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Susceptibility to the rubber hand illusion does not tell the whole body-awareness story

Nicole David · Francesca Fiori · Salvatore M. Aglioti

Abstract The rubber hand illusion (RHI) is an enigmatic illusion that creates a feeling of owning an artificial limb. Enthusiasts of this paradigm assert that it operationalizes bodily self-awareness, but there are reasons to doubt such a clear link. Because little is known about other functional contributions to the RHI, including effects of context-dependent visual processing and cognitive control or the ability to resolve intermodal conflict, we carried out two complementary experiments. In the first, we examined the relationships between the RHI and (1) body awareness, as assessed by the Body Perception Questionnaire (BPQ); (2) context-dependent visual processing, as assessed by the rod-and-frame test (RFT); and (3) conflict resolution, as assessed by the Stroop test. We found a significant positive correlation between the RHI-associated proprioceptive drift and context-dependent visual processing on the RFT, but not between the RHI and body awareness on the BPQ. In the second experiment, we examined the RHI in advanced yoga practitioners with an embodied lifestyle and a heightened sense of their own body in space. They succumbed to the illusion just as much as did yoga-naïve control participants, despite significantly greater body awareness on the BPQ. These findings suggest that susceptibility to the RHI and awareness of one's own body are at least partially independent processes.

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> If we are in search of the self, we can look either inward or outward.
>
> Ulric Neisser

The discussion about the bodily basis of the sense of self is as old as Descartes's proposed dualism between the body and the mind (Gallagher, 2011). Current views hold that bodily processes are major constituents of the sense of self and anchor self-awareness (Gallese & Sinigaglia, 2010; Legrand, 2007). Although the bodily self is also represented visually, most theorists and empiricists in the field agree that internal bodily signals are crucial for constructing a coherent sense of self (de Vignemont, 2010; Longo & Haggard, 2010; Lopez, Schreyer, Preuss, & Mast, 2012; Mehling et al., 2009; Walsh, Moseley, Taylor, & Gandevia, 2011). These signals arise from (1) proprioception—that is, the sense of one's own body/body parts in space, as signaled by receptors in, for example, muscle spindles; (2) interoception of other inner organs belonging to the autonomic nervous system; and (3) the position of the body, signaled by vestibular systems. A working definition was provided by Mehling et al.: "Body awareness is the perception of bodily states, processes and actions that is presumed to originate from sensory proprioceptive and interoceptive afferents and that an individual has the capacity to be aware of" (p. 4).

Before experimental induction of bodily illusions opened a new avenue for researchers in this field, it was difficult to investigate bodily awareness. One popular operationalization in the endeavor to examine bodily self-awareness has been the so-called *rubber hand illusion* (RHI; Botvinick & Cohen, 1998). The RHI is undoubtedly an enigmatic illusion, in which synchronous stroking of the observer's real and a

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visible rubber hand leads to the illusory subjective ownership of the rubber hand and/or mislocalization of the observer's own hand (Botvinick & Cohen, 1998). Despite the paradigm's popularity, increasing criticism has alleged that it manipulates bodily self-awareness (Folegatti, de Vignemont, Pavani, Rossetti, & Farnè, 2009; Rohde, Di Luca, & Ernst, 2011). For example, one criticism is that the illusion involves a rather narrow conception of the bodily self—that is, partial body ownership of a limb (Gallagher, 2000). This seems less crucial for self-consciousness than are more global aspects of bodily awareness (Blanke & Metzinger, 2009), such as attention to or awareness of the body as a whole or of other, more internal bodily processes. Some authors have proposed that the RHI is mainly based on the dominant role of vision (i.e., viewing a fake limb while one's own limb is hidden), which has the power to mislead other senses and drive the localization of touch, the proprioceptive location of ones' own limb, and even the irrational belief that the real hand is in a different place (Aimola Davies, White, Thew, Aimola, & Davies, 2010; Pavani, Spence, & Driver, 2000). This putatively dominant role of vision contrasts the notion of the RHI as an index of bodily awareness, which primarily relates to intero- or proprioceptive, but not necessarily exteroceptive, signals (Mehling et al., 2009). Alternatively, the RHI may result, at least in part, from cognitive-control processes such as the participant's inability to resolve conflicting information. That is, if the observer were able to withdraw from multisensory conflict during the RHI, susceptibility to the illusion might be diminished. This interpretation, which has not yet been tested, is supported by high interindividual variability in susceptibility to the illusion (Haans, Kaiser, Bouwhuis, & Ijsselsteijn, 2012) and by evidence that it results from multisensory conflict instead of a lost sense of body ownership (Folegatti et al., 2009).

Here, we sought to investigate the processes underlying the RHI—specifically, the illusion's relationship to body awareness—by asking the following: (1) Does the illusion really correlate with the awareness of one's own body and embodiment? That is, are people with almost daily training and focus of their own body in space less prone to the illusion? Or, alternatively, (2) does the illusion correlate with a dominant influence of visual context (as, e.g., also advanced by the aforementioned notion of visual capture) or the inability to disengage from distracting information and resolve intermodal conflict? Thus, to clarify this issue, we carried out two complementary experiments.

