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The monologue of the double: Allocentric reduplication of the own voice alters bodily self-perception

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ABSTRACT

During autoscopic phenomena, people perceive a double of themselves in extrapersonal space. Such clinical allocentric self-experiences sometimes co-occur with auditory hallucinations, yet experimental setups to induce similar illusions in healthy participants have generally neglected acoustic cues. We investigated whether feeling the presence of an auditory double could be provoked experimentally by recording healthy participants' own versus another person's voice and movements using binaural headphones from an egocentric (the participants' own) and an allocentric (a dummy head located elsewhere) perspective. When hearing themselves allocentrically, participants reported feeling a self-identified presence extracorporeally, an arguably distinct quality of autoscopy. Our results suggest that participants without hallucinatory experiences localized their own voice closer to themselves compared to that of another person. Explorative findings suggest that distinct patterns for hallucinators should be further investigated. This study suggests a successful induction of the feeling of an acoustic doppelganger, bridging clinical phenomena and experimental work.

1. Introduction

The subjective location and spatial boundaries of the body are considered fundamental aspects of bodily self-consciousness (Blanke et al., 2015). Yet, they might be dramatically altered in clinical conditions. During autoscopic or doppelganger phenomena, for example, people perceive themselves or a reduplication of themselves in extracorporeal space. These hallucinations are accompanied by a strong self-identification with the double and bodily sensations (Brugger et al., 1997). In an effort to better understand such conditions and their underlying neurophysiological mechanisms, experimental setups to induce illusions evoking similar states of altered bodily self-consciousness in healthy individuals have been developed (Ehrsson, 2007; Lenggenhager et al., 2007). One such case is an allocentric full-body illusion, where participants see a body in front of their actual location being stroked on the back while they are simultaneously stroked on their own back (Lenggenhager et al., 2007). These multisensory cues stimulate self-identification with the allocentrically seen body, resulting in changes of perceived self-location and peripersonal space (Lenggenhager et al., 2009; Noel et al., 2015). Similar paradigms have almost exclusively used visual capture of other sensations to evoke such autoscopy-like illusions, which reflects the prevailing role of vision in the experimental study of bodily self-consciousness. However, clinical evidence suggests a strong link between disorders of bodily self-consciousness and conditions with prevalent auditory-verbal hallucinations (Hugdahl et al., 2008; Klaver & Dijkerman, 2016; Salomon et al., 2020). Furthermore, while autoscopic phenomena are

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primarily visual hallucinations (e.g., Brugger, 2002), they sometimes are accompanied by auditory experiences including auditory doppelgänger (Lukianowicz, 1958; Posey & Losch, 1983). Notably, not only psychotic individuals seem more susceptible to alterations of bodily self-consciousness (Klaver & Dijkerman, 2016; Nelson et al., 2014), but prevalent symptoms in the condition are both auditory-verbal hallucinations (Alderson-Day et al., 2020) and abnormal bodily self experiences (Di Cosmo et al., 2018; Nelson et al., 2013). And beyond schizophrenia and psychosis, these symptoms occur in other conditions such as dissociative and anxiety disorders (e.g., PTSD; Wearne et al., 2020). Hallucinations and related phenomena have been argued to result from distorted self-monitoring and self-related predictions (Blakemore et al., 2000; Corlett et al., 2019; McGuire et al., 1995), which may be linked to distortions of self-other distinction (Asai, 2016; Jardri et al., 2011; Plaze et al., 2015). In fact, experimentally inducing the feeling of a presence through conflicting sensorimotor stimulation has shown to alter the perceived loudness of quiet voices (Orepic et al., 2021). Following this, a link between altered bodily self-consciousness and altered self-related auditory-vocal processes (such as auditory-verbal hallucinations) is likely, but has been seldom addressed directly in the abovementioned experimental research. We developed a protocol to systematically study the vocal and acoustic contribution to alterations of bodily self-consciousness by duplicating the acoustic self (voice, movement, and footsteps) of healthy participants' in allocentric space. Blindfolded healthy volunteers either heard themselves (self-allocentric) or another gender-matched person (other-allocentric) in extracorporeal space or heard themselves egocentrically (self-egocentric). This was done by using spatially accurate binaural recordings.

