in the virtual environment [14]. For this experiment we used a Meta Quest 2 Head-Mounted Display. Balloons were selected as targets due to their distinct popping sound upon successful hits, serving as unequivocal indicators of the consequences of participants' actions on the environment. In contrast, when a balloon was missed, red flags appeared and a classic "wrong answer" buzzing sound was played. To maintain the illusion of realism and challenge, we conducted previous tests in order to establish fixed parameters for balloon size relative to the distance (approximately 20 meters), resulting in a balanced success ratio of 50/50 across both motor control conditions.



Figure 3: Virtual environment representing a European medieval archery arena

### 3.2 Motor control conditions

To verify the first hypothesis, we needed two distinct motor control conditions that represented different levels of SoA. In the first condition (Full Control) the movements of the virtual hands were synchronised with the hand movements of the user. In the second condition (Joystick Control) the hands were fixed on the bow. In both conditions, participants could perceive the virtual bow as illustrated in the right of Figure 3. The Full Control condition entailed a traditional two-handed approach reminiscent of a bow and arrow minigame. Participants used one hand to hold the bow, with the grab button, and the other hand to pull the string. Both virtual hands in this condition were synchronised with the participant's real hand-movements in real-time (see left of Figure 4). Before shooting the arrow, participants were asked to take the virtual bow from a virtual table placed on their side. In the Joystick Control condition, the virtual hands were already placed on the virtual bow, and the shooting of the arrow relied solely on joystick manipulation and button pressing. Participants were asked to aim at the target using the joystick and draw by pressing and holding a button with their other hand, as seen in the right of Figure 4. Unlike in the full control condition, the bow was already placed in front of the participant. Its position was fixed (not linked to the head-mounted

display orientation or movement). Following each shot, a new arrow was automatically loaded on the bow without requiring any additional user's input. Both conditions were adaptable for right and left-handed participants, accommodating their preference for a right— or left— handed bow.



Figure 4: Full Control (left) and Joystick Control (right)

### 3.3 User task and rigged conditions

To test our second hypothesis, we altered the outcomes of the participant's actions by either assisting or hindering them in achieving their goal of popping balloons. Throughout the experiment, participants underwent two training sessions lasting one minute each, upon encountering a new motor control condition. These sessions allowed users to familiarize themselves with their virtual hands and their motor control over it. They could practice aiming at targets from various distances and positions for one minute, with the timer starting only after the first arrow was fired. Subsequently, participants were informed that the competitive phase would start. During this phase, their task was to pop as many balloons as possible with no time pressure. However, it was during these competitive sessions that we implemented the following rigged conditions. In the positively rigged condition, we assisted the user in achieving a success rate of at least 80% by redirecting the trajectory of the arrow to hit the target. The redirection of the arrow's trajectory was calculated and executed, from the outset, to minimize detection by the participant. Conversely, in the negatively rigged condition, we impeded the user's success rate, limiting it to no more than 20% by ensuring that the arrow missed the target through redirection. These threshold values were chosen in order to minimize the chance for participants to detect the rigging conditions. As well, we wanted participants to evaluate their performance either as "good" or "bad". Lastly, the neutral condition primarily served as a baseline, as we did not manipulate the player's actions and outcomes. The consequences of their actions were solely determined by the users themselves and were not manipulated. The training session for each control was not rigged. For further information about technical details regarding the redirection process, the source code is available on GIT [1].

### 3.4 Protocol and Questionnaires

Upon welcoming the participants, the protocol, excluding the rigged conditions, was elucidated to them. Consent was obtained, and they proceeded with a sociological questionnaire, including age, gender, familiarity with video games and VR. Subsequently, the Sickness Simulator Questionnaire (SSQ) [26] and the Locus of Control Questionnaire (IPC) [29] were administered before the immersion.

