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# Auditory Information in the Form of a Scratching Sound Enhances the Effects of the Rubber Hand Illusion

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The body schema describes an internal representation of the body in space, and is generated from a number of different sense modalities such as vision and proprioception. Botvinick and Cohen's rubber hand illusion (1998) demonstrates the relative contributions of vision, tactile perception and proprioception to body awareness. In this illusion, a participant's real hand is concealed from view and a prosthetic rubber hand is seen in its place. An experimenter simultaneously administers tactile stimulation to both the seen rubber hand and participant's actual hidden hand. The combination of this visual and tactile information overrides proprioceptive cues to body perception, creating a sense of ownership of the rubber hand. The present experiment extends research on the sensory inputs to the body schema by employing the rubber hand illusion to investigate the role of auditory information in construction of the body schema. Tactile stimulation was administered with sandpaper while a prerecorded scratching noise played from a concealed speaker. We found that the inclusion of a sound cue heightened the effects of the illusion and caused participants to more readily accept the rubber hand into the body schema. The findings of this study contribute to the existing understanding of body perception by demonstrating the influence of the auditory system in limb localization.

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# Table of Contents

Research on multisensory perception suggests that we interpret external stimuli through the combination and integration of the human senses (Driver & Spence, 2000; Ernst & Bülthoff, 2004; Shimojo & Shams, 2001). In most cases, different modalities complement and enhance each other to create a unitary, robust perception. Sometimes, however, one system can override others, resulting in an erroneous perception. This anomaly of multisensory conflict has been best documented in the visual system. In *visual capture*, the visual system is the dominant sensory system in the body. Thus when conflicted with another sense, vision typically has a greater influence in perception. For example, vision overrides auditory information in the McGurk effect (McGurk & Macdonald, 1976). In this experiment, participants listen to the syllable "ba-ba" as it is played over lip movements forming the syllable "ga-ga". The consequent perception is a misheard repetition of the syllables "da-da". Similarly in the ventriloquism effect (Radeua & Bertelson, 1997), when a speaker's voice is disguised to appear as though it is originating from a dummy's mouth, the listener misperceives the source of the sound as coming from the dummy rather than the speaker.

Sensory inputs from visual, proprioceptive, and kinesthetic information are integrated in the brain to generate an internal representation of the body and its positions. We refer to this representation as 'the body schema', (see Holmes & Spence, 2006, for a review). While proprioceptive and kinesthetic information play a prominent role in bodily representation, studies show that vision is an important influence in identifying body characteristics and location. For example, visual capture of limb localization is observed when prism glasses displace the seen image of one’s own hand, resulting in a conflict between visual and proprioceptive information (Hay et al., 1965). Mirrors may also be used to manipulate seen and felt location of an isolated limb. If a mirror is placed along the midsagittal plane and the right hand is concealed, participants will view the reflected image of the left hand placed in the assumed position of the unseen right hand. In turn, the reflected hand takes on ownership as the true hand. The visual-spatial conflict seen here creates sensorimotor consequences such as reaching error and inaccurate distance judgments made of the unseen hand (Homles & Spence, 2005; Kunz et al., 2009) and can be effectively used to treat patients with phantom limb pain (Ramachandran & Rogers-Ramachandran, 1996). These studies among others importantly highlight the plasticity of the body schema by displaying how visual information can cause one to misperceive one's own limb characteristics and location.

Botvinick & Cohen (1998) demonstrated another instance of visual capture of both proprioceptive and tactile information in the Rubber Hand Illusion (RHI). In this paradigm, the participant looks at a prosthetic hand while his or her real hand is concealed from view. An examiner then uses a paintbrush to stroke both the real and fake hands simultaneously. Consequently, the participant undergoes a strange phenomenon in which he or she takes ownership of the viewed hand, as though the rubber hand had experienced the tactile sensation, rather than the true limb. Thus, through visual capture, the rubber hand is integrated into the participant's body schema. Brain imaging scans have confirmed the internal link made between the rubber hand and the true body (Ehrsson, Spence, & Passingham, 2004; Ehrsson, Homles, & Passingham, 2005; Ehrsson et al., 2007). A questionnaire by Longo, Schuur, Kammers, Tsakiris, & Haggard (2008) identified three main components that participants undergo during the illusion. First, is a feeling of ownership; second, a sense of location in which the real hand is thought to be situated where the rubber hand is; and third, an impression of motor agency, where the participant feels as though he could have moved the prosthetic hand. Tactile sensations in the Rubber Hand Illusion extend even beyond touch. For example, research shows that participants can also experience a sensation of heat when a light is pointed at the prosthetic hand (Durgin, 2007).

