Bodily self-awareness and the onset of ownership illusion

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Abstract

The moving Rubber Hand Illusion (mRHI) is a paradigm which investigates the sense of ownership (SoO) and the sense of agency (SoA) towards an artificial hand. This study aimed to highlight the role of the SoA on the development of the SoO according to the information provided by an action-related auditory cue. We expected that a reinforcement of the SoO illusion by the SoA could not occur if the sound of the action was removed. In order to assess the SoO and SoA, 25 participants performed the task in the the active congruent, passive congruent, and active incongruent conditions. Also, the onset time of the SoO in the congruent conditions was reported. The results confirmed our hypothesis, showing that agency did not play a pivotal role in promoting the onset of the ownership illusion if ecological auditory feedback was removed. Further research on the cross-modal assessment of individual bodily self-consciousness is recommended.

Keywords: Moving Rubber Hand Illusion, Sense of Ownership, Sense of Agency, Auditory Feedback

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The feeling of a body as one's own and the experience of controlling an action are two components of bodily self-consciousness. While the sense of body ownership arises from integrating multisensory input from the body (Ehrsson et al., 2004), the sense of agency is a result of the relationship between motor intentions and the consequence of the movements (Frith et al., 2000). Body illusions refer to those psychological phenomena in which the perception of one's own body deviates from the configuration of the physical one through multisensory and/or sensorimotor stimulation (Kilteni et al., 2015). Illusions can involve the SoO, so that it is possible to perceive non-bodily objects as part of our own body. In this regard, it is possible to distinguish two different approaches: the bottom-up, which recognizes the illusion's development in the integration of the different sensory information, and the top-down, based on the role played by pre-existing body maps within which the rubber hand would be incorporated (Tsakiris, 2010).

Changes in the representation of the body have been investigated with the rubber hand illusion, a paradigm developed by Botvinick and Cohen (1998) that allows a SoO of an artificial hand to be developed (Abdulkarim & Ehrsson, 2016; Botvinick & Cohen, 1998; Ehrsson et al., 2004). Ehrsson et al. (2004) found that a direct threat to the artificial hand leads to an activation of the areas involved in body ownership illusion; This activation is greater in individuals who experienced a stronger ownership illusion. Also, the distance between the participant's hand and the rubber hand could influence the strength of the illusion regardless of the type of set-up used, be it horizontal or vertical (Kalckert & Ehrsson, 2014a). As mentioned above, another important aspect regarding the position of the rubber hand is the congruent position to the individual: When the rubber hand is rotated 180° (i.e., incongruent condition), the illusion does not occur or is weakly realized (Braun et al., 2016; Kalckert & Ehrsson, 2012). Also, it seems that altering the size of the fake hand (i.e., reducing or enlarging it) could have an impact on the illusion (Pavani et al., 2000). The asynchrony between the touch of the individual's hand and that of the rubber hand could likewise affect the illusion (Dummer et al., 2009; Ehrsson et al., 2004), causing it to be strongly attenuated or disappear completely (Shimada et al., 2009). The fMRI study of Guterstam et al. (2013) focused on the development of the so-called "invisible hand illusion", demonstrating that an illusion could occur even with an empty space, due to visuo-tactile-proprioceptive integration in participants. This suggests that bodily self-awareness is the result of a cross-modal decision-making process.

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The moving Rubber Hand Illusion (mRHI) is a version of the RHI which introduces movement, thereby providing an additional SoA illusion. Kalckert and Ehrsson (2012) found compatible results for the roles of the SoO and SoA separately, as well as for the relationship between the two. Since mRHI is based on finger movements, additional factors could be involved. It is possible to manipulate the individual's movement (i.e., active vs passive condition): More precisely, during the active condition the individual performs a tapping movement; In contrast, the individual does not perform any movement in the passive condition but just observes the researcher's tapping of the two hands (i.e., the individual's hand and the rubber hand). In fact, in order for the SoA to develop, it is crucial to distinguish between self-generated movements and those generated by others, since the SoA does not occur if people do not recognize themselves as executors of the action (i.e., if the action is involuntary or caused by external events).