Following this, participants started the first VR session, beginning with a period allowing them to observe their virtual hands and acclimate to the environment and to their virtual body motor control. When ready, they engaged in the initial training session during 1 minute. A trumpet sound marked the onset of the balloon-popping competition and the start of the first rigged condition. The sequence of each rigged session was determined by a Latin square.

Each session comprised five arrows and five target balloons presented sequentially. If an arrow was shot too far from its target, it was not released and returned to the participant, thereby preventing

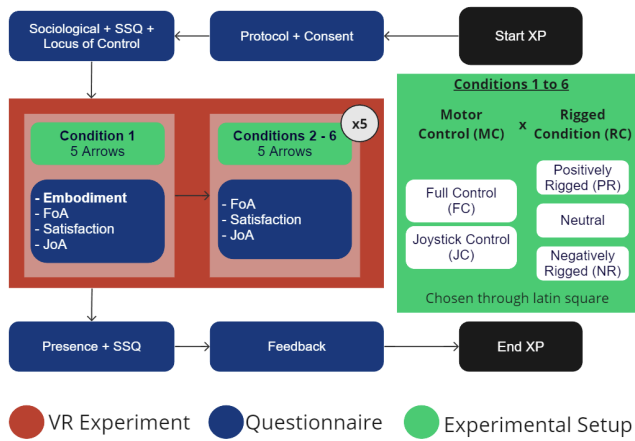


Figure 5: Overall experimental protocol.

deliberate failure or the occurrence of implausible positive redirection. Following the first session, participants were requested to complete the embodiment questionnaire by Roth and Latoschik with all axes [33] to measure their level of embodiment.

After each shooting session, including the first, participants were asked a set of nine questions, see Table 1. To assess the Sensorimotor level of their SoA (FoA), we decided to use all four SoA questions taken from the Roth and Latoschik embodiment questionnaire [33].

To assess user’s satisfaction levels depending on their motor control and their performance, we used two self-made questions. The first question focuses on satisfaction over the sensorimotor perception of the action (Motor Control) and the second question focuses on the cognitive perception of the same action (Performance).

To measure rigging awareness, we designed two self made questions. One question asked participants if they perceived any kind of influence over the arrow trajectory (which was rigged). The other question asked participants if they perceived any kind of influence over the controllers (which were not rigged).

As this experiment tries to quantify the JoA experienced during a virtual reality experiment (and acknowledges the absence of standardized questionnaires validated by the community), we opted for one self-designed question to assess the feeling of authorship and responsibility over the action’s outcome. We chose this question following Haggard [22] definition of the JoA as the explicit conceptual attributions of whether one did or did not make an action or cause an effect. It is important to note that this paper does not aim at asserting that our selection of questionnaires is definitive, nor qualitative, in measuring the Judgment of Agency in virtual reality. Instead, it endeavors to broaden the scope of Agency in VR. For all the questions presented within the virtual environment, we used Likert scales rated from 0 to 6 (0 being “Not at all” and 6 being “Completely”). Upon completion of the six trials (corresponding to 30 arrows), participants underwent a second SSQ assessment and then completed the presence questionnaire [46]. Both SSQ and Presence questionnaire were used to verify that pre-requirements for optimal user’s experience in virtual reality were met. The minimum sample size required for our study was estimated using G\*Power [13], considering two-tailed t-tests for dependant samples on the means of pre-tested JoA scores, in normal vs rigged conditions, with a significance threshold of 0.05, assuming a large effect size (0.8) and a statistical power of 0.95. Based on these parameters, a minimum of 23 participants was necessary.