In Experiment 1, participants were tested using the following four measures: (1) the RHI and (2) the Awareness Scale of Body Perception Questionnaire (BPQ; Porges, 1993), as two potential operationalizations of body awareness, and (3) the rod-and-frame test (RFT; Witkin & Asch, 1948) and (4) the Stroop interference test (Stroop, 1935), as operationalizations of visual-context processing and intermodal conflict resolution. Individuals who are able to ignore a misleading context, disengage their attention, and focus on the relevant feature or sensory/cognitive domain will perform better on the RFT and the Stroop test. What if the same process contributes to multisensory processing during the RHI? A correlation between the RHI indices and participants' performance on the RFT or Stroop test would support this idea. By contrast, a covariation of RHI indices and BPQ scores would indicate a relationship between the illusion and body awareness.

Another ecologically valid way of investigating the relationship between body awareness and the RHI would be to test body experts. Thus, in Experiment 2 we examined for the first time whether or how the RHI is modulated by an increased sense of one's own body. We tested a special class of body experts—namely, advanced yoga practitioners. These individuals are characterized not only by strong, almost daily, focus on the perception of their body in space (i.e., in vestibular–proprioceptive terms), but also by an overall embodied lifestyle. This novel approach offered a unique opportunity to explore the construct validity of the RHI with respect to bodily self-awareness. Furthermore, virtually nothing is known about the effects of yoga practice and bodily perception tasks. We predicted that yoga practitioners would report higher body awareness on the BPQ than would yoga- and meditation-naïve controls. If body awareness and the RHI are truly linked, yoga practice should modulate the strength of the illusion. The absence of any relationship would indicate that the RHI does not primarily relate to bodily self-awareness.

Experiment 1

Methods

Participants A group of 20 right-handed volunteers (mean age 36.0 years, range 26 to 52 years; 12 females, eight males; mean education 16.2 years) with normal or corrected-to-normal vision participated in this study. All participants gave informed consent and were paid €7.50/h for their participation. All procedures were approved by the ethics committee of the Santa Lucia Foundation and were in accordance with the ethical standards of the Declaration of Helsinki. Participants were naïve as to the purpose of the study.

Assessment of the rubber hand illusion To assess the RHI, we used a custom-built experimental apparatus and followed the standard procedures (Lopez, Lenggenhager, & Blanke, 2010; Tsakiris & Haggard, 2005). Both of the participants' hands were passively placed at fixed positions inside a large wooden box (which was covered by a two-way mirror; see Fig. 1) and were thus occluded from vision. When the