The synchrony variable is also involved: If the two hands are involved in an asynchronous movement, the illusion will not occur. The experiment carried out by Kalckert and Ehrsson (2012) showed that the SoO and SoA can be experimentally dissociated; They also demonstrated that individuals experienced a stronger illusion in the congruent than the incongruent condition. More precisely, higher scores were found in the active and passive synchronous conditions, while agency – but not ownership – occurred in the incongruent condition. Furthermore, a dissociation was observed in the passive congruent condition, whereby an illusory SoO – but not a SoA – developed. An onset analysis could also be relevant to estimate the time needed for the illusion to occur by comparing active and passive conditions. Kalckert and Ehrsson (2017) measured the SoO onset time using the mRHI; They reported a significant difference between the two conditions, with the illusion occurring first in the active condition. These results suggested that agency played a role of reinforcing the ownership illusion. The possible influence of voluntary actions on the SoO should be investigated, since the information provided by our actions (i.e., action-related auditory cues) could have an impact on our bodily awareness (Re et al., 2023).

It is not clear if self-produced movements also increase the sense of body ownership as there is no critical evidence on their greater contribution to inducing a strong ownership illusion than tactile stimulation (Ehrsson et al., 2004; Kalckert & Ehrsson, 2017). The aim of the present study was to investigate the role of the SoA on the development of the SoO according to the information provided by the auditory cue related to the individual's action. Accordingly, we tested the illusion with a set-up which allowed the sound of the double tapping

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to be removed and we subsequently deleted the auditory stimulation. We expected that a SoA's reinforcement of the SoO illusion could not occur if the sound of the action was removed.

Materials and Methods

Participants

Participants were recruited via volunteer and opportunity sampling. In line with the inclusion criteria (participants must be aged between 18 and 35, right-handed, and with no neuropsychological disorders), 25 Italian individuals (17 females, 8 males; M = 25.36 yrs., SD = 4.09) joined the study. All the participants provided informed consent in writing in accordance with the Declaration of Helsinki and the Italian Association of Psychology code of ethics. The protocol was approved by the ethical committee of the Department of Cognitive Science, Psychology, Education and Cultural Studies, University of Messina (approval no. COSPECS/07/2020).

The mRHI behavioral paradigm

A horizontal mRHI set-up was used in order to induce ownership and agency over the rubber hand (Kalckert & Ehrsson, 2017; Kilteni & Ehrsson, 2017; see Figure 1A). The participant sat at a table with a black drape covering their shoulder and arms and placed their right hand inside a black wooden box (40 cm × 40 cm × 16 cm) in front of them. A realistic, rubber right hand was placed on the left of the participant's hand, with a distance of 21 cm between the two index fingers (Kalckert & Ehrsson, 2014b). The participant wore the same yellow right glove as that used for the rubber hand and their index finger was mechanically connected to the index finger of the rubber hand using two rings and a lever mechanism (see Figure 1D) placed under the box (see Figure 1E). Some cotton was applied to the box's lever mechanism to remove the sound produced by the action. The participant's hand was hidden from view, being placed into a smaller box (see Figures 1A, 1B). In the test, participants were subjected to three mRHI experimental conditions. In the active congruent condition (see Figures 1A, 1B), the participant was asked to lift the index fingertip and perform a double tapping movement while observing the synchronous movement of the artificial hand placed in a congruent position to their body (see Figure 1C). In the passive congruent condition (see Figures 1A, 1B), the participant was asked to relax their hand while the experimenter generated the synchronous movement by manipulating the lever mechanism under the box. In the active incongruent condition (see Figure 1C), the participant performed

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the same task as in the active synchronous congruent condition, but the rubber hand was rotated 180 degrees with respect to the position of their real hand. All the conditions were synchronous, that is, the active / passive movement of the individual hand and of the rubber hand occurred synchronously. The SoO and SoA were rated with a questionnaire (i.e., subjective measure) and by measuring the degree of proprioceptive drift (i.e., objective measure), as described below.