We assessed explicit changes of bodily self-consciousness using a questionnaire assessing self-identification, agency, presence, and the feeling of a presence, as well previously suggested behavioral (changes in self-related spatial perception) and physiological measures (skin temperature and cardiac activity), and exploratively assessed participants' hallucination history through a questionnaire. Given that the feeling of a self-identified presence is a specific quality of autoscopic experiences (Brugger, 2002), for the questionnaire responses, participants were expected to report a similarly higher feeling of a presence for both allocentric conditions compared to the egocentric one. To confirm the simile to autoscopia for the self-allocentric condition, participants were also expected to self-identify with the acoustic cues similarly higher in both self-conditions compared to the other-allocentric condition. Behaviorally, we predicted a reduction in the perceived distance between the participants' location and the sound source for the self- compared to the other-allocentric condition based on previous findings from allocentric full-body illusions (Lenggenhager et al., 2007; 2009; Noel et al., 2015). In such studies, participants located the allocentric double closer to themselves, presumably following self-identification with the extracorporeal (visual) cues; thus, similar findings were expected for the allocentric self-related auditory cues. Given the potential link between auditory-verbal hallucinations and alterations of bodily self-consciousness—and in particular reduced self-other distinction (Plaze et al., 2015; Salomon et al., 2020)—we expected that participants with previous hallucinatory experiences would display a smaller difference in the perceived distance between self- and other-allocentric stimulation. Hallucination history in healthy participants was assessed with a 2-item questionnaire due to its simplicity and since it has been applied for assessment in the general population (Johns et al., 2002). Supporting this assessment in our sample, the prevalence of hallucinatory experiences in non-clinical populations has been reported to not be rare (Johns et al., 2002; Posey & Losch, 1983), however reported incidence varies widely according to the used method (Beavan et al., 2011). Beyond these subjective and behavioral measures, we anticipated a temperature reduction for the self-allocentric condition compared to the others, as similar effects have been found for an allocentric (visual) full-body illusion (Salomon et al., 2013), allegedly due to a disruption of self-related homeostatic processes (Moseley et al., 2008; Salomon et al., 2013). Increased heart rate for the same condition was expected as a reflection of emotional arousal (Kokkinara & Slater, 2014) and given that hearing self-attributed vocal cues is a trigger of basic physiological processes (Chang et al., 2013; and more recently, self-attribution of a heard voice was found as a trigger of emotional responses (Goupil et al., 2021)).

2. Materials and methods

2.1. Participants

Twenty-six right-handed healthy volunteers with no history of psychiatric or neurological disorders participated in the experimental procedure, data from one subject was removed from all the measurements due to technical problems during the audio recording, with twenty-five remaining (age: $M = 25.9$, $SD = 4.7$; 19 females). The sample size was chosen based on relevant studies in the field using auditory cues to manipulate bodily self-consciousness, which used a maximum sample size of 26 participants (Tajadura-Jiménez et al., 2012; 2018; 2015). For our study, participants were recruited via mailing lists of the Department of Psychology of the University of Zurich and through personal contacts. They provided informed consent and received either course credit or financial compensation (20 CHF). All protocols were approved by the Ethics Committee of the Faculty of Arts and Social Sciences at the University of Zurich (Approval Number 17.12.15). The studies were performed according to the ethical standards of the Declaration of Helsinki.

2.2. Stimulation apparatus

Two Roland CS-10EM In-ear Monitors (Roland Corporation, Japan) were used as binaural microphones to record the sound, and as earphones to play it back and for online monitoring. A Zoom H6 Handy Recorder (Zoom corporation, Japan) was used as an analogue-to-digital converter for the allocentric recordings, and a Zoom H1n (Zoom Corporation, Japan) for the egocentric recordings. Both converters recorded at a rate of 48 kHz and 24 bits. Audio management, including synchronizing, recording, monitoring, and playback was performed using Max 7 (Cycling 74, CA, USA). This software was running on a Macbook pro computer (Apple, CA, USA) with 2.3 quad-core Intel Core i7 processor and 16 GB of RAM running OS X 10.9.5 Mavericks. A 3D printed dummy

head with a pair of gum binaural ears attached (Free Space Pro II; 3DIO, WA, USA; the ears were used without the built-in microphones) with a set of the Roland binaural microphones positioned inside the ears for recording the allocentric sounds.