The rubber hand illusion is commonly assessed by a self-report measure and a behavioral measure. In the rubber hand questionnaire (Longo et al., 2008) subjects rate agreement on a 7-point Likert scale. More convincing evidence, however, is taken from behavioral measures of proprioceptive drift -- that is, the change in proprioceptively perceived position of the participant's hidden receptive hand (Aimolia Davies, White, & Davies, 2010). When both hands are concealed from view and the participant is asked to assess the location of the veridical hand, mislocation typically occurs toward the direction of the prosthetic hand.

A study conducted by Schütz-Bosbach, Tausche, & Weiss (2009) aimed to test whether visual information could affect textural perceptions in the rubber hand paradigm by administering tactile stimulations on the real and rubber hand with a rough material (sponge) and a soft material (cotton). Similarly, the present study employs a rough textural material, but also applies an additional sensory cue, audition, to complement and enhance the tactile sensation. Prior studies have suggested that tactile perception may be linked to auditory information (Hötting and Röder, 2004). For example, in a study by Zampini & Spence (2004) potato chips were perceived as crisper when the overall sound level of chewing was increased. Neuroimaging scans have supported the link between audition and tactile perception in anesthetized animals, where touch stimulation enhanced auditory activations in the caudal belt of the brain (Kaysar & Logothetis, 2007). Moreover, research on vibration detection has suggested that auditory cues enhance tactile perception (Gillmeister & Eimer, 2007).

Audition and vision have also been linked in a variety ways. Sound has been shown to enhance visual sensitivity in recognition of facial emotion (Bhullar, 2013; Selinger, Domínguez-Borrás, & Escera, 2013) and human gait (Thomas & Shiffrar, 2013). The cross-modal effect of visual and auditory cues has also been shown to enhance the illusory sensation of body movement when there is none in a phenomenon known as vection (Keshavarz et al., 2013). Additionally, the presence of an auditory cue has been shown to enhance judgments of the intensity of a visual stimulus. Stein et al. (1996) demonstrated this effect when pairing a brief, broad-band auditory stimulus with an LED light. This pairing led to greater perceptions of light intensity.  While sound often enhances vision, it sometimes completely alters visual perceptions altogether. For example, Sekuler & Sekuler (1999) found that adding a "clinking" noise to a video of two balls crossing paths changed the viewers' perceptions of the balls' movements.

Aside from its role in enhancing tactile and visual information, the auditory system is also has important functions in stimuli localization (Blauert, 1997; Middlebrooks and Green, 1991; Reijners et al., 2014). Psychoacoustic experiments have revealed 3 major mechanisms for locating auditory stimuli. The first is interaural time difference (ITD), which describes the time delay between when stimuli reach each of the two ears. Second is interaural level difference (ILD), describing the difference in signal intensity reach each ear. Both ITD and ILD are binaural cues that aid in determining azimuth. The third mechanism in sound localization filters auditory stimuli reaching the ears. We refer to this as head-related transfer function (HRTF). The combination of ITD, ILD, and HRTF allows for identification of distance, azimuth, and elevation. It is through these mechanisms that the auditory system converts 2-D stimuli into 3-D perceptions, thus allowing us to locate a sound source's position in space.

The present study aimed to test whether the addition of an auditory cue can enhance visual-tactile information in the Rubber Hand Illusion. The domain of audio-visual-tactile sensations remains largely untouched, and the Rubber Hand illusion had yet to be tested with auditory stimuli. In the experiment, the Rubber Hand Illusion was administered with two key differences. The first difference is that stroking was not administered with a paintbrush, but rather with sandpaper. The other key difference is that in the experimental conditions, a prerecorded scratching noise that mimics the sound of sandpaper against skin was played synchronously with the scratching motion administered on the rubber hand. The speaker was concealed directly underneath the rubber hand, with the prediction that sound localization processes would identify the rubber hand as the source of the sound. Given the enhancing effects that sound has been shown to have when paired individually with touch and sight, we hypothesized that by combining the factors of visual, tactile, and auditory information, participants would experience a stronger effect of the illusion and more readily adopt the rubber hand into their body schema, thus further rejecting proprioceptive cues about the location of their true hand.