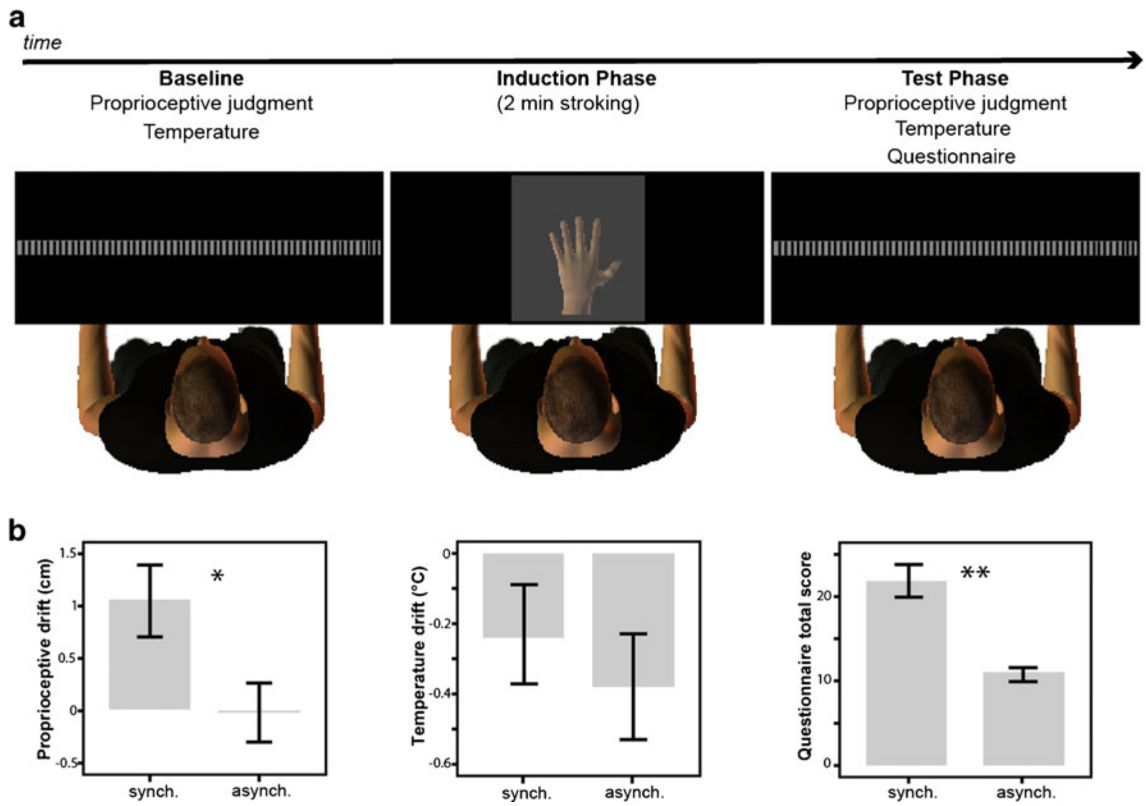

Fig. 1 The rubber hand illusion experimental protocol and results (Exp. 1). (**a**) Participants placed both of their hands inside a black wooden box. The box was covered with a two-way mirror, which showed the reflection of a ruler when the room lights switched on. Participants verbally reported the position of their own left index finger by means of the ruler (proprioceptive judgment). When the outside lights were switched off, participants looked at a left rubber hand, which had become visible through the two-way mirror. The experimenter stroked the rubber hand synchronously or asynchronously with the participants' own left hand using two brushes (not visible in the figure). After 2 min, the room lights were immediately switched on to reveal the ruler's reflection, and participants again indicated the position of their left index finger. After the participants' hand temperature was taken, they filled out the RHI questionnaire. (**b**) The three panels show the average effects of synchronous versus asynchronous stroking on proprioceptive drift (i.e., the shift, in centimeters, of the estimated position of the real toward the rubber hand), temperature drift (i.e., cooling of the participant's real hand, in degrees Celsius), and total scoring on the RHI questionnaire. Except for temperature, these measures were significantly higher for synchronous than for asynchronous stroking, indicating a positive RHI. Error bars reflect *SEM*s

overhead lights were switched "off" and the lights inside the box were switched "on," participants saw a rubber hand (i.e., a realistic model of a left hand) inside the box directly in front of them. Otherwise, they saw a ruler reflected in a mirror (Fig. 1). The ruler was located 23 cm above the mirror at the same gaze depth as the rubber hand. The distance between the participants' left index finger and the rubber hand was 19 cm. Each participant underwent two sessions—that is, of synchronous and asynchronous stroking. An hour break separated the two sessions, to prevent carryover effects. The order of sessions was randomized across participants. In each session, participants made three prestimulation estimations of their left index finger at baseline by naming the corresponding position of the ruler reflected in the mirror (Fig. 1). In each of these estimations, the ruler had a different, random offset (for details, see Tsakiris & Haggard, 2005). After these baseline estimations, the room lights were switched off and the lights inside the box were switched on (i.e., making the rubber hand visible). The experimenter stroked the participant's left hand and the rubber hand using two identical brushes. In the "synchronous" session, the participant's hand and the rubber hand were stroked simultaneously at the same location. In the "asynchronous" session, the stroking of the real and the rubber hand did not coincide, temporally or spatially. After 2 min, the room lights were switched on, and the participant estimated the position of his or her own left index finger. Skin temperature was also measured before and after stroking on the same spot on the back of the participant's hidden left hand using a hand-held thermometer (IFR100, Microlife, Switzerland), because the illusion has been associated with cooling of the observers' real hand (Kammers, Rose, & Haggard, 2011; Moseley et al., 2008).

We assessed three standard dependent variables in each stroking session (post- minus prestroking baseline): (1) the subjectively perceived "proprioceptive drift" (in centimeters) of a participant's real left hand, (2) the temperature of the participant's left hand (i.e., "cooling," in degrees Celsius), and

(3) the standard 9-item self-report questionnaire, which was rated on the 7-point Likert scale originally devised by Botvinick and Cohen (1998).

Body Perception Questionnaire To test whether the RHI is related to body awareness, we had participants complete the Awareness subscale of the BPQ (Porges, 1993). We asked them to respond to 45 items to determine how aware they were of their body processes in most situations (e.g., whether they experienced goose bumps, swelling of the body or body parts, muscle tension in the legs or arms, sweating palms, etc.). Awareness was rated on a 5-point scale (1 = *never aware*, 5 = *always aware*). The total score was obtained by summing all 45 responses and dividing by the number of questions (Porges, 1993). We predicted that if the RHI and body awareness are related, increased self-reported awareness on the BPQ might diminish the strength of the illusion.

The rod-and-frame test An individual who is field-dependent is highly influenced by the context of the visual scene during perception (Witkin & Asch, 1948; Witkin, Dyk, Faterson, Goodenough, & Karp, 1962). The RFT measures visual-context effects (i.e., of a tilted frame surrounding a vertical rod) on the perception of gravitational verticality, which is normally supported by interactions between visual and internal (e.g., proprioceptive and vestibular) signals. For example, patients with damage to the vestibular system or vestibular disorders show larger deviations of the subjective visual vertical during the RFT, suggesting that vestibular signals are necessary to counteract the perceptual effects of a tilted frame (Lopez, Lacour, Magnan, & Borel, 2006; Vibert, Häusler, & Safran, 1999). Moreover, on the RFT representations based on egocentric coordinates are in conflict with an object-centered/allocentric visual representation (Zoccolotti, Antonucci, Daini, Martelli, & Spinelli, 1997). We predicted that if visual-context dependency plays into the RHI, a biased subjective visual vertical might positively correlate with the RHI.