## 4 RESULTS

We tested our protocol with 30 participants (9 females, 20 males and 1 non-binary), recruited by announcement through leaflets and

Concept	Questionnaire	Questions
FoA	Roth 2020	The movements of the virtual body felt like they were my movements
		I felt like I was controlling the movements of the virtual body
		I felt like I was causing the movements of the virtual body
		The movements of the virtual body were in sync with my own movements
JoA	Authorship	Overall, I feel like the author and responsible for the outcome of my actions
Affective Level	Satisfaction	Rate your satisfaction regarding the control you had
		Rate your satisfaction regarding your performance
SSAB	Rigging Awareness	Was my controller influenced to change the outcome of my action? (Reversed)
		Was the trajectory of the arrow influenced by an external factor? (Reversed)
LoC	LoC Levenson 1974	All questions: Internal, Powerful Others, Chance

Table 1: Detailed questions used during the experiment to assess FoA, JoA, Affective level, SSAB and Locus of Control.

emails around the campus, aged between 17 and 59 (mean=25.53, sd=10.84). Jamovi [17, 42] and R [32] were used for all statistical analyses. Most of the participants had a low usage of virtual reality in their daily life (median = “Rarely”, on a scale from “Never” to “Every day”). In the following section, we present the statistical analysis of our experimental data.

### 4.1 General results

We measured SSQ pre— and post—experiment to evaluate global increase in simulator sickness during the test. SSQ results were calculated with weights [4]. SSQ scores were low throughout the experiment (mean=21.25, sd=22.96). We compared SSQ variations pre- and post-experiment using a Wilcoxon signed-rank test, since our data did not respect normality condition. There was a significant difference ( $W=261$ ,  $p=0.043$ ,  $r=0.38$ ) between SSQ values before immersion (mean=15.45, sd=15.2) and after immersion (mean=27.8, sd=27.8), showing a slight increase after the virtual reality session.

Presence was evaluated only once, after the experiment. Results of the Presence Questionnaire indicate a satisfactory level of Presence throughout the whole experiment (mean=107.4, sd=16.8).

Embodiment scores were calculated using the full questionnaire by Roth et al. [33]. After checking for homogeneity and normality of the residuals, we used linear models to assess the influence of Motor Control and the Rigged Condition on Embodiment. We found a significant main effect of Motor Control ( $F=9.24$ ,  $p=0.006$ ) but no effect of Rigged Condition ( $F=1.45$ ,  $p=0.255$ ). The Full Control condition led to significantly higher levels of Embodiment (mean=3.79, sd=1.01) than the Joystick Control condition (mean=2.59, sd=0.77). There was no significant interaction between Motor Control and Rigged Condition ( $F=0.0179$ ,  $p=0.98$ ).

### 4.2 Feeling of Agency

To confirm the hypotheses regarding the factors contributing to FoA (i.e Motor Control and Rigged Condition), and to take inter-individual variability into account, we used mixed models. Again, we checked for normality of the residuals before conducting our analysis. Given our relatively small number of participants we employed a restricted maximum likelihood (REML) estimation method [36]. We introduced Locus of Control (LoC) dimensions, Internal, Powerful Others and Chance as covariates (values were centered to improve interpretability and reduce multicollinearity) to evaluate their correlation with FoA. Finally, since we had repeated measures over participants, participant ID was introduced as a random intercept.

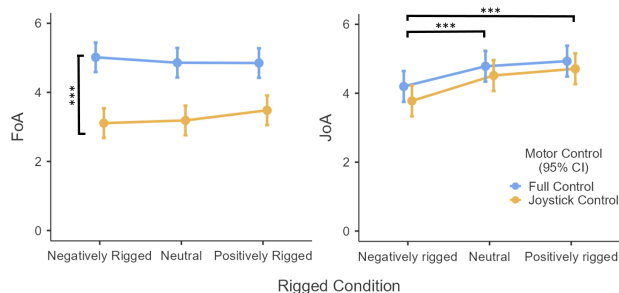


Figure 6: Feeling of Agency (Left) and Judgement of Agency (Right) rated by subjective evaluation with 95%CI, presented by Motor Control Condition through Rigged Condition.