# Method

## Study 1

### *Participants*

A total of 51 (37 female) undergraduate students at the University of Dayton with normal non-impaired vision and hearing were selected for our first sample group. Ages ranged from 18-21, with a mean age of 19.36. Ninety six percent reported their handedness as right-handed. No participants identified themselves as ambidextrous. The 51 participants were split into 2 groups. The first group (scratching sound condition) was made up of 25 participants (19 female), 92% of which identified as right-handed. The second group (white noise condition) consisted of 26 participants (18 female). All participants in this group were right-handed. Informed consent was obtained prior to the experiment. Each participant was tested individually over the course of ~40 minutes. Participants received one hour of course credit in exchange for their time.

### *Procedure*

The participants' right arms were positioned at a marked location beneath a wooden apparatus (55 cm * 63 cm * 8.5 cm) that rested on a table. Participants were asked to rest their left arms either on the table outside of the apparatus. Vision of their right hands was prevented by the occluding rooftop to the apparatus. Resting in front of them and approximately 10 cm to the right of their midline was a rubber hand, which could be viewed through the clear glass top of the wooden framework. The rubber hand was placed (17.5 cm) to the left of their concealed right hand, which has shown to be the most effective distance to elicit the illusion. Participants were encouraged to move their elbows into a comfortable position, but were reminded repeatedly throughout the duration of the experiment to keep their right hands as still as possible.

An experimenter, sitting 80 cm across the table from the participant, simultaneously administered tactile stimulation on both the participant's real hand and the rubber hand. Tactile stimulation was generated from two scratching devices that were made from sandpaper sheets attached to the end of paintbrushes. This allowed the experimenter a certain degree of control over the mobility of the scratching motion, while also evoking a rough sensation on the participant's hand. The experimenter stroked the real and rubber hands for 120 seconds while a prerecorded noise was heard. Once tactile sensation ceased, participants were instructed to briefly close their eyes while the experimenter covered the apparatus so that the rubber hand was no longer visible. After telling the participant to open their eyes, the experimenter then ran his or her index finger across the upper edge of the box, randomizing starting position between the left and right corners of the apparatus. Tied around the experimenter's index finger was a thread with a weight attached to the bottom that ran approximately 1 cm above the surface of the table, where a measuring stick was attached. When the participants perceived the experimenter's finger as being directly above the location of their right middle finger (which actually lay underneath the box) they told the experimenter to stop. The experimenter then measured participants' perceived hand location by recording the corresponding number on the measuring stick where the weight hovered.

Each participant experienced two conditions: either the scratching sound/rubber hand visible and scratching sound/rubber hand not visible conditions or the white noise/rubber hand visible and white noise/rubber hand not visible conditions. The scratching sound condition served as the experimental group. Participants in this group experienced the scratching noise with and without the rubber hand visible, three times each, for a total of 6 trials. In both conditions, participants heard a sound similar to that of skin being scratched. This noise was played from a concealed speaker that was attached to the bottom of the table, directly underneath the rubber hand. For half of the trials, the rubber hand was visible, and participants were instructed to focus their visual attention on the rubber hand being scratched. In the remaining trials, the experimenter covered the entire apparatus, so that neither the real nor rubber hand was visible. In this condition, there was presumed to be no conflict between proprioception and the other sensory modalities, and thus served as our control. Trials were randomized for each participant. The white noise condition was used to represent the classic Rubber Hand Illusion. Here, participants watched the rubber hand being scratched while a loud white noise was played from the speaker. We administered this sound with the assumption that it would drown out the noise of any authentic sound that may be produced from the sandpaper on the real and rubber hands. As with the group that experienced the scratching sound, each condition was experienced three times for a total of 6 trials. Visibility of rubber hand and starting position were randomized for each participant.