The RFT was carried out using a custom-built black wooden apparatus previously described in Zoccolotti et al. (1997; see our Fig. 2). Each side of the square frame measured 96 cm (34º of visual angle). The rod anchored at the center of the frame was 15 cm long (i.e., 5º). These dimensions (i.e., large frames) particularly probe vestibular contributions to the subjective visual vertical (Daunton & Thomsen, 1979; Zoccolotti et al., 1997). The rod and frame were outlined with 1.2-cm-wide fluorescent tape. The experimenter, who was located behind the apparatus, operated it by changing and measuring the angle of the rod and frame. Participants (who had their eyes closed) were led into a pitch-black room and seated on a chair in front of the apparatus. The distance between their eyes and the rod was 150 cm. The experimenter asked them to open their eyes and to give verbal instructions about how to adjust the rod to the earth-vertical, in binocular vision and ignoring the frame. The rod was tilted 11º or 22º clockwise (CW) or counterclockwise (CCW), and the frame was tilted 33º CW or CCW or was not tilted (0º; see Fig. 2—the values are analogous to those of Zoccolotti et al., 1997). Thus, we used 12 conditions with three trials each. The conditions were presented randomly. A frame tilt usually leads to errors; that is, the tilt systematically biases the subjective visual vertical related to the rod. To maximize performance, participants have to gather information from nonvisual bodily cues (proprioceptive, somatosensory, and vestibular). We assessed the end angle of the rod per condition (in degrees) as a dependent variable, collapsing it across the CW and CCW conditions. For correlation purposes, we calculated the mean absolute end angle (i.e., deviation from the earth-vertical) collapsed across the 11º and 22º conditions, which did not differ from each other, when the frame was tilted [Friedman test; $\chi^2(7, n = 20) = 10.511$, $p > .05$, n.s.].

The Stroop interference test We administered a paper-and-pencil version of the Stroop color–word interference test (Jensen & Rohwer, 1966; Stroop, 1935). Shum, McFarland, and Bain (1990) proposed that the Stroop test requires selective processing of one visual/semantic feature while blocking out the ongoing processing of another. We assessed reaction times and numbers of errors in (1) color name reading (i.e., "red," "blue," "green," and "yellow"), (2) color denomination (i.e., red, blue, green, and yellow squares were shown), and (3) color–word interference (i.e., color names were printed in a different color; e.g., "red" written in blue). Reaction times and errors increased in Part 3 of the test as a result of response conflict, difficulty in warding off distractions, or failure of selective attention (Lezak, Howieson, & Loring, 2004; Shum et al., 1990). To test whether the RHI is related to such failures, the degree of Stroop interference was computed by subtracting performance on Part 3 from that on Part 2 and correlating it with RHI indices. We predicted that, if the ability to resolve or ignore intermodal conflict contributes to the RHI, conflict resolution might correlate negatively with the RHI.

Results

Rubber hand illusion Overall, our results indicated successful application of the RHI (see Fig. 1b). That is, after synchronous relative to asynchronous stroking, participants, on average, showed a significantly stronger mislocalization of their own hand [sync, mean 1.05 cm, range −1.8 to 4.3 cm; async, mean −0.02 cm, range −2.3 to 1.7 cm; $t(19) = 2.568$, $p = .019$] and a higher overall score on the RHI questionnaire