For visual stimulation and interaction with a virtual 3D space, an Oculus CV1 head-mounted display (with detached headphones) was used together with an Oculus Touch controller and four Oculus Sensors (Oculus VR, Irvine, CA, USA). The sensors tracked the head-mounted display and the controller with six degrees of freedom. The control system was designed using Unity 2017 for displaying the 3D virtual room, depicting a virtual laser pointer, mapping and storing the 3D coordinates of the Oculus Touch controller, sending triggers to the audio software, and displaying the questionnaires on a computer screen. The system ran on a PC (Nvidia Geforce GTX 1070 8 GB; 16 GB RAM; Intel Core (TM) i7-8700, 3.2 GHz; Windows 10).

3. Procedure

3.1. Stimuli preparation

The two sets of binaural microphones were used for recording spatially accurate tridimensional sounds from different perspectives. One set was positioned in the ears of a dummy head localized in the experimental room at a height of 1.45 m, corresponding to the participants' position during the stimulation part of the experiment (see Fig. 2a for a depiction of the recording phase). From this perspective, the participants, as well as a gender-matched (prerecorded) stranger, were recorded while speaking out loud and walking in the room (self-allocentric and other-allocentric conditions, respectively). Both were recorded following the same actions. With the other set of binaural microphones, we simultaneously recorded sounds from the ears of the walking and talking participants (self-egocentric; Fig. 2a). For a first experimental block (experimental block on phenomenology and physiology) participants were recorded opening the door to the experimental room, entering, and then closing the door again. Afterwards, they walked to a point marked on the floor and began reading a fragment of *The Little Prince* (Saint-Exupéry, 2000) while walking a path. The direction to follow for each sentence was marked on the floor and their reading sheet. For recording cues for the second block (experimental block on spatial perception), participants were requested to repeat out loud the phrase “one, two, three, four, five; point at my feet” 18 times as they walked following a laser pointer on the floor and holding a spatially tracked virtual reality controller (Oculus Touch) on their heads. They stopped and faced the dummy head every time before saying “point at my feet”, after which they clicked a button on the controller that would track and record their position at that moment. Each trajectory was marked by the experimenter using a laser pointer for participants to follow.

3.2. Experimental block on phenomenology and physiology

Before proceeding to the stimulation and data recording, participants were helped to attach two thermocouples (one placed on the back of the neck, another on the left dorsal side of the left wrist) to measure temperature during stimulation, and three electrodes (on the collarbones and the left lower rib) for recording electro-cardiac signals. During the experimental stimulation (see Fig. 1 for an

Fig. 1. Overview of the experimental design showing each of the two experimental blocks horizontally. The conditions of each block are represented by the squares and the corresponding measures inside them. The conditions were counterbalanced between participants, and the experimental block on phenomenology and physiology always preceded that on spatial perception.

overview of the experimental design), participants sat down with the position of their heads matching that of the dummy head during the recording using a height-adjustable stool. In the first block, they heard the recordings corresponding to the three counterbalanced conditions (self-egocentric, self-allocentric, other-allocentric), each followed by a 14-item questionnaire that was responded on a visual analogue scale (VAS).

3.3. Experimental block on spatial perception

For the second block, we measured the perceived location of the heard voice while participants heard either themselves (self-allocentric) or another person (other-allocentric) speaking while walking towards and upon arrival at 18 different target positions (see Fig. 1 for an overview of the experimental design). Unlike for the previous block, here only these two conditions with multiple repetitions were necessary for our evaluation. Participants wore the head-mounted display and held the virtual reality controller as they heard these sounds on the binaural headphones. They saw a laser pointer coming out from the controller and were required to point with it at the location of each of the heard targets as they saw the room's dimensions plus an extra meter on each side on the head-mounted display (Fig. 2b). They could only hear but not see the recorded speaker. After the procedure, participants were asked to answer a 2-item questionnaire on the computer to assess whether they had any previous hallucinatory experiences. The overall procedure, including the stimuli recording, lasted approximately 60 min.