After all six trials were completed, participants were asked to fill out a 9-item questionnaire that assessed what they experienced in the illusion. They were reminded that there were no right or wrong answers and to answer as honestly as possible. The questionnaire includes questions adapted from Botvinick and Cohen's Rubber Hand Illusion study (1998). We measured true effects of the rubber hand illusion using three questions (It seemed as though the touch I felt was caused by the sandpaper on the rubber hand; It seemed as if I were feeling the touch of the sandpaper in the location where I saw the rubber hand being touched; It felt as if the rubber hand were my hand). These questions have been shown to be a valid indicator of the strength of the illusion (e.g.

consistent with behavioral measures of unseen perceived hand position) and are reliable across at least two studies (Botvinick & Cohen, 1998; Bertamini et al., 2011). The remaining questions were added to account for response biases, and did not reflect actual effects of the illusion (e.g. It felt as if my real hand were turning rubbery). Participants reported agreeability on a 7-point Likert Scale ranging from strongly disagree (=1) to strongly agree (=7). We also added three items to the end of the questionnaire to assess age, sex, and handedness.

## Study 2

### *Participants*

The sample group consisted of 19 undergraduate students (13 female) at the University of Dayton in good health. Ages ranged from 18-20. The mean age was 18.84. 89% identified themselves as right-handed. Informed consent was obtained prior to the experiment. Participants were tested individually over the course of 60 minutes. They received one hour of course credit in exchange for their time.

### *Procedure*

The experimental procedure in this study is nearly identical to that of Study 1, in that the same materials and measurements were used to test the illusion. However, rather than split subjects into two subgroups as we did in the first study, we used a within-subjects design, so that every participant would experience all four conditions (scratching sound/rubber hand visible, scratching sound/rubber hand not visible, white noise/rubber hand visible, white noise/rubber hand not visible). Participants began the study with two practice trials, lasting ~30 seconds each. The scratching sound was played in one of the practice trials, and the white noise in the other. Each of the four conditions was repeated three times, for a total of twelve trials per participant. Auditory cue (scratching sound vs. white noise), rubber hand visibility (visible vs. not visible), and starting position (left vs. right) were randomized for each participant. Participants were offered a break between every three trials, where they were allowed to stretch their fingers and move their hand. After completing twelve trials, participants were once again asked to respond to a questionnaire. We utilized the same questionnaire as in Study 1, however each item was asked twice - the first time specifying to when the scratching sound was heard, and the second time specifying to the inclusion of the white noise. When giving instructions for the questionnaire, the experimenter replayed both sounds to specify to the participant which was the ‘scratching sound’ and which was the ‘white noise.’

# Results

## Study 1

### *Proprioceptive Drift*

Participants in the scratching sound condition experienced greater degrees of proprioceptive drift than those in the white noise condition (Fig. 1). Those in the scratching sound/rubber hand visible condition demonstrated the strongest instances of drift, with a mean perceived hand location of 4.07 cm (SD = 3.77) away from the real hand and closer toward the rubber hand. Following this is the white noise/rubber hand visible condition, which displayed a mean drift of 2.35 cm toward the rubber hand (SD = 3.05). In the conditions where visibility of the rubber hand was obstructed, participants who heard a scratching sound had a mean drift of 0.27 cm (SD = 2.94) and those who heard a white noise showed a mean of 1.12 cm (SD = 2.51). A paired samples t-test (one-tailed) showed that a significant difference existed between the scratching sound/rubber hand present & scratching sound/rubber hand not present conditions ($t$ (24) = 5.96, $p < .001$) as well as between the white noise/rubber hand present and white noise/rubber hand not present conditions ($t$ (25) = 1.985, p = .029). In a one-tailed independent samples *t-test*, the scratching sound/rubber hand visible condition showed significantly higher reports of proprioceptive drift than the white noise/rubber hand visible condition ($t$ (49) = 1.79, p = .04).