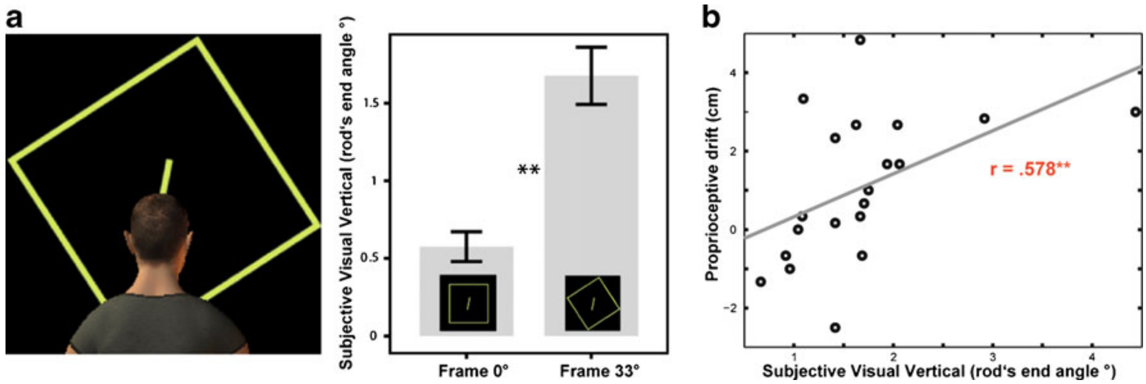

Fig. 2 Rod-and-frame test experimental setup and results (Exp. 1). (**a**) Participants sat in front of a large fluorescent frame in an otherwise pitch-black room (left panel). The frame was either tilted or vertical and surrounded a tilted rod, which participants had to verbally set to the vertical (i.e., end angle of the rod = 0º). Displayed is the effect of the tilted frame on the subjective visual vertical, as indexed by the end angle of the rod (middle panel). Error bars reflect *SEM*s. Participants showed a significantly higher deviation of the subjective visual vertical (i.e., a larger deviation from 0º) for the earth-vertical when the frame was tilted as compared to when it was not. (**b**) This effect of visual context was significantly correlated with the degree of proprioceptive drift during the RHI paradigm (see Fig. 1)

[sync, mean 21.9, range 10 to 43; async, mean 11.1, range 9 to 25; $t(19) = 7.429$, $p < .001$]. We did not, however, detect any differential change in hand temperature after synchronous as compared to asynchronous stroking [sync, mean −0.23º, range −1.2º to 1.6º; async, mean −0.38º, range −1.9º to 0.5º; $t(14) = 0.934$, $p = .362$]. Thus, this variable was excluded from the subsequent correlational analyses.

Body Perception Questionnaire Participants' perception of their bodily responses on the BPQ Awareness subscale was consistent with normative data (mean 3.1, range 2.1–4.4; Porges, 1993).

Rod-and-frame test As expected, participants set the rod more vertically when the frame surrounding was vertical (mean end angle of rod 0.6º, range 0º–1.4º) as compared to when the frame was tilted 33º (mean end angle of rod 1.7°, range 0.7°- 4.4°) [$t(19) = -5.53$, $p < .001$; see Fig. 2]. Thus, verticality judgments on the rod were dominated by the biasing visual context of the frame.

Stroop interference test As expected, participants showed interference-related slowing [mean RT increase 19.4 s, range 6.3 to 30.5 s; $t(19) = -14.97$, $p = .000$] and an increased error rate [mean percentage of errors 2.6 %, range 0 % to 5 %; $t(19) = -2.90$, $p = .009$] when naming the color of a semantically incompatible word.

Correlation analyses Difference scores (i.e., synchronous minus asynchronous stroking) for proprioceptive drift and the total score on the RHI questionnaire were calculated to test for covariations with RFT performance, BPQ scoring, and Stroop interference via Spearman's rank correlations. These were tested at the Bonferroni-adjusted significance level of $p < .005$.

We found no significant relationship of any RHI index (i.e., drift or questionnaire score) with body awareness on the BPQ (all r_{sp}s < |.132|, all ps > .289), which suggests that no significant relationship exists between the two.

We found evidence of a relationship between the RHI and a biased subjective visual vertical on the RFT. That is, participants with higher proprioceptive drift also showed larger bias (i.e., more deflection from 0º) in their verticality judgments when the visual context was misleading ($r_{sp} = .578$, $p = .004$; see Fig. 2b). There was an inverse relationship between RHI questionnaire scores and verticality perception, which did not survive correction for multiple comparisons ($r_{sp} = -.471$, $p = .018$, n.s.).

Also, interference-related slowing (i.e., reaction times) on the Stroop test did not significantly correlate with RHI drift or questionnaire score (all r_{sp}s < |.313|, all ps > .089). Nevertheless, participants who showed a larger proprioceptive drift as a result of synchronous stroking also made more interference-related errors on the Stroop test ($r_{sp} = .472$, $p = .018$; did not survive correction for multiple comparisons).

Experiment 2

Method

Participants A group of 14 advanced yoga practitioners (nine females, five males; mean age 38.4 years, range 28–53 years; mean education 18.3 years, range 13–25 years) participated in this study. They were compared with 14 control participants from Experiment 1 (six females, eight males; mean age 38.6 years, range 26–52 years; mean education 17.4 years, range 11–26 years), who had no yoga or meditative experience and who matched the yoga group for age [$t(26) = -0.101$, $p = .917$], gender ($\chi^2 = 1.29$, $p = .256$), and education [$t(26) = 0.505$, $p = .618$]. To keep the sample of yoga practitioners as homogeneous as possible, all of the participants practiced the same kind of yoga—namely, Ashtanga yoga. This is a particularly body-focused type of yoga (Benavides & Caballero, 2009; Varambally & Gangadhar, 2012), which is characterized by the synchronization of a fixed series of postures, breathing, and body-focused points of gaze. This type of yoga focuses on the nonvisual experience of the body in space, so that practitioners gain a better sense of body proprioception and vestibular signals in order to correctly execute the yoga postures (see, e.g., Fig. 3a). It is taught by means of supervised self-practice, during which students progress at their own pace, without verbal instructions from the teacher (only physical adjustments) or visual feedback (no mirrors, gaze is focused). We included only practitioners who had regular, continuous Ashtanga yoga practice and had reached the expert level (mean times/week 5.1, range 3–7 times; mean years of regular practice 6.1, range 1.5–12 years; all performed the intermediate or advanced Ashtanga yoga series). All participants gave their informed consent and were paid €7.50/h for participation. They were naïve as to the purpose of the study.