Fig. 2. Experimental setup during the (a) recording phase, showing the perspective from which the self and other-allocentric and the self-egocentric audios were recorded. The stimulation phase (b) shows the experimental block on spatial perception, with participants taking the position of the dummy head and hearing themselves or somebody else around them, at given moments they were required to point at the feet of the speaker. Plot (c) shows means and standard errors for the mean scores of each question grouping, and (d) raw differences between actual and perceived distance for each target, central tendencies, and distribution of the perceived distance to the speaker (self/other) separated by hallucination group (non-hallucinators $N = 14$; hallucinators $N = 4$). Negative values point at the perceived distance being larger than the actual. The hallucinator group measures (highlighted in yellow) are considered explorative given the small sample size. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

4. Measures

4.1. Experimental block on phenomenology and physiology

4.1.1. Bodily self-consciousness questionnaire

The 14-item questionnaire was presented after each condition and was adapted from questionnaires used for previous related studies (Blanke et al., 2014; Dobricki & Rosa, 2013). These items were grouped according to the self-identification, spatial presence, agency, and feeling of a presence phenomenal components (see Table 1). The questionnaire proposed by Dobricki and Rosa (2013) is based on a principal component analysis following an allocentric (visual) full-body illusion and was adapted to the auditory modality. One of the items for assessing the feeling of a presence is further considered an implicit measure in a study by Blanke et al. (2014). An additional item on voice recognition was included to confirm that participants could recognize their own recorded voice. The questionnaire was displayed and answered using a mouse and a computer screen displaying a VAS ranging from 0 to 1 (respectively displayed as *strongly disagree* to *strongly agree*).

4.2. Temperature

The temperature was recorded with an HH309A Data Logger thermometer (Omega, Stanford, CT, USA) at a 0.5 Hz sampling rate. The same device is used in previous similar studies (e.g., Salomon et al., 2013). Thermocouples recorded body temperature at two different locations (on the back of the neck, and the left dorsal side of the left wrist respectively) given that differences both in global temperature but also exclusively in specific body parts during experimental manipulations of bodily self-consciousness have been reported (Moseley et al., 2008; Salomon et al., 2013). An additional thermocouple was used to record the room temperature, controlling for environmental changes.

Table 1

Descriptive statistics and Bonferroni corrected pairwise comparisons of individual questionnaire items, N = 23.

Item	Self egocentric		Self allocentric		Other allocentric		Perspective comparisons			Self/other comparisons		
	Median	IQR	Median	IQR	Median	IQR	p	r	Z	p	r	Z
<i>Self identification</i>	0.43	0.18	0.49	0.38	0.08	0.27	1.00	−0.07	−0.31	0.00	−0.70	−3.34
Sometimes I felt like I was walking around the room myself	0.11	0.29	0.41	0.57	0.04	0.17	0.01	−0.56	−2.71	0.00	−0.66	−3.16
Sometimes I felt like I was in the place of the person speaking	0.51	0.41	0.41	0.63	0.10	0.40	1.00	−0.02	−0.10	0.02	−0.56	−2.66
Sometimes I had the feeling that the person speaking and I were one.	0.58	0.22	0.56	0.40	0.00	0.19	0.69	−0.20	−0.94	0.00	−0.70	−3.34
Sometimes I had the feeling to speak for myself while hearing the voice.	0.51	0.42	0.32	0.46	0.12	0.33	0.46	−0.25	−1.20	0.01	−0.61	−2.92
<i>Agency</i>	0.20	0.27	0.21	0.37	0.04	0.15	1.00	−0.07	−0.31	0.00	−0.75	−3.60
Sometimes it felt like I had control over what I said.	0.34	0.44	0.25	0.57	0.05	0.18	0.51	−0.24	−1.14	0.01	−0.59	−2.83
Sometimes it felt like I could have changed the content of the spoken words.	0.10	0.34	0.05	0.28	0.03	0.08	1.00	−0.01	−0.06	0.00	−0.66	−3.18
Sometimes it felt like I could have moved the speaking person's body if I wanted to.	0.17	0.37	0.18	0.44	0.02	0.23	0.81	−0.17	−0.83	0.04	−0.48	−2.31
<i>Spatial presence</i>	0.42	0.25	0.53	0.51	0.46	0.36	0.27	−0.31	−1.50	0.93	−0.15	−0.73
Sometimes I feel like I'm in the thick of things, not just listening	0.43	0.33	0.65	0.69	0.51	0.46	0.76	−0.18	−0.88	1.00	−0.09	−0.42
Sometimes I could not tell what I heard from what actually happened in the room.	0.20	0.58	0.36	0.70	0.29	0.56	0.31	−0.30	−1.43	1.00	0.00	0.00
Sometimes it seemed like I was actually attending the event.	0.36	0.38	0.58	0.53	0.28	0.51	0.14	−0.38	−1.82	0.31	−0.30	−1.43
Sometimes I felt physically present in the action	0.51	0.36	0.60	0.41	0.66	0.37	0.31	−0.29	−1.41	0.66	−0.20	−0.97
<i>Feeling of a presence</i>	0.35	0.42	0.73	0.32	0.85	0.17	0.00	−0.74	−3.55	0.03	−0.50	−2.40
Sometimes I felt that someone other than me and the experimenter was present in the room.	0.17	0.57	0.69	0.74	0.82	0.23	0.08	−0.42	−2.03	0.02	−0.53	−2.56
Sometimes I feel that someone is walking around me.	0.18	0.47	0.87	0.22	0.88	0.27	0.00	−0.83	−3.96	0.80	−0.18	−0.84
<i>Additional items</i>												
I recognized the voice of the person speaking	1.00	0.05	1.00	0.04	0.21	0.79	0.93	−0.15	−0.73	0.00	−0.77	−3.71