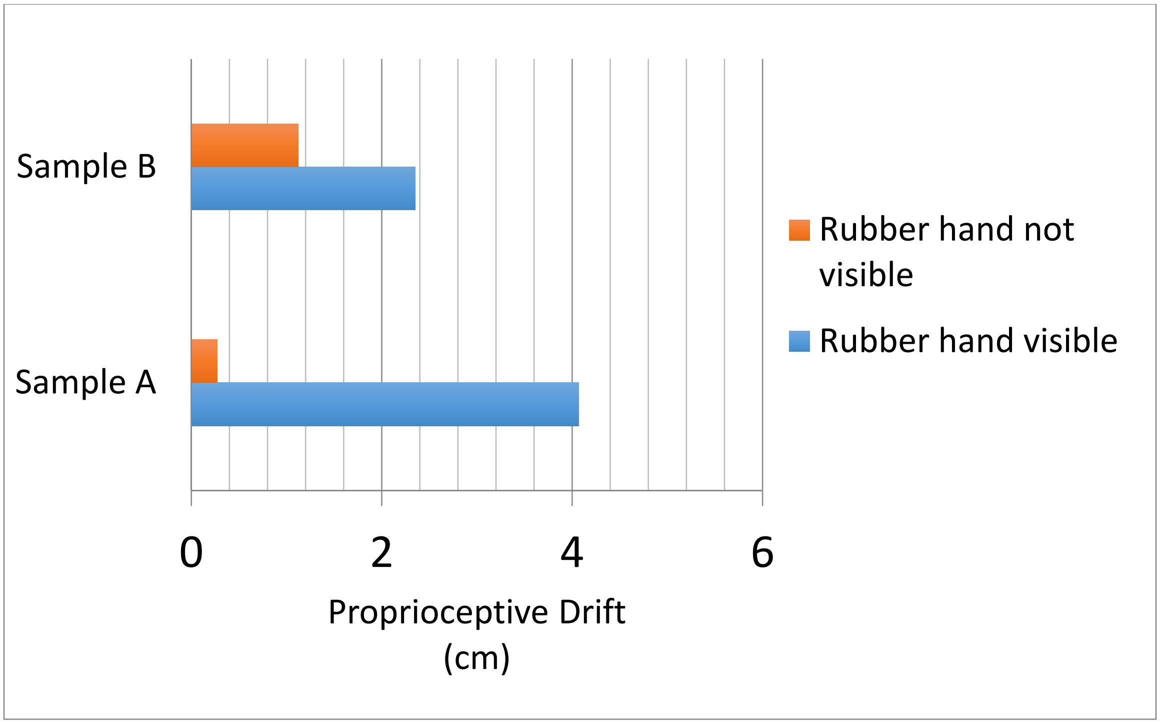


**Fig. 1** Empirical Data based on mean judgments of distance away from real hand and toward rubber hand. Larger numbers indicate perceived location as being closer to the rubber hand.

## *Self-Reports*

A one-sample t-test of questionnaire responses showed that the three items intended to assess the true effect of the illusion were rated significantly more affirmative than neutral ($t$ (50) = 2.58, p = .01; $t$ (50) = 2.12, p = .04; $t$ (50) = 7.18, p = <.01) on a 7-point Likert scale (see Table 1 for mean ratings). As predicted, the other items did not indicate a significant tendency to respond above the neutral test value. An independent samples t-test found no significant differences between responses based on sound conditions, however participants who heard a scratching sound displayed an average tendency to rate slightly higher than those who heard the white noise only (Table 1).

**Table 1.** Mean responses (and standard deviation) to single items on questionnaire

| | Scratching & White Noise | Scratching Sound | White Noise |
|---|---|---|---|
| 1. It felt as if the rubber hand were my hand | 4.65* (2.18) | 4.96 (2.03) | 4.35 (2.31) |
| 2. It seemed as though the touch I felt was caused by the sandpaper on the rubber hand | 4.69* (1.90) | 4.88 (1.56) | 4.50 (2.19) |
| 3. It seemed as if I were feeling the touch of the sandpaper in the location where I saw the rubber hand being touched | 5.67** (1.66) | 6.00 (1.44) | 5.36 (1.81) |
| 4. It felt as if my (real) hand were turning rubbery | 3.88 (1.67) | 3.96 (1.51) | 3.81 (1.83) |
| 5. It appeared as if the rubber hand were drifting toward the right | 3.02 (1.67) | 3.28 (1.65) | 2.77 (1.68) |
| 6. It felt as though my (real) hand were drifting toward the left | 4.51 (1.88) | 5.04 (1.69) | 4.00 (1.94) |
| 7. It seemed as if I might have more than one right hand | 3.08 (1.86) | 3.40 (1.68) | 2.77 (2.00) |
| 8. It seemed as if the touch I felt came from somewhere between my own hand and the rubber hand | 3.76 (1.69) | 4.00 (1.68) | 3.54 (1.70) |
| 9. The rubber hand began to resemble my own (real) hand | 3.35 (2.04) | 3.28 (1.97) | 3.42 (2.14) |

