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Cognitive Psychology

Order Effects on the Rubber Hand Illusion Expectancy: A Replication and Extension of Lush (2020)

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The rubber hand illusion (RHI) is an illusion where the synchronized stroking of a rubber hand, placed in front of a participant, along with their concealed real hand results in a sense of ownership over the rubber hand. The questionnaire used to subjectively measure the RHI incorporated control and illusion statements to address demand characteristics. However, Lush (2020) demonstrated participants expected the illusion upon viewing a video of the RHI procedure despite the absence of tactile stimuli, indicating a lack of control over demand characteristics. In our study, Experiment 1, conducted with a Japanese sample (n = 27), was a preliminary direct replication of Lush (2020). Experiment 2, involving a larger sample (n = 185), also directly replicated Lush's study and further investigated the influence of condition order on expectancies for the RHI. In both experiments, participants showed stronger agreement with the illusion statement expectancies in the synchronous condition compared to the asynchronous condition. However, this difference was not observed in the control statement expectancies, thereby replicating the outcomes of the original study. In Experiment 2, the group exposed to the asynchronous condition first showed stronger agreement with the illusion statement expectancies in that condition than those exposed to the synchronous condition first. As the RHI has been defined as the difference in direct and indirect measures between synchronous and asynchronous conditions, our results suggest that the methods in the RHI paradigm insufficiently control demand characteristics and order effects; thus, findings based on these methods are confounded by these effects.

Introduction

Rubber Hand Illusion

The rubber hand illusion (RHI) is a phenomenon in which participants report feelings of ownership over a visible rubber hand, positioned in front of them when it is stroked synchronously with their concealed real hand (Botvinick & Cohen, 1998). The RHI paradigm has been used to elucidate cognitive and neural underpinnings of the human embodied sense of self (Ehrsson, 2020; Riemer et al., 2019). The RHI is more likely to emerge when the tactile input to the participant's hand and the visual input from the rubber hand are aligned under synchronous conditions. Visuo-tactile temporal congruence is posited as a key factor in facilitating the RHI.

Subjective measures of the RHI often deploy questionnaires containing illusion-related statements (i.e., sense of ownership and referred touch) and control statements that are unrelated to the RHI experience (Botvinick & Cohen, 1998). In synchronous conditions, there is typically agreement with the illusion statements, whereas there is less agreement with the control statements. Furthermore, there is little difference between the synchronous and asynchronous conditions for the control statements. These response trends have been thought to indicate that the RHI occurs in the synchronous condition, controlling for demand characteristics (Orne, 1962).

However, Lush et al. (2020) demonstrated that reports of the RHI correlated with the capacity for phenomenological control, which involves modifying subjective experiences, such as perception, to align with intentions and goals (Dienes & Lush, 2023). This suggests that the understanding of the RHI goes beyond multisensory integration and also involves top-down control.

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Demand Characteristics in the Rubber Hand Illusion

Using a questionnaire, Lush (2020) demonstrated that participants, while watching a video of another person undergoing the RHI procedure with visual-tactile stimuli, anticipated the RHI manifestation in the synchronous condition. This expectancy was evident in the differences in responses to the illusion versus control statements, with a stronger agreement with the illusion statements in the synchronous condition compared to asynchronous condition, despite participants not receiving tactile stimuli themselves. These findings suggest that traditional procedure of the RHI may not adequately control for demand characteristics. Moreover, the discrepancies between the synchronous and asynchronous conditions in the illusion statements may not solely be attributed to multisensory integration.

Researchers have employed measures other than questionnaires to mitigate these demand characteristics, such as proprioceptive drift (i.e., perceived position of the participant's hand moving closer to the fake hand after inducing the illusion; Botvinick & Cohen, 1998) and the skin conductance response when the fake hand is threatened (Armel & Ramachandran, 2003). However, in a study similar to Lush (2020), Lush et al. (2021) found that expectancies for proprioceptive drift and skin conductance response still emerged. This result implies that as demand characteristics can affect responses, these measures assess the RHI indirectly rather than objectively.

Other studies have also suggested that demand characteristics could confound the RHI and related embodiment phenomena. In a conceptual replication of Lush (2020), Reader (2022) counterbalanced the order of conditions and introduced a free description between viewing the RHI video and completing the questionnaire. The results replicated Lush's (2020) findings, and the analysis of the free descriptions suggested that these expectancies might be triggered by exposure to the questionnaire itself. Additionally, Forster et al. (2022) expanded on Lush (2020) by examining expectancies for the sense of ownership over a full-body avatar in VR. Participants who experienced VR in the lab and online viewers of the VR experiment videos exhibited comparable ratings, suggesting that demand characteristics may also influence the results of laboratory experiments in VR embodiment research.