4.3. Heart rate

The electrocardiac signals were recorded into the computer using an Arduino Uno (Arduino AG) and a e-Health Sensor Platform 2.0 (Libelium Comunicaciones Distribuidas S.L., Spain) with a sampling rate of 62.37 Hz through a USB serial connection.

4.4. Experimental block on space perception

4.4.1. Perceived distance

Participants selected the perceived position by pointing with a virtual laser pointer —while wearing a head-mounted display depicting a virtual model of the room— at the location where they thought the speaker to be for each of the 18 targets. This location consisted of the pointer's position at the floor level, thus keeping that axis constant and calculating the position on the depth and horizontal axes.

4.5. Post experimental measures

4.5.1. Hallucination questionnaire

The questionnaire was adapted from Johns et al. (2002) and included two items. These were derived from the Psychosis Screening Questionnaire (Bebbington & Nayani, 1995), a brief test used for screening symptoms commonly found in psychiatric disorders (Beards et al., 2013; Johns et al., 2002, 2004; King et al., 2013), given that they were the single items assessing hallucinations in such test. Johns et al. (2002) applied this measure to assess hallucination history in a large sample of the general population. One of the questions is related to hearing or seeing things that others could not, and another to hearing voices when there is nobody around. The first question was “Over the past year, have there been times when you heard or saw things that other people couldn't?” while the second “Did you at any time hear voices saying quite a few words or sentences when there was no one around that might account for it?”. They were responded on a VAS ranging from *strongly disagree* to *strongly agree* (respectively coded as 0 and 1). Due to the short nature of this questionnaire for addressing the underlying complexity of auditory-verbal hallucinations this measure is considered an initial approachable step for distinguishing between hallucinators and non-hallucinators, but future studies should consider using more thorough assessments.

5. Data treatment and statistical analysis

Data were analyzed with R (R Core Team, 2018) version 3.5.1. Alpha level set to 0.05, or 95% confidence intervals, and p-values were adjusted for multiple comparisons (the respective adjustments are reported in the Results section). Data were tested for normality and analyzed correspondingly and are available together with the associated scripts on <https://osf.io/c26rd/>.

5.1. Experimental block on phenomenology and physiology

5.1.1. Bodily self-consciousness questionnaire

Data from two participants were removed from the analysis ($N = 23$; age: $M = 25.3$; $SD = 4.36$ years old; 18 female), one because the task was unexpectedly interrupted for one condition and another because the participant reported not having understood the instructions. We calculated the mean of the items belonging to each question grouping (*self-identification*, *spatial presence*, *agency*, and *feeling of a presence*, respectively). Wilcoxon signed-rank tests were performed to compare the responses between conditions both for the question groupings as well as for the individual items of the questionnaire (Table 1). Comparisons were performed to assess self/other (i.e., between the self-allocentric and other-allocentric conditions) and perspective (i.e., between the self-egocentric self-allocentric conditions) differences. To account for multiple comparisons, Bonferroni corrections were applied.