Items 1, 2, & 3 indicate perceived ownership of the rubber hand (Longo et al. 2008). Significant differences between mean responses and the neutral test value (4) were analyzed for paired samples (two-tailed).
** $p < .001$, *$p < .05$

# Study 2

## *Proprioceptive Drift*

Once again, the greatest levels of proprioceptive drift were observed in the scratching sound/rubber hand visible condition (Fig. 2). Here we saw a mean of 4.97 cm (SD = 3.76), which was higher than the mean drift of 4.0 cm in the white noise/rubber hand visible condition (SD = 2.75). The scratching sound/rubber hand not visible condition resulted in a mean drift of 3.2 cm (SD = 2.36) and the white noise/rubber hand not visible condition averaged the lowest mean of 2.74 (SD = 2.0).

A repeated measures ANOVA revealed a significant main effect for sound condition ($F = (1, 17) = 9.23$, p = .007) as well as presence of rubber hand ($F = (1, 17) =$

13.20, p = .002). This indicates that the illusion had the strongest effect when a scratching sound was played and/or the rubber hand was visible. The interaction between sound condition and visibility of rubber hand, however, was not statistically significant. Because we predicted that the scratching sound with the rubber hand would produce the largest proprioceptive drift (e.g. largest errors), we conducted additional an paired samples t-test, which showed significant differences between scratching sound/rubber hand present & scratching sound/rubber hand not present ($t$ (17) = 3.38, p = .004), white noise/rubber hand present & white noise/rubber hand not present ($t$ (17) = 2.77, p = .013), and scratching sound/rubber hand present & white noise/rubber hand present ($t$ (17) = 2.63, p = .018). As predicted, there was no significant difference between conditions where rubber hand was not visible.