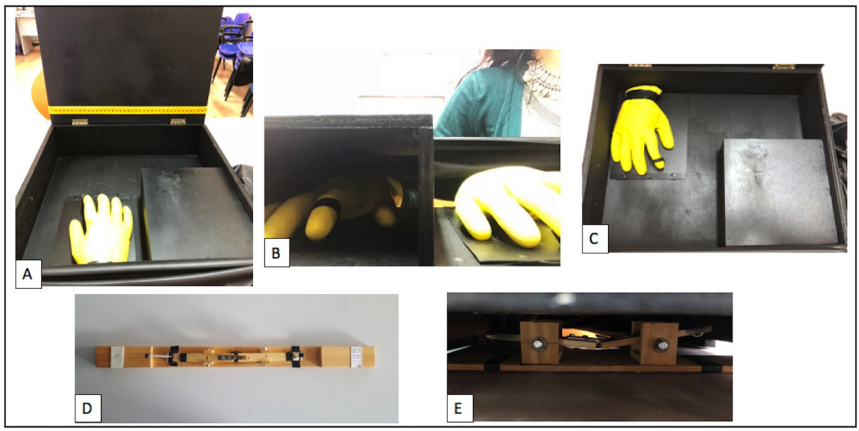

Figure 1 - *The moving Rubber Hand Illusion (mRHI) set-up. A) The set-up during the active and passive synchronous congruent conditions, with the rubber hand visible. A ruler was used to report the proprioceptive drift. B) During each trial, the participant's hand was hidden in the smaller box on the right of the visible rubber hand. C) In the active incongruent condition, the artificial hand was rotated 180° with respect to the participant's real hand; D) The index fingertips of the participant and of the rubber hand were mechanically connected with a lever mechanism. E) The lever mechanism was placed under the box*

mRHI questionnaire

The mRHI questionnaire of Kalckert & Ehrsson (2014a) used 12 statements on a 7-point Likert scale (ranging from -3 = "Strongly disagree" to 3 = "Strongly agree") to determine the SoO and SoA of participants. The questionnaire was in the Italian language. 6 of the statements (3 for each illusion) were related to the SoO and SoA (i.e., experimental statements), while the remaining 6 statements concerned task reliability (i.e., control statements; see Tab. 1).

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Tab. 1 - *The mRHI questionnaire, reported in the English original version (Kalckert & Erhsson, 2014) and in the Italian version used in this study*

ENGLISH VERSION	ITALIAN VERSION
Ownership	
1. I felt as if I was looking at my own hand.	1. Mi sentivo come se stessi guardando la mia mano.
2. I felt as if the rubber hand was part of my body.	2. Mi sentivo come se la mano di gomma fosse parte del mio corpo.
3. I felt as if the rubber hand was my hand.	3. Mi sentivo come se la mano di gomma fosse la mia mano.
Ownership-control	
4. It seems as if I had more than one right hand.	4. Sembra come se avessi più di una mano destra.
5. It felt as if I had no longer a right hand, as if my right hand had disappeared.	5. Sembrava come se non avessi più la mano destra, come se la mia mano destra fosse scomparsa.
6. I felt as if my real hand were turning rubbery.	6. Mi sentivo come se la mia mano reale stesse diventando di gomma.
Agency	
7. I felt as if I could cause movements of the rubber hand.	7. Mi sentivo come se stessi causando i movimenti della mano di gomma.
8. I felt as if I could control movements of the rubber hand.	8. Mi sentivo come se potessi controllare i movimenti della mano di gomma.
9. The rubber hand was obeying my will and I can make it move just like I want it.	9. La mano di gomma si muoveva proprio come volevo, come se stesse obbedendo alla mia volontà.
Agency-control	
10. I felt as if the rubber hand was controlling my will.	10. Mi sentivo come se la mano di gomma stesse controllando la mia volontà.
11. It seemed as if the rubber hand had a will of its own.	11. Sembrava che la mano di gomma avesse una propria volontà.
12. I felt as if the rubber hand was controlling me.	12. Mi sentivo come se la mano di gomma stesse controllando i miei movimenti.

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Proprioceptive drift

Proprioceptive drift is an implicit measure (Kalckert & Ehrsson, 2014a) for the development of the illusion of ownership over the artificial rubber hand. Before and after each trial, with the box closed, the participant was asked to indicate on the box where they felt their index fingertip was, using a tape measure placed horizontally in front of them. The degree of proprioceptive drift was obtained by calculating the difference between the two measurements (i.e., before and after the trial). A positive drift score shows that the participant perceived their hand as drifting towards the rubber hand.

SoO onset time

We assessed the SoO onset time as an additional, complementary measurement of the SoO (Kalckert, 2018; Yeh et al., 2017). Accordingly, participants were asked to verbally report the point at which they began to develop a SoO towards the rubber hand (Kalckert & Ehrsson, 2017) during the active and passive congruent conditions. The time was recorded twice (with an interval of 45 seconds) for each participant using a chronometer.