5.2. Temperature

The room temperature was subtracted from the recordings of the two other (body) thermocouples. A baseline was calculated as the average temperature of the first 8 s of recording for each thermocouple. This value was then subtracted from the rest of the recording, to represent the relative change in skin temperature across the stimulation period. For each condition, the average temperature change was computed over 96 s (104 – 8 s baseline) based on the duration of the shortest audio recording. Data from seven participants for this measure were excluded due to missing data, with 17 participants assessed for this measure (25.2 ± 4.7 years old; 14 female). The resulting mean temperatures were compared between the three conditions (self-egocentric, self-allocentric and other-allocentric) using Friedman tests.

5.3. Heart rate

The raw ECG signal was plotted to inspect the quality of the signal (one participant was removed due to noisy data). The instantaneous heart rate out of the R-peak from each ECG recording was extracted using R. Data was then filtered to exclude heart rate values above 200 and below 25 bpm (García Martínez et al., 2017). Data from 3 participants was lost due to signal noise. As with the temperature recordings, data for each participant was cut to match the duration of the shortest recording. Data from five additional

participants were excluded due to data loss, resulting in a total of 17 participants assessed for this measure (age: $M = 25.1$, $SD = 5.3$; 13 female). A repeated measures ANOVA was performed to compare the mean heartrate between the three conditions.

5.4. Experimental block on spatial perception

5.4.1. Perceived distance

The perceived distance to the speaker was calculated by computing the Euclidean distance between the participants' location (the middle of the stool where they sat down), and the coordinate pointed by participants for every trial. The actual distance to the speaker was calculated by determining the distance between the participants' position and the recorded position for each trial. For assessing the drift in perceived location, the difference between actual and perceived distance to the speaker was computed for each of the 18 trials. One data point was removed because it exceeded the plausible values for the room size, suggesting a measurement error (>2.5 m). Data from seven participants were lost due to system malfunctioning during data storage for the perceived distance task. To compare the perceived distance to the speaker between conditions (self-allocentric and other-allocentric), generalized linear mixed models using the lme4 package in R (Bates et al., 2015) were performed. We assessed the random structure of the data and other considerations justifying our modeling procedure (reported in the Results section). Given that we found only a small portion of our sample belonging to the hallucinators group ($N = 14$; age: $M = 25.93$, $SD = 4.7$; 10 female), we separately computed two models based on our hypotheses. The first one included the sample belonging to the non-hallucinator group ($N = 4$; age: $M = 28.25$, $SD = 5.9$; 3 female) according to our hallucination history questionnaire. The second model concerned only the hallucinator group, and is considered explorative due to the small resulting sample. Since the Bonferroni correction method for multiple comparisons has proven highly conservative when applied to linear mixed models, and instead bootstrap data are recommended (Joo et al., 2016), a Westfall correction was applied (Westfall, 2011). Additional Bayesian statistics were performed to assess the probability that our findings concerning the hallucinator group differed from chance, this again given the small sample.

5.5. Post experimental measures

5.5.1. Questionnaire on hallucination history

In order to group participants according to their previous hallucinatory experiences, those that scored above 0.5 on either of the two items of the hallucination questionnaire were considered to be in the hallucination group. From the total sample, 7 participants were in the hallucinator (question 1 $M = 0.54$, $SD = 0.36$; question 2 $M = 0.54$, $SD = 0.32$) and 18 in the non-hallucinator group (question 1 $M = 0.05$, $SD = 0.1$; question 2 $M = 0.03$, $SD = 0.06$). After considering the data loss from the perceived distance measures, this resulted in 4 participants in the hallucinator (question 1 $M = 0.39$, $SD = 0.29$; question 2 $M = 0.36$, $SD = 0.29$) and 14 participants in the non-hallucinator group (question 1 $M = 0.06$, $SD = 0.1$; question 2 $M = 0.04$, $SD = 0.08$) for the comparisons related to such task. As mentioned above, given the small percentage of our sample in the hallucinator group, we consider this grouping explorative and assess it separately for the relevant tasks. Due to reported differences in hallucination prevalence in the general population (ranging from 0.6% to 84%) depending on the used method (see Beavan et al., 2011), the proportion of our sample with hallucination history was difficult to predict (28% of our total sample).

6. Results

6.1. Phenomenology and physiology

6.1.1. Bodily self-consciousness questionnaire

Wilcoxon comparisons showed significant differences for the VAS ratings between perspectives (i.e., self-egocentric and self-allocentric conditions) for the feeling of a presence question grouping ($W = 13$, $p < 0.001$, $r = -0.52$). Self/other differences (i.e., between self-allocentric and other-allocentric conditions) were found for the self-identification ($W = 230$, $p < 0.01$, $r = -0.49$), agency ($W = 185$, $p < 0.001$, $r = -0.53$) and feeling of a presence ($W = 60$, $p < 0.05$, $r = -0.35$) question groupings (Fig. 2c). Results for the individual items of the questionnaire and additional comparisons are shown in Table 1.