We found a significant main effect of Motor Control ( $F=144.11$ ,  $p<0.001$ ) but no effect of Rigged Condition ( $F=0.38$ ,  $p=0.682$ ). A greater FoA was measured when participants were in the Full Control condition (mean=4.91,  $sd=0.754$ ) rather than in the Joystick Control condition (mean=3.26,  $sd=1.54$ ), see Figure 6. There was no interaction between Motor Control and Rigged Condition ( $F=1.282$ ,  $p=0.28$ ). Concerning LoC, there was no significant influence of Chance ( $F=0.2$ ,  $p=0.659$ ) or Powerful Others ( $F=1.28$ ,  $p=0.267$ ) dimensions but there was a significant influence of the Internal dimension ( $F=4.578$ ,  $p=0.042$ ).

### 4.3 Judgement of Agency

We used the same approach to confirm hypotheses regarding the factors contributing to JoA with Motor Control and Rigged Condition as main effects, LoC dimensions as covariates and participant ID as random intercept. Our results show a significant main effect of Rigged Condition ( $F=22.00$ ,  $p<0.001$ ) but no effect of Motor Control ( $F=2.17$ ,  $p=0.143$ ) and no influence of LoC whatsoever (Chance ( $F=0.96$ ,  $p=0.334$ ), Powerful Others ( $F=0.412$ ,  $p=0.526$ ), Internal ( $F=0.053$ ,  $p=0.819$ )). We found no interaction between Rigged Condition and Motor Control ( $F=0.036$ ,  $p=0.965$ ). Post-hoc analysis on the effect of Rigged Condition over JoA using Bonferroni correction, showed a significant difference between Negatively Rigged and Neutral ( $p<0.001$ ) and between Negatively Rigged and Positively Rigged (PR) ( $p<0.001$ ) but no differences between Positively Rigged and Neutral ( $p=0.628$ ). In the Negatively Rigged Condition (mean=3.27,  $sd=1.1$ ), JoA was significantly lower than in the Neutral (mean=4.19,  $sd=1.11$ ) and Positively Rigged (mean=4.43,  $sd=1.01$ ) conditions (see Figure 6).

### 4.4 Influence of Satisfaction on SoA

We analysed the influence of Motor Control and Rigged Condition on Satisfaction, with separate analysis for Satisfaction over motor control and Satisfaction over Performance, using mixed models with Motor Control and Rigged Condition as factor and ID as a random intercept. We found a significant main effect of both Motor Control ( $F=13.02$ ,  $p<0.001$ ) and Rigged Condition ( $F=31.69$ ,  $p<0.001$ ) on Satisfaction over motor control but no significant interaction between Motor Control and Rigged Condition ( $F=0.340$ ,  $p=0.712$ ). Satisfaction over motor control was significantly higher ( $p<0.001$ ) in Full Control (mean=3.98,  $sd=1.8$ ) than in Joystick Control (mean=3.15,  $sd=1.86$ ). Negatively Rigged was significantly different than Neutral ( $p<0.001$ ) and significantly different than Positively Rigged ( $p<0.001$ ). Neutral was significantly different than Positively Rigged ( $p=0.007$ ). Satisfaction over motor control was lower in Negatively Rigged (mean=2.38,  $sd=1.82$ ), intermediate in Neutral (mean=3.73,  $sd=1.77$ ) and higher in Positively Rigged (mean=4.6,  $sd=1.26$ ) (see Figure 7 left).

For Satisfaction over performance, we found a significant effect

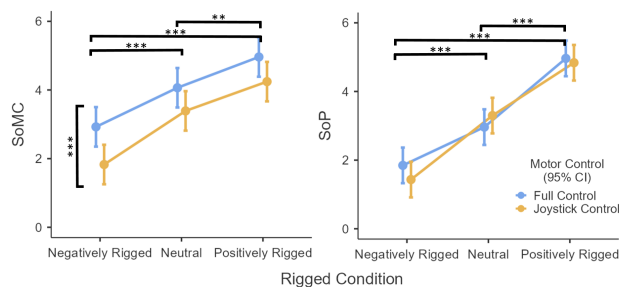


Figure 7: Satisfaction over Motor Control (Left) and Performance (Right) rated by subjective evaluation with 95%CI, presented by Motor Control Condition through Rigged Condition.