Purposes of the Present Study

Experiments 1 and 2 in the present study aimed to replicate and generalize the RHI expectancies (Lush, 2020). Previous studies primarily involved university students studying psychology in English-speaking countries (Lush, 2020; Lush et al., 2020; Study 1 of Lush et al., 2021; Reader, 2022). Even if these participants were unfamiliar with the RHI, they may have been aware of psychological research methods, such as the use of control statements and conditions, which could have generated or increased RHI expectancies. However, it remains unclear whether RHI expectancies occur in samples with diverse backgrounds. To address this, the present study collected data from a general Japanese sample, not limited to psychology students, to examine the generalizability of RHI expectancies.

Experiment 1 also aimed to examine the moderating effect of prior knowledge about the RHI on RHI expectancies. Lush (2020) acknowledged the influence of prior knowledge and found that difference in expectancy ratings between synchronous and asynchronous conditions arise regardless of participants' prior RHI knowledge. However, as Lush (2020) did not test the differences in questionnaire responses between participants with and without prior knowledge, the extent to which prior knowledge contributes to RHI expectancies remains unclear.

Experiment 2 also aimed to examine the effect of the order of the synchronous and asynchronous conditions on RHI expectancies. In Lush's (2020) procedural video of the RHI, the synchronous condition preceded the asynchronous condition, and participants were asked to respond to each statement in the same order. Therefore, due to the fixed order of conditions, order effects on expectancies cannot be disregarded. Lush (2021) analyzed data from Lush et al. (2020), who performed an RHI experiment involving visuotactile stimulation, and found an effect of condition order. Specifically, when the asynchronous condition preceded the synchronous condition, the difference in illusion rating score between the two conditions was larger compared to when the synchronous condition preceded the asynchronous condition. Reader (2022), in their analysis of free descriptions, discovered that the proportion of participants reporting an expectancy of a sense of ownership over the rubber hand in the synchronous condition was 22% for the group that experienced the synchronous condition first, compared to 59% for the group that experienced the asynchronous condition first. These findings suggest that participants' ratings may vary depending on the order of conditions, and in Lush (2020), the preceding synchronous condition may have generated or modulated RHI expectancies.

Furthermore, in Lush's (2020) study, the order of the statements in the RHI questionnaire was fixed. Specifically, three illusion statements preceded six control statements. The possibility that this fixed order may modulate RHI expectancies cannot be disregarded. Therefore, in Experiment 2, we also examined whether RHI expectancies would be observed with a fully randomized order of the statements.

To achieve these goals, Experiment 1 was conducted online using a Japanese sample. It served as a direct replication of Lush (2020), with the additional analysis of prior knowledge about the RHI. In Experiment 2, we examined the effect of the order of the synchronous and asynchronous conditions in a larger general sample. Investigating the influence of prior knowledge and order effects on RHI expectancies and demand characteristics will help to enhance the validity of measurements in RHI experiments involving actual multisensory stimulation and to elucidate the mechanism of the sense of ownership.

Table 1. Illusion and Control Statements

S1	It seemed as if I were feeling the touch of the paintbrush in the location where I saw the rubber hand touched.
S2	It seemed as though the touch I felt was caused by the paintbrush touching the rubber hand.
S3	I felt as if the rubber hand were my hand.
C1	It felt as if my (real) hand were drifting toward the rubber hand.
C2	It seemed as if I might have more than one left hand or arm.
C3	It seemed as if the touch I was feeling came from somewhere between my own hand and the rubber hand.
C4	It felt as if my (real) hand were turning 'rubbery'.
C5	It appeared (visually) as if the rubber hand were drifting towards the left (towards my hand).
C6	The rubber hand began to resemble my own (real) hand, in terms of shape, skin tone, freckles or some other visual feature.

Note. S1–S3 are illusion statements describing experiences related to the RHI, and C1–C6 are control statements describing experiences unrelated to the RHI.

Experiment 1

The results and conclusions of this experiment are considered preliminary because the small sample size was not determined by power analysis or a valid stopping rule.

Methods

This experiment was not pre-registered.

Participants

Twenty-eight university students in introductory psychology classes and acquaintances of the first author participated in this experiment voluntarily without compensation. Our limited resources were the reason for this sample size. Following Lush (2020), we excluded one participant who had participated in an experiment with a procedure similar to that depicted in the RHI video. Therefore, our final analysis included 27 participants (19 women, 7 men, 1 unknown; mean age of 29.92 years, *SD* = 14.48, range = 19-61). One participant's age was invalid (i.e., two) and was excluded from the descriptive statistics. Unlike Lush's (2020) study, we did not record the response time as an exclusion criterion. The experiment was conducted online from December 2020 to January 2021.

Electronic informed consent was obtained from all participants in Experiments 1 and 2. This study was approved by the Humanities and Social Sciences Research Ethics Committee of Ochanomizu University (approval number: 2020-138).

Materials

The instructions, video stimuli showing the RHI induction procedures, and questionnaires used in Lush (2020) were translated into Japanese by the authors and employed in the present study. The questionnaire consisted of three illusion statements describing a sense of ownership and a referred touch and six control statements describing experiences unrelated to the RHI (Table 1; Botvinick & Cohen, 1998). Participants answered to each statement by using a 7-point Likert scale ranging from -3 ("I am certain I won't feel any effect") to 3 ("I am certain I will feel some effect").