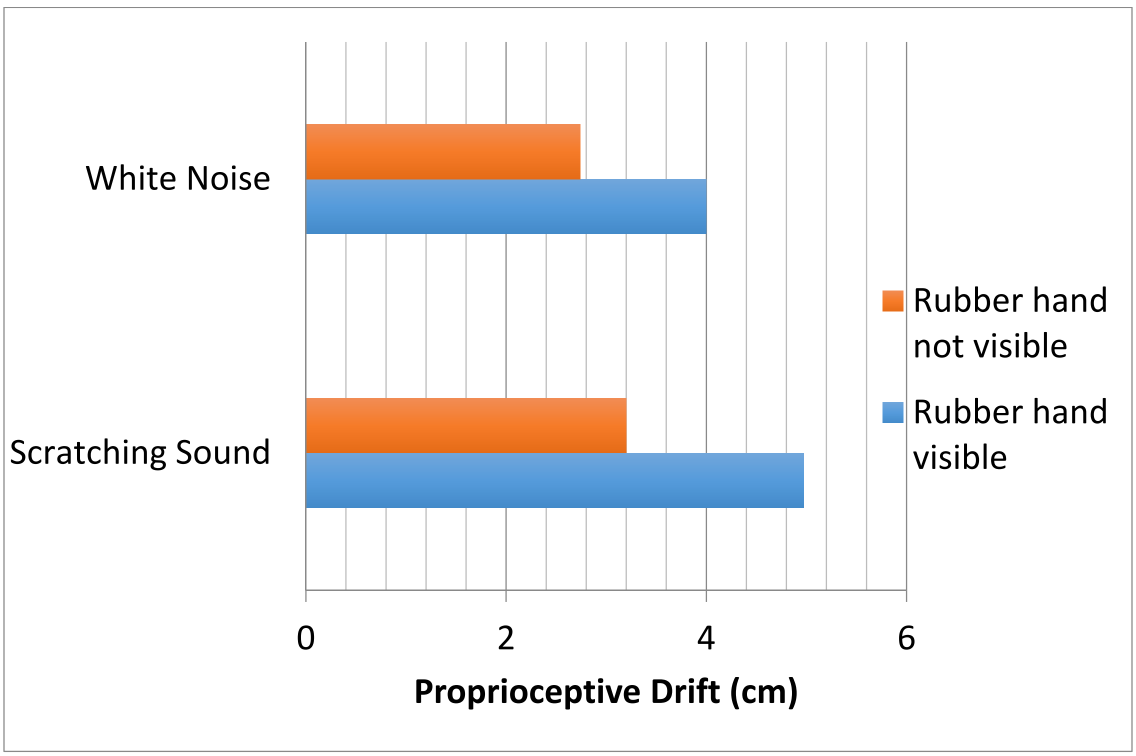


**Fig. 2** Empirical data based on mean judgments of distance (cm) away from real hand and toward rubber hand. Larger numbers indicate perceived location as being closer to the rubber hand.

## *Self-Reports*

A paired samples t-test (two-tailed) was administered to test the effects of sound conditions within subjects. As predicted, a significant difference was found between the scratching and white noise conditions on items 1 (*t* (18) = 4.44, p < 001), 2 (*t* (18) = 2.96, p < .01, and 3 (*t* (18) = 3.09, p < 01), which measure perceived ownership of the rubber hand. Mean responses to individual items are displayed in Figure 3.

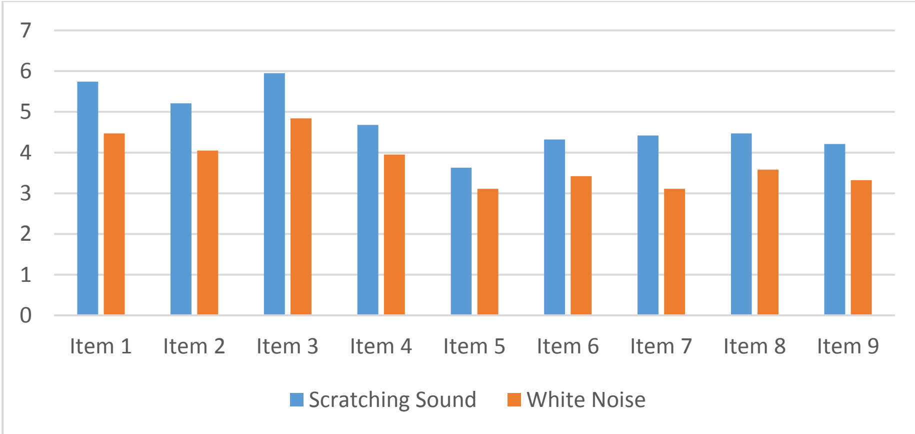


**Fig 3.** Responses to questionnaire items. Item 1: It felt as if the rubber hand were my own hand. Item 2: It felt as though the touch I felt was caused by the sandpaper on the rubber hand. Item 3: It seemed as though I were feeling the touch of the sandpaper on the location where I saw the rubber hand being touched. Items 4-9 are not direct measures of the illusion.

## General Discussion

The findings of this study support our hypothesis that auditory information would complement and enhance visual and tactile information to strengthen the effects of the Rubber Hand Illusion. To our knowledge, this is the first reported evidence of auditory information contributing to a sensory neglect of proprioceptive cues. The findings in this study support Durgin's (2007) assumption that other sensory modalities may influence the outcomes of the Rubber Hand Illusion. Consistent with the findings that auditory information can enhance our perceptions of tactile information (Hötting & Röder, 2004; Zampini & Spence, 2004; Kaysar & Logothetis, 2007; Gillmeister & Eimer, 2007) and visual information (Bhullar, 2013; Selinger, Domínguez-Borrás, & Escera, 2013; Thomas & Shiffrar, 2013; Keshavarz et al., 2013; Stein et al., 1996), we discovered that the combination of these three major sensory systems (sight, touch, and sound) in a complementary fashion strengthens misperceptions of body position and orientation.