of Rigged Condition ( $F=79.41$ ,  $p<0.001$ ) but no significant effect of Motor Control ( $F=0.103$ ,  $p=0.749$ ) nor any interaction between Rigged Condition and Motor Control ( $F=1.067$ ,  $p=0.347$ ). Post-hoc analysis showed a significant difference between all the Rigged Conditions (all  $p$ -values $<0.001$ ). Satisfaction over performance was lower in Negatively Rigged condition (mean=1.64,  $sd=1.26$ ), intermediate in Neutral (mean=3.13,  $sd=1.85$ ) and higher in Positively Rigged (mean=4.9,  $sd=1.09$ ) (see Figure 7 right).

We wanted to investigate the impact of affective level (satisfaction over motor control, satisfaction over performance) on FoA and JoA, in line with the model of Synofzik et al. [41]. A Pearson product-moment correlation was conducted to evaluate the relationship between Satisfaction over motor control, Satisfaction over performance, JoA and FoA. Satisfaction over motor control was found to be strongly positively correlated with JoA ( $r=0.51$ ,  $p<0.001$ ) and weakly positively correlated with FoA ( $r=0.19$ ,  $p=0.01$ ). Satisfaction over performance was found to be moderately correlated with JoA ( $r=0.38$ ,  $p<0.001$ ) and no correlation was found with FoA ( $r=0.045$ ,  $p=0.547$ ).

### 4.5 Rigged Outcomes, effect of outcome valence

Previous results were calculated using only Rigged Condition as a main effect. However, these results do not take into account the number of occurrences in which we actually had to modify the outcome of the participant's action to meet the success and failure rates of each condition (Positively Rigged 80%, Negatively Rigged 20%). We call Rigged Outcomes the results of each participant's session, e.g a session is considered "Helped" if the participant has been helped to hit the target 3 or more times during his 5 shots. They are grouped as follows: Helped, Prevented (we prevented most of the hits), Hit (participant is the main author of his success) and Missed (main author of his failure). Regarding task difficulty, success ratio are exposed in Table 2.

Conditions	NR	Neutral	PR	FC	JC
Success Ratio	9%	39%	86%	43%	46%
	(±8)	(±19)	(±8)	(±11)	(±11)

Table 2: Success ratio and inter-participant standard deviations observed in the different experimental conditions: Negatively Rigged (NR), Neutral, Positively Rigged (PR), Full Control (FC), Joystick Control (JC) .

We used mixed models to evaluate the influence of the Rigged Outcomes on JoA. We found a significant main effect of Rigged Outcomes ( $F=21.045$ ,  $p<0.001$ ). Post-hoc comparison, using Bonferroni correction, showed a significant difference between Hit and both conditions with negative outcome: Missed ( $p<0.001$ ) and Prevented ( $p<0.001$ ), but no difference with the Helped condition ( $p=0.449$ ). The Hit condition (mean=4.71,  $sd=0.935$ ) was associated with a

higher JoA than the Missed condition (mean=3.56, sd=1.04) and the Prevented condition (mean=3.25, sd=1.27). The Hit condition had similar JoA levels to the Helped condition (mean=4.40, sd=1.04). Conversely, the difference between Missed and Prevented conditions was not significant ( $p=1.0$ ). This result indicates that the outcome (hit or miss) does have an influence on the JoA. Whereas, the cause of the outcome, i.e. whether it is the intrinsic consequence of the participant's control or linked to an intervention on the result of the action, does not have an influence on JoA (see Figure 8).