The materials used in the present study can be found in the Open Science Framework (https://osf.io/bsfwu/); for the original English version, see Lush's (2020) open materials.

Procedures

Participants completed the task using their own computers on Google Forms. After providing informed consent and demographic information, participants read a text describing experimental procedures for inducing the RHI with manipulations of synchrony in paintbrush stroking (i.e., synchronous and asynchronous conditions). Next, participants watched a 59-second movie that displayed RHI induction under both synchronous and asynchronous conditions, with subtitles describing the induction procedures. The movie's viewpoints changed from that of a participant to that of an experimenter. After watching the video, participants read a brief summary of the video on the previous web page and answered the following questions: "What do you think procedure is supposed to cause (what is the participant expected to experience)? Please answer this question briefly (in not more than two sentences)." They then responded with yes/no answers to the questions: "Have you heard of this procedure before?" and "Have you previously participated in an experiment in which this procedure was used?" Finally, participants rated their expectancies for the experience described in each of the illusion and control statements under the synchronous and asynchronous conditions. The order of the conditions and statements was consistent across all participants.

Data Analysis

For each participant, we calculated the mean expectancy score for the illusion and control statements in the synchronous and asynchronous conditions. To examine the effect of prior knowledge about the RHI on RHI expectancies, we conducted a repeated measure analysis of variance (rmANOVA) with Statement (illusion or control statement) and Condition (synchronous or asynchronous condition) as within-participant factors, and Familiarity (familiar or unfamiliar with the RHI) as a between-participant factor. We performed Bayesian rmANOVA for non-significant main and interactive effects of the factor(s) to quantify the evidence for null effects of the factor(s) by calculating the ex-

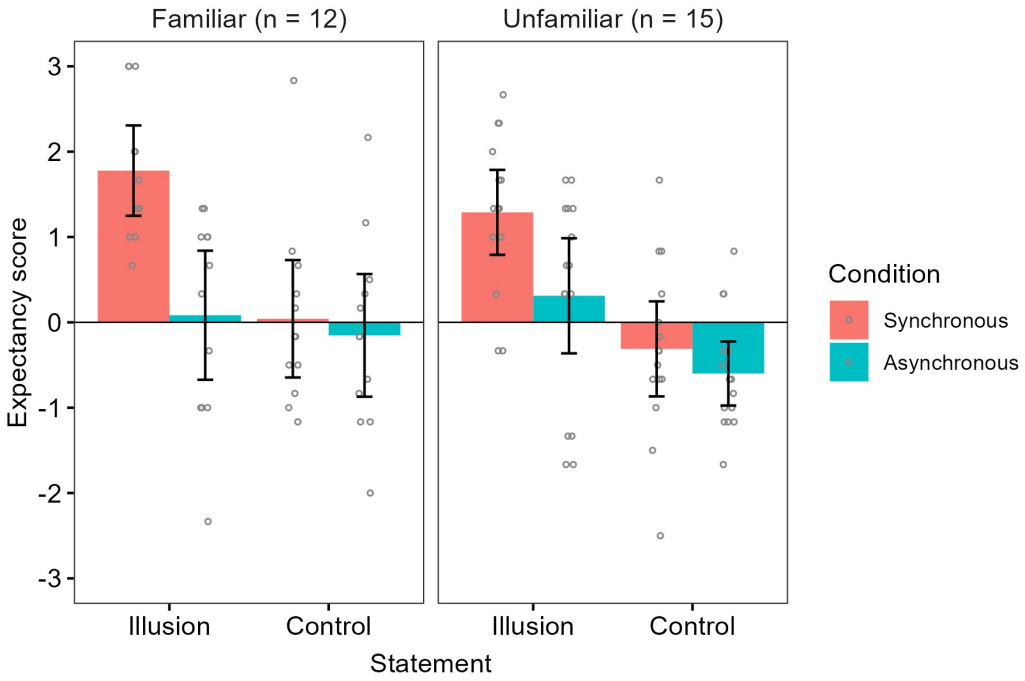

Figure 1. Mean Expectancy Scores in Experiment 1

Note. Open circles represent individual data. Error bars indicate 95% confidence intervals.

clusion Bayes factor (BF_{excl}) across all models. We interpreted BF_{excl} values between 3 and 10 as moderate evidence for null effects and values between 0.33 and 3.00 as anecdotal insensitive evidence (Lee & Wagenmakers, 2014). The emergence of RHI expectancy was determined if agreement with the illusion statement in the synchronous condition was stronger than agreement with the illusion statements in the asynchronous condition and the control statements in the synchronous condition.