General Procedure

The procedure followed Kalckert and Ehrsson's design (2012). Participants firstly attended a training session to familiarize themselves with the double tapping movement, with a metronome being used to change the interval between the tapping. In this phase, the mRHI set-up was not used. After concluding the training, participants put on the yellow glove and closed their eyes, while the researcher covered their right arm and inserted their right hand into the mRHI box. During this phase, the participant's eyes were closed and they were instructed not to move their arms during the entire procedure. The box was opened only during the execution of the three conditions. For each condition, the proprioceptive drift was measured before and after the execution, with the box closed and participants being asked to state the position of their covered right index finger using a ruler positioned in front of them. During the active conditions the participants were asked to perform the double tapping movement, while during the passive condition they observed the movement produced by the researcher. The order of conditions was counterbalanced across participants. Each condition lasted 90 seconds, with a break of 90 seconds between each task. After all the three conditions had been performed, the participant's hand was removed from the box, the arm was free from the draft and participants

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were given a break of thirty minutes. Then, participants again performed the active and passive congruent conditions (in a random order), but this time they were instructed to also verbally declare at what point they began to develop a SoO to the rubber hand (to determine the SoO onset time). They then filled out the part of the questionnaire concerning the experimental SoO for each condition. Finally, the participants were debriefed.

Data Analyses

We carried out a within-subjects experimental design with a critical value of $p = .05$. The Shapiro-Wilk test was preliminarily conducted to assess our data distribution. Since the data were not normally distributed ($p < .05$), non-parametric statistics were used. Using the Wilcoxon signed-rank test, the reliability of the paradigm in inducing the SoO and SoA was first checked. Then, the test was used to compare the experimental SoO and SoA, and the degree of proprioceptive drift, between conditions. The Friedman test was carried out for comparison across conditions, for both the mRHI questionnaire and the proprioceptive drift. Onset times were considered only for participants who registered an experimental ownership score of ≥ 1 in the active and congruent conditions before attending the onset time session. We decided to again measure the SoO in order to control the potential suggestibility bias from the previously executed tasks. The Wilcoxon signed-rank test was used to compare the onset times in the two sessions. All of the performed tests were two-tailed.

Results

Reliability of the mRHI paradigm

According to the Wilcoxon signed-rank test, the ownership statements were higher than control in the active congruent ($Z = -4.09$, $p < .001$) and passive congruent ($Z = -3.95$, $p < .001$) conditions, confirming that the two conditions evoked a SoO. In contrast, the ownership statements were lower than control in the active incongruent condition ($Z = -3.03$, $p = .002$). The agency statements were higher than control in the active congruent ($Z = -4.30$, $p < .001$) and incongruent ($Z = -4.35$, $p < .001$) conditions, while there was no significant difference in the passive congruent condition ($Z = -1.83$, $p = .07$), however, the negative value indicated a general disagreement in assessing a SoA. In sum, the results confirmed the development of the SoO in the two

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congruent conditions but not in the active incongruent condition and of SoA in the two active conditions but not in the passive condition. (see Tab. 2).

Ownership and agency across and between conditions

The Friedman test revealed a significant factor condition for both ownership ($\chi^2 = 32.36$, $p < .001$) and agency ($\chi^2 = 10.56$, $p = .01$). The higher ownership was reported in the passive congruent condition, while the higher agency was reported in the active congruent condition (see Table 2).

The Wilcoxon signed-rank test showed a higher ownership in the active congruent than incongruent condition ($Z = -4.21$, $p < .001$) and in the passive congruent than active incongruent condition ($Z = -4.25$, $p < .001$); No significant difference was revealed between active and passive congruent conditions ($Z = -.73$, $p = .47$). For the agency, a higher result was reported in the active than passive congruent condition ($Z = -3.25$, $p = .001$) and in the active incongruent than passive congruent condition ($Z = -3.20$, $p = .001$); In contrast, the difference between active congruent and incongruent condition was not significant ($Z = -.89$, $p = .38$) (see Tab. 2, Figure 2).