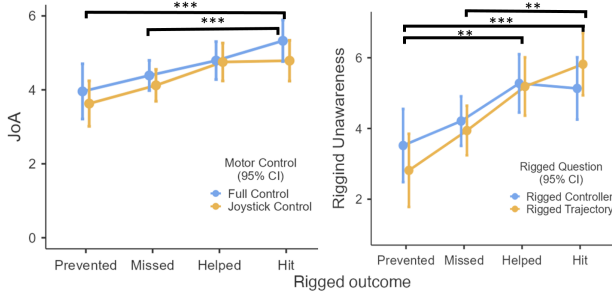


Figure 8: Judgement of Agency and Rigging Unawareness rated by subjective evaluation with 95%CI, presented through Rigged Outcome.

We did the same for questions related to Rigging Unawareness and found a significant main effect of Rigged Outcomes ( $F=13.771$ ,  $p<0.001$ ) on the level of Rigging Unawareness. Post-hoc comparisons, using Bonferroni correction, show no significant differences for the question about the rigged controller. Concerning the Rigged Trajectory question, we found no differences between Hit and Help ( $p=1$ ) nor between Missed and Prevented ( $p=0.381$ ). We found a significant difference between Hit and Missed ( $p=0.004$ ), as well as between Prevented (mean=2.78, sd=2.64) and both conditions with positive outcome: Help (mean=5.25, sd=2.73,  $p=0.003$ ) and Hit (mean=5.80, sd=2.20,  $p<0.001$ ). As exposed in the right of Figure 8, participants felt more control over the arrow trajectory in the Hit outcome than in the Missed outcome (mean=3.64, sd=2.36). When the outcome was successful (being rigged or not) the level of Rigging Unawareness was higher. Once again, the cause of the outcome did not influence the level of Rigging Unawareness while the outcome itself did.

## 5 DISCUSSION

### 5.1 Validation of experimental control conditions

Our results show an increase in SSQ values after immersion in the virtual environment, however the post-SSQ values remained low according to the average levels observed in the literature (less than 40 [8]). Furthermore, participants did not express strong signs of simulator sickness that might have impacted the results of the experiment. This result is in line with nowadays static VR experiments. Presence levels, measured by the Presence Questionnaire [46], gave a mean score of 107 showing that the participants felt immersed in the virtual environment and perceived it as enough realistic.

For the "task difficulty", we aimed at a success ratio of 50% for the neutral condition on both motor control conditions. Results (Table 2), confirmed that the "task difficulty" was balanced. Indeed, we observed differences between the different Rigged Conditions: the negatively rigged condition resulting in more failure than the neutral condition; and the positively rigged condition resulting in more success than the neutral condition. On the contrary, there was no impact of the motor control condition on success or failure.

Looking at the embodiment, we can see that the Full Control condition gave a medium score of embodiment. This result can be explained by the fact that our participants had a full motor control

over their virtual hands, without having a full representation of their virtual body. Those results are similar to other results reported in the literature when using this kind of virtual body [14]. For the joystick control, as the virtual body was not linked to the user but to the bow, the overall embodiment score was lower. Still, both scores gave good enough results to not disturb the experimental protocol.

In order to make sure that our participants did not perceive that some results of their actions were rigged, we asked them, during the experiment, if they felt that an external factor was affecting their motor control over the virtual hands or affecting the arrow trajectory. Results observed in Figure 8 show that there was no significant difference between Prevented outcome and Missed outcome. This indicates that the participants had the same level of rigging awareness when the target was missed, either because of their poor performance (Missed outcome) or because of the arrow being redirected ("Prevented" outcome). There was no significant difference either between Helped outcome and Hit outcome. We measured as well the levels of authorship when participants were prevented from accomplishing the task. Authorship stayed high for all outcomes, showing that participants did not get the sensation that the results of their actions were rigged. This result is corroborated by post-experimental informal feedback, indeed several participants expressed suspicions regarding the potential manipulation of the outcomes of their actions. However, none of them exhibited certainty about these suspicions. Furthermore, none of them tried to miss deliberately the target and everyone tried their best to obtain the highest score during the game, this means that their intention was always to reach the target and that they were trusting the game to not be rigged.