6.1.2. Temperature

Friedman tests for temperature comparisons between conditions (i.e., self-egocentric, self-allocentric, and other-allocentric) revealed no significant differences for neither the neck ($\chi^2(2) = 0.35$, $p = 0.84$) nor the left wrist ($\chi^2(2) = 0$, $p = 1$).

6.1.3. Heartrate

A repeated measures ANOVA was run for comparing between the three conditions (self-egocentric, self-allocentric and other-allocentric) yielding no significant differences in heartrate between the three conditions $F(2, 32) = 0.181$, $p = 0.84$.

6.2. Space perception

6.2.1. Non-hallucinators

Before fitting linear mixed models to the perceived location data, non-independence within participants was confirmed for the dataset concerning exclusively the non-hallucinators (intraclass correlation coefficient (ICC(1)) = 0.33, $F(13, 489) = 18.37$, $p <$

0.0001), confirming the longitudinal and random structure of the data. To further assess the need for linear mixed model procedure we applied the methods described in Field et al. (2012). A model including exclusively the intercept, and another model that allowed the intercept to vary over the participants were formally compared by examining the change in the $-2\log$ -likelihood (Bliese & Ployhart, 2002). The model's fit improved as a result of including a random intercept for each participant ($\chi^2(1) = 146, p < 0.0001$). A total of 504 observations across 14 participants were modelled. For testing the hypothesis that participants would locate the source closer to themselves in the self-allocentric compared to the self-egocentric condition, the factor *Condition* was included as a fixed effect, while participants as a random effect. The model showed an effect of condition ($b = -0.09$, 95% CI: $-0.16, -0.02$ $t(488) = -2.51, p = 0.012$), confirming that participants in the non-hallucinator group locating the own compared to the other's voice closer to themselves compared to the actual source location. We additionally estimated the effect size for the final model according to the method suggested by Johnson (2014) and Nakagawa & Schielzeth (2013) which indicated a substantial model's explanatory model power (*conditional* $R^2 = 0.34$). Visual exploration showed a normal distribution of the residuals for the described model.

6.3. Exploratory assessment on participants reporting hallucination history

To assess how hallucination history might affect the results, we separately modeled the data for the hallucinator group, including 4 participants (a total of 144 observations). Non-independence within participants was confirmed ($ICC(1) = 0.31, F(3, 140) = 17.21, p < 0.0001$). As above, a model including exclusively the intercept was compared to one allowing the intercept to vary over the participants were compared, with the later showing a model improvement ($\chi^2(1) = 30.92, p < 0.0001$). Thus, a model with the factor *Condition* (self- and other-allocentric) as a fixed effect including participants as a random effect was performed. The results showed a main effect of *Condition* ($b = 0.35$, 95% CI: $0.22, 0.49, t(139) = 5.18, p < 0.0001$). Contrary to our expectations, hallucinators showed a drift of the perceived targets closer to themselves when listening to the other's compared to the own voice. A substantial model's explanatory model power is reflected by the *conditional* $R^2 = 0.42$. Visual and formal exploration confirmed a normal distribution of the residuals.

Given the small sample size, further Bayesian analyses were performed to assess the posterior probability that our findings differed from chance. The procedure described in detail in Macauley et al. (2019) was followed. The probable range of the estimated parameter given the data and the model is expressed by the 95% Bayesian credible intervals (CI). The presence of an effect is inferred when the CI is not crossing the value 0. For the model including the fixed effect of condition, a Bayesian linear mixed model showed an effect (difference of mean parameter estimates (MPE) "other-allocentric" - "self-allocentric" = 0.356 , 95% CI = $(0.213, 0.487)$). These findings show that the posterior probability, given the data, that in the hallucinators group, participants located the self-allocentric sounds further away from their actual location in the self-allocentric condition compared to the other-allocentric condition was almost 100%.