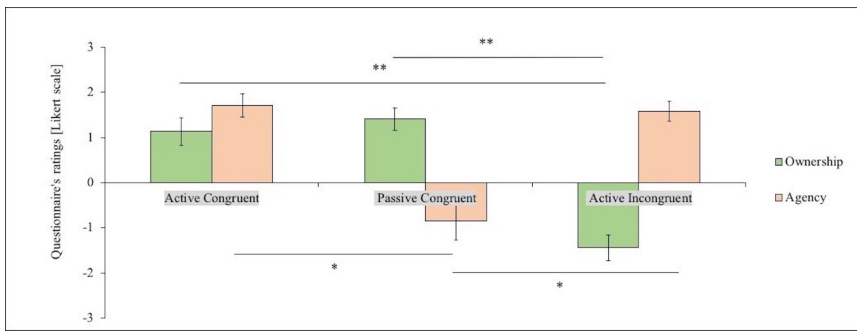

Figure 2 - *Mean ownership and agency scores in the questionnaire. Error bars indicate standard error (SE)*

* $p < .05$

** $p < .001$

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Proprioceptive drift

The Friedman test revealed a significant factor condition ($\chi^2 = 13.41$, $p = .001$), with the higher proprioceptive drift in the passive congruent condition (Table 2). The Wilcoxon signed-rank test reported a higher drift in the active congruent than incongruent condition ($Z = -3.15$, $p = .002$) and in the passive congruent than active incongruent condition ($Z = -3.34$, $p < .001$) (Table 2). The difference between active and passive congruent conditions was not significant ($Z = -.73$, $p = .47$) (see Figure 3).

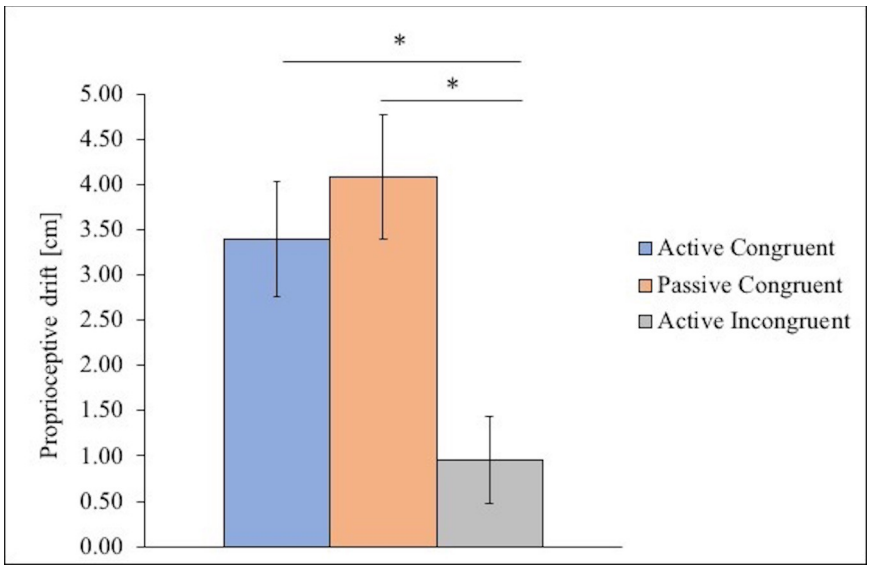

Figure 3 - *Mean proprioceptive drift in each condition. Error bars indicate standard error (SE)*

* $p < .05$

Ownership onset

Eleven participants reported experimental ownership scores ≥ 1 in the mRHI questionnaire during the active and passive synchronous congruent conditions performed for the onset time's measurement. A significant difference between active ($M = 19.07$, $SE = 2.19$) and passive ($M = 17.91$, $SE = 2.15$) congruent conditions ($Z = -.60$, $p = .55$) was not reported (see Figure 4).