In regard of the Roth et al. questionnaire, we can see a significant difference of Agency levels between the two Motor Control conditions but no difference of Agency levels between the three Rigged Conditions (on the left of Figure 6). This shows that the outcome of one's action does not impact the Feeling of Agency measured with VR questionnaires. Moreover, we can see that authorship is not correlated with Motor Control conditions but with the Rigged Conditions (on the right of Figure 6). We have a significant difference between authorship level in the Negatively Rigged condition and in the Neutral condition. We observe, no difference in authorship levels between the two Motor Control conditions. This shows that the outcome of one's action has a direct impact on the Judgement of Agency, whereas motor control over the virtual body does not. Hence,  $H_1$  and  $H_2$  are fully supported by our results, and we can conclude that our protocol and experimental setup permitted to highlight the two sub components of the Sense of Agency: Feeling of Agency and Judgement of Agency.

### 5.2 Effect of Locus of Control and Satisfaction over SoA

Results show a significant influence of Internal Locus of Control on FoA. We found no other correlation between LoC and SoA, thus supporting  $H_3$  and refuting  $H_3Bis$ . This result is interesting as LoC is the tendency to assign action's outcome to oneself or to external factors. Therefore, we expected to see an effect of External LoC (Powerful Others and Chance) and Internal LoC on JoA. However, this result is coherent with the results of Jeunet et al. [24], as they found a correlation of Internal LoC with SoA, but we expected this influence to be split between both dimensions of SoA. This absence of correlation between JoA and LoC could be attributed to our small number of participants ( $n=30$ ) compared to other experiments studying effect of LoC dimensions. Still, those results are promising as they further delve into our knowledge over Locus of Control and Agency in VR.

We found a moderate positive correlation between levels of satisfaction over one's performance and JoA. This is in line with the model of Agency presented in Figure 2, as one's cognitive assessment of performance is linked with one's knowledge and intentions.



This interaction could be explained by the fact that evaluation of performance (according to background beliefs and intentions) influenced the subsequent levels of satisfaction and levels of JoA. We observed that participants had higher levels of satisfaction over their motor control when they could interact with the virtual environment using both their hands rather than a joystick. This result could be explained by the “two hands interaction” being more natural for the users in VR. Furthermore, we can see in Figure 7 that those results are modulated by the overall outcome of their task completion. If the outcome is successful, users will tend to feel a stronger satisfaction over their motor control. Additionally, we found a strong positive correlation between the satisfaction over motor control and JoA; and a weak positive correlation between satisfaction over motor control and FoA, thus fully supporting  $H_4$ . While one’s satisfaction over their motor control and their assessment of FoA seems natural, the strong positive correlation with JoA is interesting. We believe that a strong satisfaction over motor control lead to a strong sensation of being the author and responsible of the action (being in control of the outcome of the action). Having a satisfying motor control, coherent with one’s intentions, lead to evaluating one’s actions as being “under control”, coherent with one’s anticipation of one’s actions’ consequences (coherent with one’s predictions internal model). The affective valence of the evaluation of one’s action’s outcome (level of satisfaction) could be seen as a post hoc cue that interacts with the sense of Agency, mostly with JoA, as in the model of Synofzik et al. [41].

### 5.3 Appropriation of action outcome

In this experiment, we measured the cognitive aspect of the SoA, the JoA, with an explicit question regarding authorship over one’s actions and their consequences. This question was asked in an explicit way to participants and therefore the answers could be affected by the Self-Serving Attributional Bias (SSAB), as observed in real life. In our results, we can see that participants felt a stronger JoA over their action when the outcome of this action was successful (rather than failed). Furthermore, when asked about the arrow trajectory, participants did not have any doubt about their success, in the Hit or Helped outcomes, because they believed they were fully responsible for these results. Conversely, in the Prevented or Missed outcomes, they attributed their failure to a perceived loss of control, though they could not identify the source of this loss. We hypothesize that with a larger sample size, significant differences might emerge regarding the ‘Rigged Controller’ question corroborating further the idea that participants tend to attribute their failures to external factors, despite there being no actual manipulation. Additionally, both JoA and unawareness scores were higher when the outcome was positive, regardless of whether the trial was rigged. This effect can be explained by the self-serving attribution bias, protecting one’s self esteem. Participants felt more authorship and responsibility over the trials with successful outcomes, thus supporting  $H_5$ .