The RHI was investigated, as in Experiment 1. Body awareness was also assessed with the Awareness subscale of the BPQ (Porges, 1993; see Exp. 1).

Results

The yoga practitioners reported significantly higher body awareness on the BPQ (mean score 3.6, range 2.1–4.6) than did the control participants (mean score 3.1, range 2.1–4.4) [$t(26) = 2.172$, $p = .039$; Fig. 3b].

On the RHI, the yoga group's performance was not significantly different from that of the control group. Yoga practitioners showed a slightly more pronounced proprioceptive drift (for all variables, measured as sync – async as compared with the prestroking baseline; mean_{Yog} 1.7 cm, range −3.3 to 10.2 cm) and cooling effect (mean_{Yog} –0.1º, range −6.8º to 2.6º) than did controls (proprioceptive drift, mean_{Con} 0.7 cm, range −2.5 to 4.8 cm; cooling, mean_{Con} 0.2º, range −1.2º to 2º). Closer inspection of the data revealed that this observation was mainly driven by one outlier in the yoga group, who showed a proprioceptive drift (10.1 cm) and cooling effect (−6.8º) more than two standard deviations from the group mean. Excluding this outlier (rectified drift, mean_{Yog} 0.9 cm, range −3.3 to 4.3 cm; rectified cooling, mean_{Yog} 0.4º, range −1.3º to 2.6º), the group differences were not significant with respect to proprioceptive drift [$t(16.6)$[1] = 1.329, $p = .202$], physical hand cooling [$t(25) = −0.448$, $p = .658$], and scores on Botvinick and Cohen's (1998) RHI questionnaire [$t(26) = −1.011$, $p = .321$; see Fig. 3c].

Body awareness on the BPQ did not correlate significantly with any RHI index in either the yoga (all r_{sp}s < |.287|; all