Preprocessing was performed using RStudio 2023.09.1 and R 4.3.2 (R Core Team, 2023). The frequentist rmANOVA was performed using an R package *anovakun* 4.8.9 (Iseki, 2023). The bias-corrected and accelerated 95% confidence interval (CI) using 2,000 bootstrapping samples was calculated for the effect size of rmANOVA. The Bayesian rmANOVA was performed using JASP 0.18.3 (JASP Team, 2024)

Results and Discussion

The responses to the illusion and control statements are summarized in Figure 1 and Table 2. For transparency, the descriptive statistics for each statement are presented in Figure 2.

The rmANOVA showed significant main effects of Statement and Condition and their significant interaction (Table 3). The simple main effect of Condition was significant only for the illusion statement (illusion: $F(1, 25) = 24.46$, $p < .001$, $\eta_g^2 = .301$, 95%CI [.142, .441]; control: $F(1, 25) = 1.70$, $p = .204$, $\eta_g^2 = .016$ [.000, .096]), while the simple main effect of Statement was significant only for the synchronous condition (synchronous: $F(1, 25) = 54.98$, $p < .001$, $\eta_g^2 = .447$ [.236, .615]; asynchronous: $F(1, 25) = 4.24$, $p = .050$, $\eta_g^2 = .072$ [.000, .229]). In the familiar and unfamiliar groups, agreement with the illusion statement was stronger in the synchronous condition than in the asynchronous condition. It was also stronger compared to the agreement with the control statement in the synchronous condition. These preliminary results replicate the previously found RHI expectancies (Lush, 2020) and suggest that subjective measures of the RHI may be confounded by demand characteristics in the present Japanese sample.

The non-significant main and interactive effects of Familiarity provide insensitive evidence (BF_{excl}s = 0.64–1.53). Therefore, we cannot conclude whether prior knowledge of the RHI modulates RHI expectancies. While the primary factor for this insensitive evidence could be attributed to the small sample size lacking sufficient power, undetailed questions about the participants' prior knowledge may also contribute as a potential factor. In Experiment 1, the questions did not determine what and how much experience participants had with the RHI. There might have been variations in the degree of knowledge within the familiar and unfamiliar groups. Consequently, the effect of prior knowledge may not have been detected. To address this, in Experiment 2, we assessed knowledge of the RHI using multiple detailed items and collected sufficiently large samples based on an a priori power analysis.

Experiment 2

In Experiment 2, we examined the effects of the order of the synchronous and asynchronous conditions on RHI expectancies using a larger general sample. The order of the statements was completely randomized. Initially, we also aimed to explore the effect of prior knowledge about the

Table 2. Descriptives in Experiment 1

Familiarity	Statement	Condition	*M*	*SD*
Familiar group (*n* = 12)	Illusion	Synchronous	1.78	0.83
		Asynchronous	0.08	1.19
	Control	Synchronous	0.04	1.08
		Asynchronous	-0.15	1.13
Unfamiliar group (*n* = 15)	Illusion	Synchronous	1.29	0.90
		Asynchronous	0.31	1.22
	Control	Synchronous	-0.31	1.01
		Asynchronous	-0.60	0.68

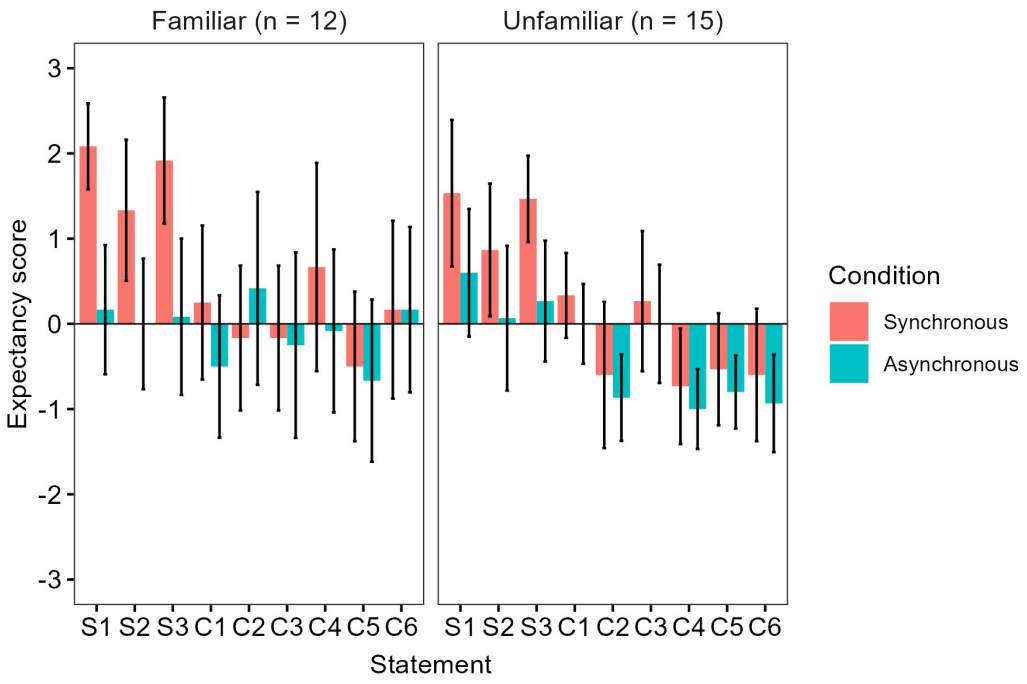

Figure 2. Mean Expectancy Scores for Individual Statements in Experiment 1

Note. Error bars indicate 95% confidence intervals.