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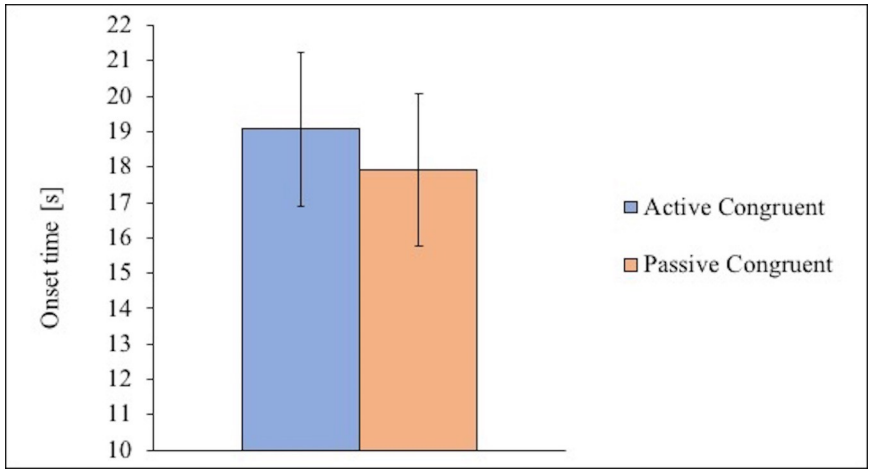

Figure 4 - *Mean SoO's onset times in the active congruent and passive congruent conditions. Error bars indicate standard error (SE*)

Discussion and Conclusions

The core of the rubber hand illusion is the development of a mechanism for the embodiment of an artificial hand (Riemer et al., 2019). It assesses the SoO according to a paradigm involving both visual and tactile stimuli. The mRHI is an improved version of the classical paradigm that inserts movement into the procedure, allowing the individual to also experience a SoA illusion. According to the different conditions, the mRHI can enable the development of the SoO and the SoA either simultaneously or separately. By manipulating the position of the rubber hand with respect to the individual's body and movement, it is possible to analyse the role of the two senses in bodily self-consciousness. More precisely, the active and passive congruent conditions both involve a position of the rubber hand which is congruent with the individual's body, but the movement occurs only in the active one. With the aim of investigating the role of the SoA on the SoO, our experimental procedure removed the action-related auditory cue, from which we expected to observe a lack of reinforcement of the SoO by the SoA.

We first assessed the reliability of our mRHI paradigm; We confirmed that the SoO was evoked by both active and passive congruent conditions, but only the active condition also evoked a SoA. In contrast, the active incongruent condition elicited a SoA but not a SoO. The two senses were measured using a validated questionnaire, while the degree of proprioceptive drift provided an implicit measure of the SoO. Overall,

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a comparison between active and passive congruent conditions revealed no significantly higher levels of SoO for both the questionnaire and the proprioceptive drift. These results suggested that, although the active movements played a positive role in relocating the spatial position of the individual's own hand (Abdulkarim & Ehrsson, 2018), in this case the congruent position was dominant in assessing the SoO, confirming the multisensory integration of visual, tactile and proprioceptive signals in bodily representation (Barnsley et al., 2011; Ehrsson et al., 2005). Also, a reinforcement provided by the synchrony of the visual and tactile stimuli was observed (Bekrater-Bodmann et al., 2014), since in the active incongruent condition the SoO was actually lower. The same consideration could be made for the SoO onset times, since a significant difference was not revealed. Previous research has reported a stronger experience of illusion with active movements (Braun et al., 2014; Kalckert et al., 2017), but our findings suggested that voluntary actions could not be crucial in inducing a stronger sense of body ownership (Walsh et al., 2011) if there were no ecological auditory feedback. In fact, our set-up removed the action-related auditory feedback, so participants could not integrate the visual and tactile information with the auditory information.

There are certain limitations to our study. Firstly, carrying out the three conditions before the assessment of the SoO onset times could have had an impact on the task in terms of the susceptibility of individuals. Although we aimed to control such a bias by asking participants to declare again their SoO with the questionnaire, the previous experience of SoO by participants could have influenced its development the second time. Secondly, caution must be exercised regarding the relationship between the classical RHI and the individual's bodily self-awareness. The study of David et al. (2013) used the Body Perception Questionnaire to investigate the development of the illusion in the RHI and the individual's bodily awareness; it revealed a lack of positive correlation. Thus, it was suggested that an individual's susceptibility to the RHI could be independent from their bodily awareness. Although there is a difference between the cues provided by the mRHI and those related to the RHI, future investigations into the aforementioned relationship should be carried out.

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Acknowledgments

The Authors contributed equally to this work.

Declaration of interest statement

The Authors report there are no competing interests to declare.

Data availability statement

The data that support the findings of this study are openly available in OSF at https://osf.io/akt75/.

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