When studying stimuli that contribute to the body schema, we traditionally think of sensory systems such as vision, touch, proprioception, equilibrioception, and vection

(Maravita, A., Spence, C., Driver, J., 2003). Auditory perception is not a typical sensory modality that is considered when understanding the way that we perceive our body position, location, and orientation. However, these findings suggest that auditory information, when paired with other sensory stimuli, can indeed be an important contributor to internal representations of the body. This may be an important consideration when manufacturing artificial devices to represent the body schema. We see this for example in telerobotics equipment, which are intended to give the users the feeling that the robotic device is an extension of their own body. Knowing that sound can be an important contributor in perceptions of limb ownership, manufacturers may find it useful to install meaningful auditory cues in the equipment. The findings of this study, which contribute to our overall understanding of limb localization and ownership, may also be used to better understand and perhaps alleviate symptoms of phantom limb pain.

## Limitations and Conclusions

This study leaves us with several unanswered questions. We remain puzzled by the results of the control groups (scratching sound/rubber hand not visible & white noise/scratching sound not visible) of both studies. Given that there was no visual conflict in these conditions, we assumed that participants would consistently perceive their real hand as close to the zero error mark, thus displaying little to no proprioceptive drift. However, we did not see the result that we anticipated, with the exception of the control condition in the scratching sound condition of Study 1, which had a mean drift of 0.27 cm. The white noise condition, however, had a slightly (but not significantly) higher mean drift of 1.12. There is a small, but unlikely, chance that this variance was the result of the scratching sound, meaning that tactile and auditory information alone are capable of overriding proprioceptive information. Although auditory information is an important localizer, we found it difficult to believe that it could have such a large effect without the inclusion of visual stimuli. Instead, we attributed this anomaly to an unseen variable that existed between the two sample groups. To resolve this inconsistency, we decided to test the study on a within subjects sample, predicting that the higher sensitivity of the test would result in clearer data. Paradoxically, the control group of Study 2 saw a similar and more exaggerated pattern that we witnessed in Study 1. Once again, the scratching sound/rubber hand not visible condition displayed greater drift ($M = 3.2$) than the white noise/rubber hand not visible condition (M= 2.74). In addition to this, the control conditions in Study 2 displayed drastically higher accounts of proprioceptive drift than those of Study 1. Likewise, the experimental conditions in Study 2 had a larger effect than Study 1.

We can speculate a few possible explanations for why this abnormality occurred. First, are the limitations of Study 2. Due to time constraints and technical difficulties, we had to cease data collection at a less than optimal sample size of 19. Had we collected more data, we may have seen quite different results. A second explanation is that although Study 1 and Study 2 had a very similar structure, there was an important difference in the amount of time that participants spent undergoing the illusion. In Study 2, participants experienced twice the amount of trials as participants in Study 1. It is possible that this overall increase in time spent experiencing the Rubber Hand Illusion caused participants to succumb to its effects more readily and in higher intensity as the study went on. The relatively high misperceptions of hand location in the control conditions may also be a result of our procedure. In most studies on the Rubber Hand Illusion, experimenters obtain control data by asynchronously stroking the real and rubber hand. Thus, rather than remove the conflict of vision, they removed the conflict of tactile information. Unfortunately, this was more difficult to do in our study, as it required us to keep our scratching motions consistent with a timed, pre-recorded auditory cue. Thus, we had to compromise and use the absence of visual information, rather than asynchronous stroking, as our control. It is possible that by occluding the view of the rubber hand for 120 seconds, participants lost a reference point to judge from, and thus showed more inaccurate judgments of perceived hand location.

Future research is needed to fully understand the effects of auditory information on the Rubber Hand Illusion. It may be more effective to produce an authentic scratching sound, rather than a pre-recorded sound, when administering the stroking. This would allow researchers to use asynchronous stroking, rather than absence of vision, as a control condition. However, this brings with it several complications. For one, the novel scratching sound may be inconsistent across participants and experimenters, which would produce obvious complications to reliability. Also, it is crucial that localization comes only from the rubber hand in this illusion. It would be difficult to produce the scratching sound on the rubber hand alone, without generating the same noise on the skin of the real hand. In order to account for this, secure soundproofing equipment would be needed to muffle the authentic scratching sound coming from the real hand only. Future research should also consider whether the number of trials that participants experience affects the overall strength of the illusion.

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