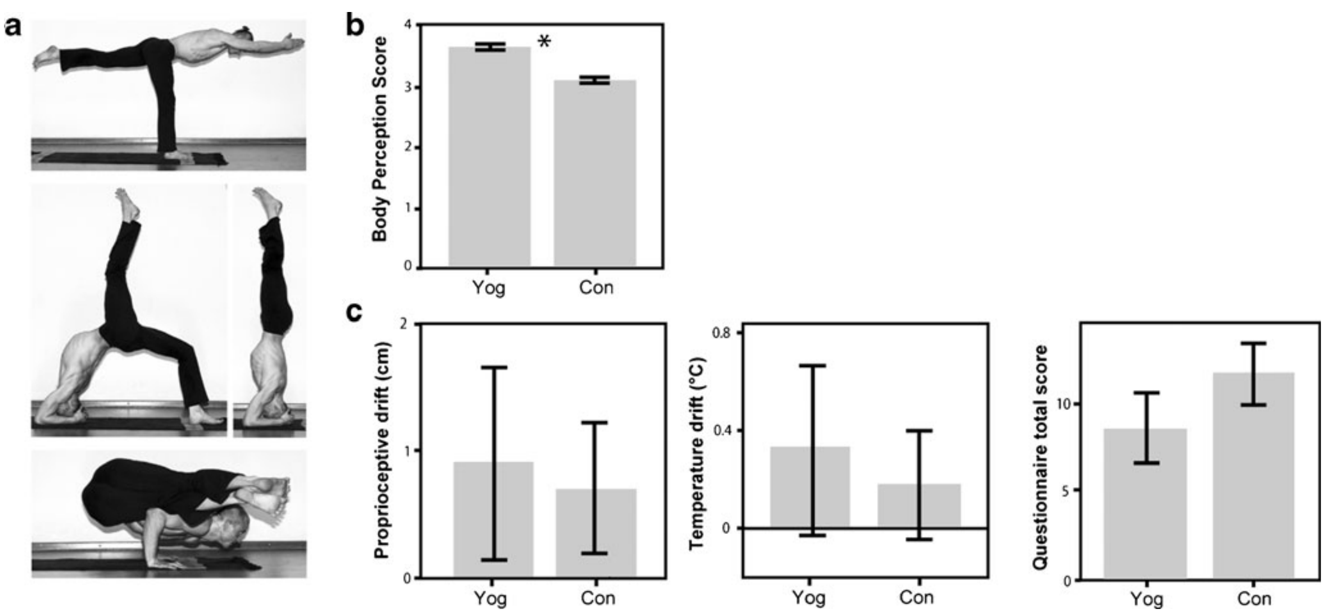

Fig. 3 Body awareness and the rubber hand illusion in advanced yoga practitioners (Exp. 2). (**a**) Example postures of advanced Ashtanga yoga practitioners, which demonstrate the high requirements for vestibular–proprioceptive abilities (with the kind permission of R. Steiner, www.AshtangaYoga.info). (**b**) Scores on the Body Perception Questionnaire for the yoga and control groups. Higher values indicate high/frequent awareness of ongoing bodily processes. Error bars reflect *SEM*s. Yoga practitioners scored significantly higher on the Body Perception Questionnaire. (**c**) The three panels show, for each group, the differences between synchronous minus asynchronous stroking (relative to the prestroking baseline) for proprioceptive drift, temperature drift/cooling of the real hand, and scoring on the RHI questionnaire. Error bars reflect *SEM*s. No significant group differences emerged between yoga practitioners and controls

$ps > .320$) or the control (all r_{sp}s < |.185|; all $ps > .517$) group, or across groups ($N = 28$; all r_{sp}s < |.188|; all $ps > .348$).

Discussion

In two complementary experiments, we set out to investigate the validity of the RHI as an operationalization of bodily awareness and to test alternative interpretations of the illusion, which relate it to visual-context dependency and conflict resolution. The RHI did not correlate with self-reported body awareness, as assessed by the Body Perception Questionnaire, and yoga practitioners with an embodied lifestyle, regular training of their own sense of body in space, and increased self-reported body awareness showed no altered RHI performance, as compared with controls. These results suggest a weaker link between the RHI and bodily self-awareness than has previously been assumed. Instead, we found evidence of a relationship between visual-context dependency and RHI-related proprioceptive drift.

The rubber hand illusion and body awareness

Bodily self-awareness hinges on signals arising from within the body (e.g., Mehling et al., 2009). Classically considered a multisensory phenomenon (Blanke, 2012; Ehrsson, Holmes, & Passingham, 2005; Tsakiris & Haggard, 2005), a strong bodily basis for the RHI has also been posited. For example, Tsakiris, Tajadura-Jiménez, and Costantini (2011) used a heartbeat interoception task, which could be considered an operationalization of bodily self-awareness confined to cardiac awareness. They found that individuals who were less accurate in counting their heartbeats showed larger RHI effects (Tsakiris et al., 2011). By contrast, we found no link between behavioral (i.e., proprioceptive drift) or subjective (i.e., self-reported questionnaire scores) indices of the RHI and either self-reported awareness of bodily processes on the BPQ, in Experiment 1 (Porges, 1993), or an embodied lifestyle and regular training of an individual's own body in space, in Experiment 2. Importantly, yoga practitioners also scored higher on the BPQ, indicating increased perception of ongoing bodily processes as compared with nonbody experts. The BPQ includes items on awareness of all sorts of bodily processes, such as body swaying, speed of breathing, muscle tension, joint pain, clumsiness/bumping into people, and so forth. Therefore, both our operationalizations are more in line with the notion of bodily self-awareness "as awareness of one's own body postures, of one's own body parts and limbs, with their position, with their boundaries, and with their being at rest or in movement" (Gallese & Sinigaglia, 2011, p. 124). Hence, our results cannot be directly compared with those of Tsakiris et al. (2011; e.g., the BPQ includes only one item on cardiac awareness). Indeed, Critchley, Wiens, Rotshtein, Öhman, and Dolan (2004) found that heartbeat detection and body awareness as indexed by the BPQ are not correlated. The BPQ is a subjective self-report measure that might not be sensitive enough to correlate with more implicit measures, such as proprioceptive drift; nevertheless, we found no relationship with its equivalent, the RHI questionnaire. It is worth noting that behavioural and subjective indices of the RHI have been dissociated (Ionta, Sforza, Funato, & Blanke, 2013; Rohde, Di Luca, & Ernst, 2011).

To reconcile the present findings with Tsakiris et al.'s (2011) work, one may conclude that the RHI is specifically linked to heartbeat interoception (Tsakiris et al. 2011), possibly via a common process. Selective attention might represent such a common process. In fact, Tsakiris et al. (2011) hypothesized that people with bad interoception have more attention resources left for multisensory processing during the RHI; thus, they exhibit a stronger illusion. Conversely, Matthias, Schandry, Duschek, and Pollatos (2009) found a significant correlation between high interoceptive awareness in heartbeat counting and better performance on tasks measuring selective and divided attention to external, non-body-related visual events. What if selective or divided attention (e.g., to visual events such as the sight of the rubber hand) were also able to explain some variance on the RHI? The present findings suggest that the illusion may partially relate to cognitive functions such as the subject's ability to disengage attention or reduce cognitive–perceptual interference, as we discuss in the following section.