Table 3. Main and Interactive Effects of Familiarity, Statement, and Condition on Expectancy in Experiment 1

Factor	*F*	*p*	BF_{excl}	η_g^2	95%CI
Familiarity	1.51	.230	1.53	.018	.002, .155
Statement	23.22	< .001	< 0.01	.246	.055, .422
Condition	14.26	< .001	< 0.01	.139	.042, .256
Familiarity × Statement	0.34	.568	1.23	.005	.000, .050
Familiarity × Condition	0.55	.463	1.37	.006	.000, .061
Statement × Condition	29.95	< .001	< 0.01	.072	.037, .113
Familiarity × Statement × Condition	4.11	.053	0.64	.011	.008, .032

Note. Degrees of freedom for all *F* tests were 1 and 25.

RHI, as in Experiment 1. However, only a few participants (nine out of 253; see Data Analysis) in Experiment 2 were familiar with the RHI. Consequently, we decided not to examine the effect of prior knowledge. This lack of familiarity among participants may be attributed to sampling from the general population which generally consist of individuals who are not frequently exposed to specialized scientific topics.

Methods

This experiment was not pre-registered.

Participants

The effect size for the difference in the subjective RHI index (i.e., difference between synchronous and asynchronous conditions) between the synchronous-first and asynchronous-first groups was reported as Cohen's *d* of 0.38 (Lush, 2021). As we were also interested in examining the interactive effect of a group factor (i.e., prior knowledge or condition order), we justified our sample size based on detecting an interaction between Condition and a prior knowledge or condition order, with an effect size *d* of 0.38. According to an a priori power analysis using PANGEA v0.2 (https://jakewestfall.shinyapps.io/pangea/), 148 participants were required to detect this effect with a power of .80 and alpha of .05.

Two hundred fifty-three adults were recruited from Lancers (https://www.lancers.jp/), a crowdsourcing market in Japan, to participate in this experiment. Participants were compensated with 55 Japanese yen. To account for potential exclusion of participants due to inappropriate behavior such as satisficing, we recruited more participants than the required number mentioned earlier. We analyzed data from 185 participants who met the inclusion criteria (as detailed in the Data Analysis section). The final sample consisted of 76 women and 109 men (mean age of 43.44 years, *SD* = 8.64, range = 26-75). The experiment was conducted online in February, 2022.

Materials

The video used in Experiment 1 to show the RHI induction procedures was divided into three movie clips. The first clip explained the experimental setup (32 seconds), the second clip explained the synchronous condition procedure (11 seconds), and the third clip explained the asynchronous condition procedure (15 seconds).

Procedures

The procedures in Experiment 2 were identical to those in Experiment 1, with a few exceptions. The experiment was conducted using Qualtrics. Participants were presented with a video clip and given instructions on the RHI induction and the expectancy questionnaire for either the synchronous or asynchronous condition. Then, they completed the task in the other condition. The order of the conditions was counterbalanced across participants. The order of the statements was randomized for each trial. Participants answered an instructional manipulation check item ("Which hand usually holds the eraser? Please select both "left" and "right") to ensure careful reading of instructions. While this check was not included in Experiment 1 or the original study (Lush, 2020), we included it because of expected presence of satisficing behavior in this experiment, which offered monetary rewards. Finally, participants reported their prior participation in an experiment using RHI procedures and indicated their familiarity with the procedures. If they reported knowing the RHI, they selected all the applicable items from the following options: the name of the experimental procedure, the manipulation of synchrony, and types of experience associated with the RHI.

Data Analysis

The analytical procedures for Experiment 2, were the same as those in Experiment 1, with a few exceptions. Participants who did not complete the experiment (n = 3), stayed on the RHI video web page for less than the video duration (n = 11), failed the instructional manipulation check (n = 54), or had prior knowledge or experience with the RHI paradigm (n = 9) were excluded from the analysis. Some participants met multiple exclusion criteria. Due to the very small number of participants who were familiar with the RHI, we did not examine the effect of prior knowledge.

To examine the effects of condition order on RHI expectancies, an rmANOVA was conducted with two within-participant factors (Statement and Condition) and the Order (synchronous-first or asynchronous-first group) as a between-participant factor. As the expectancy scores for the illusion statement in the asynchronous condition showed agreement and disagreement in the asynchronous-first and synchronous-first groups, respectively, two-sided one-sample t-tests were performed to test whether the expectancy scores in each group deviated from zero in a post-hoc exploratory analysis. We performed a Bayesian t-test when the frequentist t-test yielded non- significant results to assess the evidence for equivalence, using the Bayes factor (BF_{01}).