It is interesting to note that when participants were in the Helped condition at the beginning of the experiment and the Prevented condition at the end, they explained their sudden tendency to fail by blaming tiredness or calibration loss of the virtual system. Conversely, when participants started by the Prevented condition, they explained their new success in the Helped condition by acknowledging that practice was improving their ability to aim at the target. Success was assigned to oneself while failure was blamed either on external factors, such as bad VR calibration and lack of visual feedback over the arrow trajectory, or on factors independent from one’s will, such as tiredness, thus agreeing with  $H_5$ . At the end, when asked about the rigging of the game, participants mentioned the plausibility of a negative rigging but never the possibility of a positive one. This is in line with SSAB and the model of predictive coding, as participants perceived the causality of their action’s outcomes according to their high level beliefs about themselves. This illusion,

due to predictions and beliefs, was observed only when the outcome was positive. When the outcome was negative, the error observed in the prediction of success was explained by a possible rigging of the game or its malfunction. Interestingly, although authorship did decrease with the negative outcomes, the tendency points towards mitigating authorship, meaning that it was not completely rejected. This means that even if participants failed to achieve their goal of popping balloons, they agreed that they were still, at least partly, author and responsible for it. This result is interesting and reassuring for society and for collaboration within virtual environments.

## 6 CONCLUSIONS AND FUTURE WORKS

We have demonstrated that our protocol and experimental setup, which included two different motor control conditions and three rigged archery conditions, efficiently highlighted the two sub-components of Agency. Additionally, for users with internal LoC profile, we found a positive correlation between the level of their locus of control and the sensorimotor aspect of their sense of Agency (FoA). However, we found no correlation between their Locus of Control profile and their sense of Agency on the cognitive level (JoA). We found that, in VR, SoA and user’s satisfaction levels are linked. Indeed, satisfaction over one’s motor control had a direct impact on both sensorimotor and cognitive dimensions of Agency. Whereas satisfaction over one’s performance, was positively correlated only with the cognitive dimension of Agency. Lastly, we observed that, as in the real world, people tend to be biased when being asked to cognitively and retrospectively assess the causality of their failure or success. As expected, even in VR, one tends to attribute the causality of successful actions to oneself, and to blame failure on external factors.

One limitation of our study is gender balance. Indeed, we believe that participants’ gender might impact their assessment of authorship, and we aim to integrate this variable into our next experimental procedure. Additionally, this study did not allow us to highlight the impact of the previous trial’s outcome on the perceived Sense of Agency during subsequent actions, necessitating further investigation. Nonetheless, based on these interesting results, we plan to continue our work to better understand the Sense of Agency in virtual reality and generalize these findings to the broader population. We saw that subjective cognitive assessments of the causality of one’s success or failure can be biased, but we can imagine combining it with implicit measurements. However, implicit measurements of the Judgement of Agency can as well be influenced by other factors, such as the emotional valence associated to one’s action outcome [9]. Future work could look at the impact of the valence and intensity of emotions following or preceding an action, on implicit and explicit assessment of Agency in VR. More investigation on the user’s Locus of Control profile and their cognitive assessment of authorship is also necessary to fully understand SoA in virtual environments. This work is the first study to acknowledge the presence of Self-Serving Attributional Bias in the context of consequences appreciation in VR. As well, this study highlights the effect of user’s satisfaction over Agency. This experiment provides useful results for the community, as it allows to better understand, and therefore modulate, user’s subjective perception of their sense of Agency in a virtual environment.

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