The influence of visual context and the rubber hand illusion

The RHI is thought to reflect visuotactile integration during which internal veridical signals from proprioception are systemically distorted as a consequence and manifested in a proprioceptive mislocalization of one's own hand. Botvinick and Cohen (1998) conceived this proprioceptive drift as resulting from the interaction of proprioception, vision, and touch. A multisensory interaction is also immanent to the rod-and-frame test (i.e., of vision, proprioception, and vestibular processing), suggesting commonalities between the RHI and RFT. Indeed, Experiment 1 revealed a significant relationship between the two—that is, the more biased an observer was by visual context, the higher was the observer's proprioceptive drift. Previous evidence was in line with the observed relationship between vision and proprioception. For example, individuals with eating disorders show a stronger proprioceptive drift than do healthy controls (Eshkevari, Rieger, Longo, Haggard, & Treasure, 2012). These patients show a characteristic disturbance of their body image (i.e., the *visual* sense of their own physical appearance)—a construct related but not identical to body awareness, which is typically conceived as being nonvisual. It is also in line with evidence that individuals who rely more on vision may show unstable body balance

(Golomer, Cremieux, Dupui, Isableu, & Ohlmann, 1999; Isableu, Ohlmann, Cremieux, & Amblard, 1997). Thus, instead of listening to what their proprioceptive–vestibular systems tell them, on both the RFT and RHI, observers might be more strongly guided by exteroception (see also Lopez, Bieri, Preuss, & Mast, 2012; Lopez et al., 2010). In sum, the present correlation suggests a key role of visual capture for the RHI (Pavani et al., 2000), especially in driving proprioceptive drift.

Two other interpretations of the illusory tilt of the rod in the RFT also seem plausible for the RHI. First, in both phenomena, object-centered or allocentric representations might dominate over egocentric coordinates (Makin, Holmes, & Ehrsson, 2008; Zoccolotti et al., 1997). For example, Makin and colleagues previously suggested that the observed stroking of the rubber hand, which is represented in an object- or, better, hand-centered reference frame, evokes re-referencing of the felt stroking of the real hand. The present evidence supports Makin et al.'s model. Moreover, very recent data show that visual-field dependence on the RFT correlates with the direction of visuospatial perspective in the whole-body variant of the RHI (Pfeiffer et al., 2013). Second, selective attention abilities or cognitive control might play a role in both the RHI and RFT. In the RFT, some observers cannot disengage their attention from the given visual context in order to focus on the relevant element—that is, the rod (Li & Matin, 2005). Similarly, attention can be directed to states of the self, including signals arising from the body, or to the outside world. Attention allocated to the latter might come at the expense of attention to one's own body, such as vestibular–proprioceptive signals during the RFT and RHI. Selective attention might interact with visual–tactile integration during the RHI, particularly when competition to focus elsewhere is low (Talsma, Senkowski, Soto-Faraco, & Woldorff, 2010). Evidence that the RHI can temporarily ameliorate visuospatial neglect and the here-reported trend between the extent of Stroop interference and the degree of proprioceptive drift supports this view (Kitadono & Humphreys, 2007). Fluctuations in attention might also account for the RHI variability seen across individuals (Haans et al., 2012), which cannot be accounted for only by an automatic process such as multisensory integration.

Caveats and alternative accounts

Here, we discuss some controversies and alternative accounts related to the RHI that are important for putting the present results into perspective. First, proprioceptive drift, for which we reported a significant correlation with visual-context dependency in the RFT (Exp. 1), has been criticized as an inadequate measure. Rohde et al. (2011), for example, argued that a drift also occurs after asynchronous stroking or even in the absence of stroking, and that the drift does not necessarily go hand in hand with more explicit (i.e., questionnaire) indices of the illusion. Thus, the processes underlying proprioceptive drift might be distinct from those causing the subjective RHI. Our findings might be in line with the notion that the different RHI phenomena are distinct and underpinned by different mechanisms (cf. Moseley, Gallace, & Spence, 2012). Specifically, proprioceptive drift—but not subjective RHI—might be related to processes involved in context-dependent visual processing on the RFT. Second, our findings suggest only weak somatic associations with the RHI. Nevertheless, physiological changes, such as a drop in temperature after synchronous stroking of the stimulated hand, suggest the opposite (Kammers et al., 2011; Moseley et al., 2008). The authors do not, however, rule out that the real hand's cooling may simply be due to multisensory conflict (Kammers et al., 2011; Moseley et al., 2008). We tested the relationship between the RHI and response conflict or conflict resolution and found a trend toward a possible relationship between an interference-related increase in error rates on the Stroop test (in which two different systems compete) and proprioceptive drift. In any case, this possibility requires further testing.

Conclusion

Here we have provided twofold evidence (e.g., from psychometric correlations and a class of body experts) that the link between the RHI and body awareness is weaker than has been assumed. The aim of the present study was not to endorse an alternative account to the commonly accepted view that multisensory integration underlies the RHI or bodily self-awareness in general (Blanke, 2012; Botvinick & Cohen, 1998; Ehrsson et al., 2005; Tsakiris, 2010). Instead, the present findings suggest that a more intricate and multifaceted interplay of factors (e.g., selective attention, visual context, and conflict processing) might act together with multisensory integration during the RHI.

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