Results and Discussion

The responses to the illusion and control statements are summarized in Figure 3 and Table 4. Descriptive statistics for each statement are shown in Figure 4.

The rmANOVA showed that all the factors, as well as their interactions, were significant (Table 5). Therefore, further analysis was conducted on simple interactions and simple main effects. In both groups, there was a significant interaction between Statement and Condition (synchronous first: $F(1, 87) = 47.21$, $p < .001$, $\eta_g^2 = .025$, 95%CI [.012, .042]; asynchronous first: $F(1, 96) = 8.88$, $p = .004$, $\eta_g^2 = .004$ [.000, .011]), with expectancy scores higher for the illusion statements in the synchronous condition than in the asynchronous condition (synchronous first: $F(1, 87) = 68.17$, $p < .001$, $\eta_g^2 = .181$ [.102, .265]; asynchronous first: $F(1, 96) = 23.16$, $p < .001$, $\eta_g^2 = .034$ [.011, .070]). Moreover, in both groups, the scores for the illusion statements in the synchronous condition were higher than those for the control statements in the synchronous condition (synchronous first: $F(1, 87) = 139.89$, $p < .001$, $\eta_g^2 = .247$ [.165, .330]; asynchronous first: $F(1, 96) = 182.77$, $p < .001$, $\eta_g^2 = .245$ [.171, .333]). These results indicate that difference in expectancies between conditions occurred regardless of the order of presentation of the synchronous and asynchronous conditions. Additionally, the expectancies were observed even

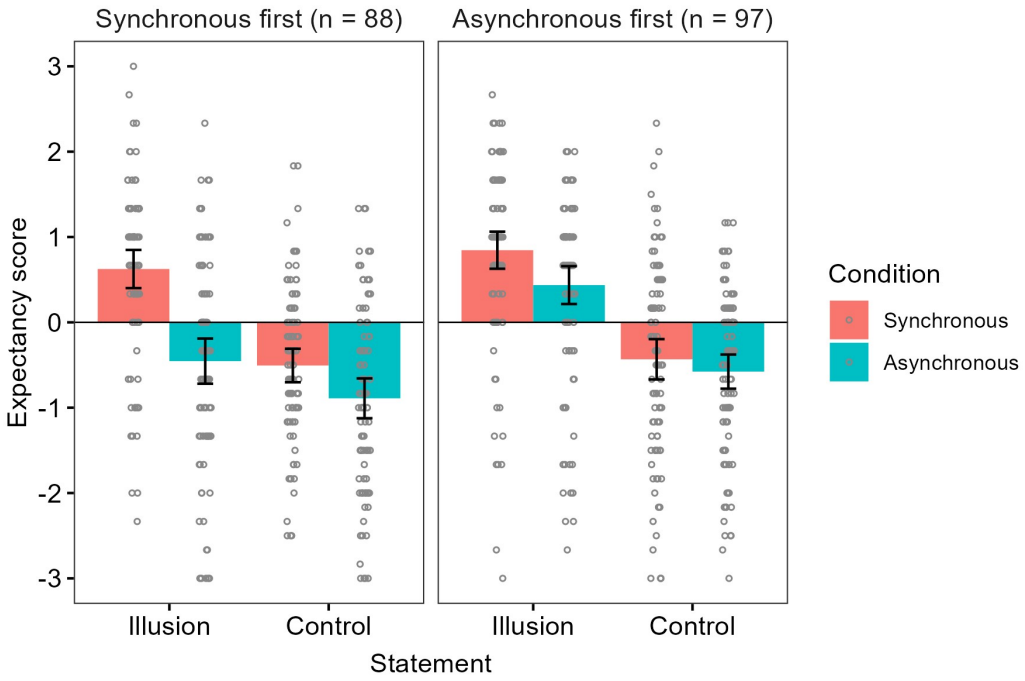

Figure 3. Mean Expectancy Scores in Experiment 2

Note. Open circles represent individual data. Error bars indicate 95% confidence intervals.

Table 4. Descriptives in Experiment 2

Order	Statement	Condition	*M*	*SD*
Synchronous first group (*n* = 88)	Illusion	Synchronous	0.63	1.06
		Asynchronous	-0.45	1.25
	Control	Synchronous	-0.51	0.93
		Asynchronous	-0.89	1.10
Asynchronous first group (*n* = 97)	Illusion	Synchronous	0.85	1.08
		Asynchronous	0.44	1.10
	Control	Synchronous	-0.43	1.17
		Asynchronous	-0.58	0.99

with full randomization of the order of the illusion and control statements. These results replicate and extend Lush's (2020) findings with fixed condition and statement orders.

Regarding the interaction between Order and Statement, the simple main effect of Order on the illusion statement was significant ($F(1, 183) = 14.42$, $p < .001$, $\eta_g^2 = .058$, 95%CI [.059, .059]) while it was not significant on the control statement ($F(1, 183) = 1.76$, $p = .186$, $\eta_g^2 = .008$ [.002, .063]). This was reflected in the higher expectancy scores for the illusion statements in the asynchronous-first group. However, these trends were significantly interacted by the Condition factor (Table 4). The interaction between Order and Statement was observed in the asynchronous condition ($F(1, 183) = 22.42$, $p < .001$, $\eta_g^2 = .017$ [.005, .034]) but not in the synchronous condition ($F(1, 183) = 1.20$, $p = .274$, $\eta_g^2 = .001$ [.000, .009]). In the asynchronous condition, the asynchronous-first group scored higher on the illusion statement than the synchronous-first group. This was supported by a two-tailed one-sample *t*-test, showing that the asynchronous-first group significantly agreed with the illusion statement in the asynchronous condition (scores higher than zero, $t(96) = 3.91$, $p < .001$, $d = 0.40$ [0.19, 0.60]) while the synchronous-first group significantly disagreed (scores lower than zero, $t(87) = -3.41$, $p < .001$, $d = -0.36$ [-0.58, -0.15]).

The asynchronous-first group was inclined to agree with the expectancy of the RHI upon encountering the asynchronous condition in the initial trial. Another possible interpretation, not mutually exclusive, is that the synchronous-first group, having previously experienced the synchronous condition where an illusion is anticipated, may be less likely to agree with the expectancy of the RHI in the asynchronous condition due to a contrast effect.

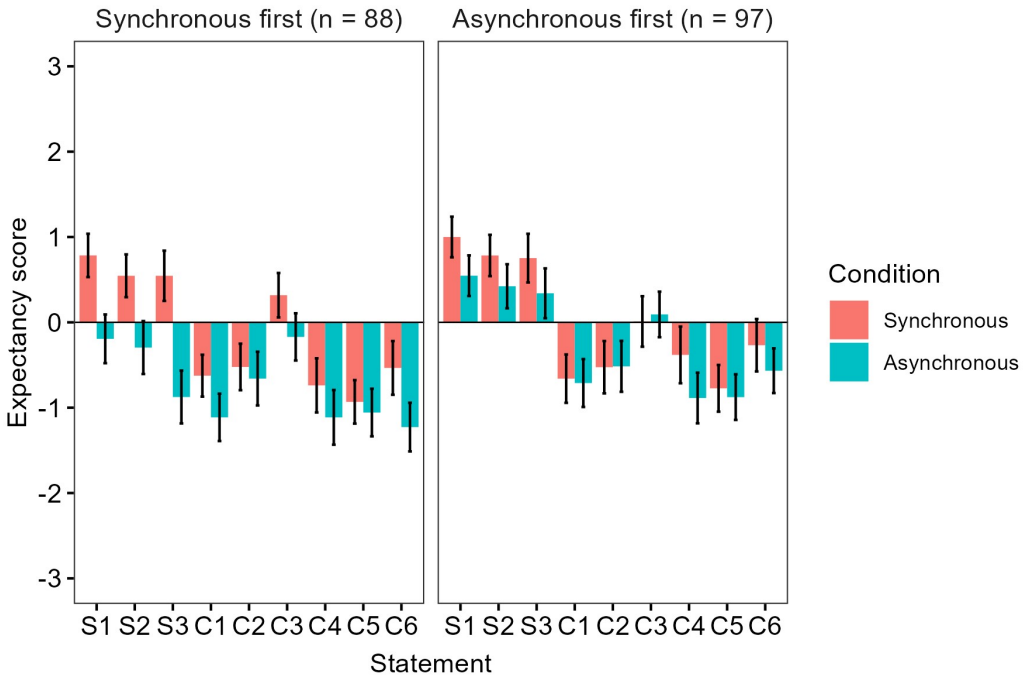

Figure 4. Mean Expectancy Scores for Individual Statements in Experiment 2

Note. Error bars indicate 95% confidence intervals.

Table 5. Main and Interactive Effects of Order, Statement, and Condition on Expectancy in Experiment 2

Factor	*F*	*p*	η_g^2	95%CI
Order	7.68	.006	.029	.048, .061
Statement	309.25	< .001	.165	.131, .213
Condition	76.91	< .001	.051	.035, .082
Order × Statement	10.94	.001	.007	.008, .008
Order × Condition	15.68	< .001	.011	.012, .012
Statement × Condition	51.24	< .001	.012	.007, .021
Order × Statement × Condition	10.31	.002	.003	.003, .003

Note. Degrees of freedom for all *F* tests were 1 and 183.

General Discussion

The present study aimed to replicate the findings of Lush (2020) and investigate the effects of prior knowledge about the RHI and condition order on illusion expectancies when viewing an RHI procedural video. Our study successfully replicated Lush's (2020) findings, as participants formed RHI expectancies by watching the procedural video. In Experiment 1, although preliminary, we could not conclude whether prior knowledge modulates illusion expectancies. In Experiment 2, we observed an effect of condition order; the synchronous-first group did not expect the illusion in the asynchronous condition, whereas the asynchronous-first group did expect the illusion in the asynchronous condition.

Participants exhibited a stronger expectancy of experiencing the RHI in the synchronous condition than in the asynchronous condition. This findings aligns with previous results showing that participants expect a higher sense of ownership when the timing of the stroking of the real and fake hands (Lush, 2020; Reader, 2022) and the movements of the avatar and participant (Forster et al., 2022) are synchronized, than when they are not. While the differences in stimulation synchrony between the two conditions were explicitly explained to participants in this study, a previous study (Reader, 2022) showed that participants still had higher expectancies in the synchronous condition even without explicit instructions, similar to laboratory experiment (e.g., Armel & Ramachandran, 2003). Since the RHI is characterized by a difference in direct and indirect measures between synchronous and asynchronous conditions, differences in expectancies between these conditions suggest that asynchronous stimulation insufficiently controls demand characteristics. Therefore, the effects of synchrony of actual visuotactile stimulation on the RHI in laboratory experiments may be confounded by expectancy and demand characteristics.

In the asynchronous-first group, participants expected an illusion even in the asynchronous condition, which is considered less likely to produce the RHI. This finding is inconsistent with previous findings regarding order effects in the RHI. In Lush (2021), where participants received visuotactile stimuli, they did not report experiencing the RHI in the asynchronous condition, regardless of the condition order. Reader's (2022) analysis of participant's free descriptions showed that the proportion of participants (23%) expecting a sense of ownership in the asynchronous-first group was comparable to that (17%) in the synchronous-first group. The present study differs from Lush (2021) in that participants did not receive visuotactile stimuli and from Reader (2022) in that the participants were not limited to university students studying psychology. The former difference suggests that qualitatively different order effects may arise when experiencing RHI induction through visuotactile stimuli compared to expecting RHI based on observing others' experiences. The latter difference suggests that in our Experiment 2, the expectancy of the RHI in the asynchronous condition in the asynchronous-first group may be attributed to the participants who are not familiar with psychological experiments expecting an effect from the unique RHI experimental situation (i.e., stroking real and fake hands) itself.

There is also the possibility that the asynchronous stimuli depicted in the video were not sufficiently perceived as asynchronous by the participants. Reader (2022) posited that because the visuotactile stimuli in the video were not entirely asynchronous, they may have exhibited characteristics akin to synchronous stimuli, potentially increasing the likelihood of agreement with the illusion statement in the asynchronous condition. In the present study, participants were explicitly informed about the differences in stimuli between the synchronous and asynchronous conditions, following previous studies (Lush, 2020; Lush et al., 2021). However, it is possible that the two brushstrokes in the asynchronous condition did not possess a sufficient degree of visual asynchrony. This may have encouraged the asynchronous-first group to develop expectancies and speculations regarding the RHI. However, the synchronous-first group, having observed synchrony in the synchronous condition, more easily noticed the asynchrony in the asynchronous condition, leading to a reduced likelihood of agreement with the illusion statement.

The generalizability of our findings is limited to the populations sampled in this study, which included Japanese university students (Experiment 1) and a general Japanese sample recruited through crowdsourcing (Experiment 2). To enhance generalizability, future research should aim to replicate these findings in diverse populations, including individuals who are familiar or unfamiliar with psychological experiments, and in regions outside of English-speaking area as done in previous studies (e.g., Lush, 2020) and Japanese-speaking regions.

In conclusion, using a Japanese student sample in Experiment 1 and a general Japanese sample in Experiment 2, this study consistently replicated the findings of Lush (2020). However, the findings of Experiment 1 should be considered preliminary. Participants exhibited stronger expectancies for subjective experiences described in illusion statements under the synchronous condition, compared to both the illusion statements under the asynchronous condition and the control statements under the synchronous condition. These results suggest that a difference in illusion expectancies between synchronous and asynchronous conditions can arise during the induction and control procedures, regardless of the order of conditions and statements (Experiment 2). Moreover, when the asynchronous condition was presented first, participants still showed expectancies for the onset of the RHI, even though this condition was intended to serve as a control. It is preferable to replace the asynchronous control condition with the expectancy-matched control condition to reduce the influence of the demand characteristics. Even if asynchronous control is employed, counterbalancing the condition order or including it as a factor in the analysis is advisable. Further investigation into the mechanisms by which expectancies arise in RHI procedures and their influence on reported experiences of the RHI will contribute to the study of the sense of ownership using the RHI paradigm.

Contributions

Contributed to conception and design: NT, SI
Contributed to acquisition of data: NT, SI
Contributed to analysis and interpretation of data: NT, SI
Drafted and revised the article: NT, SI
Approved the submitted version for publication: NT, SI

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Competing Interests

The authors declare no competing interests.

Data Accessibility Statement

Materials and raw data associated with this study are available on the Open Science Framework (https://osf.io/bsfwu/).

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Supplementary Materials

Peer Review History

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