7. Discussion

These results suggest that listening to one's acoustic self in extracorporeal space can manipulate phenomenal aspects of bodily self-consciousness and self-related spatial perception in healthy volunteers. As hypothesized, participants indicated a strong feeling of a presence of a speaking person walking around themselves while self-identifying with that person, thus reporting the perception of an auditory doppelgänger. This provides evidence for an experimentally induced autoscopia-like experience in healthy participants stimulated acoustically. Importantly, our measure of self-identification was based on a previous principal component analysis after an allocentric full-body illusion (Dobricki & Rosa, 2013) and is different to voice recognition, including the sense of body ownership (Blanke, 2012) and attributing own-experiential qualities to the self-identified object. These findings on altered bodily self-consciousness confirm verbal reports from healthy participants during piloting:

"So, my experience was strange at the beginning, but soon it felt... it felt familiar, and I immediately recognized myself. That it was my voice. And in some way, it was also like listening to your own self, to your consciousness in a way. It seemed also very real, as if I was going around myself. Yes, it was impressive to hear myself in such way, as if I was around myself. As if you were around yourself."

"As if you feel in that person too, but at the same time you are in between and you are surrounded. So, I don't know, I feel that I'm surrounded, but at the same time it's myself. So, I feel in two places simultaneously, let's say."

These strong phenomenal descriptions, however, were not in line with the physiological measures, which might indicate that the effect was not as strong as in previously described multisensory illusions, but might also be linked to accumulating evidence not consistently replicating the link between phenomenal alterations of the bodily self and physiological measures such as temperature (de Haan et al., 2017; Roel Lesur et al., 2020).

We found clear changes in the location of self-identified extracorporeal sounds. As predicted, participants without previous hallucinatory experiences perceived their own allocentric voice closer to themselves compared to the voice of another person, presumably due to a change in self-location resulting from self-identification with the extracorporeal cues (Lenggenhager et al., 2007; 2009; Noel et al., 2015). Alterations of self-location have been traditionally considered as an implicit measure of experimentally induced autoscopia (Lenggenhager et al., 2007, 2009; Noel et al., 2015), given that confusion in regard to self-location has been described as an aspect of clinical autoscopia (Blanke et al., 2004; Brugger et al., 1994). In previous studies, experimentally induced drifts of self-location have been attributed to a mislocation of somatosensory cues, arguably due to the reliability of touch for distinguishing between the self and the environment (Lenggenhager et al., 2009). Our findings, however, suggest that this phenomenon

might go beyond somatosensation and extend to other teleceptive modalities such as audition. While the findings regarding self-location were in line with our hypothesis, we expected this effect to be smaller for participants with previous hallucinatory experiences due to potentially more self-other confusion (Asai, 2016), as it has been suggested that hearing voices and altered auditory-verbal processing might be related to alterations in self-monitoring and self-other distinction (Blakemore et al., 2000; McGuire et al., 1995; Orepic et al., 2021). However, participants in the hallucination group showed an effect in the opposite direction, locating their own voice further away compared to the other person's. Despite the statistical support, our findings should be considered explorative and with caution given the small number of participants tested in the hallucination group ($N = 4$) and the measure used for such grouping. In any case, we could currently only speculate why they would show a drift further away from their location when hearing themselves allocentrically compared to when hearing someone else. A reduced capacity to recognize the own voice has been shown for early psychotic patients with passivity experiences during somatosensory-motor experimentally-induced feeling of a presence (Salomon et al., 2020). While schizotypal individuals tend to show a narrower peripersonal space compared to controls (Di Cosmo et al., 2018)—potentially related to distorted self-other discrimination—, a previous study with a visually-driven allocentric full-body illusion found no differences between schizophrenic patients and controls in neither self-location nor subjective responses (Shaqiri et al., 2018). While future research is needed, our results might suggest an interesting avenue of research both in clinical and healthy populations to further understand the link between alterations of self-related vocal-acoustic signals and allocentric self-perception. Notably, auditory-verbal hallucinations are often linked to a feeling of a presence (Alderson-Day et al., 2020), accompanied by bodily alterations (Alderson-Day et al., 2020; Woods et al., 2015), and appear to come from extracorporeal space (Copolov, 2004; McCarthy-Jones et al., 2014; Woods et al., 2015), and auditory-based feelings of a presence (hearing of a presence) have been reported (e.g., Blanke et al., 2003). These bodily and spatial aspects during auditory hallucinations are thus linked to primary characteristics of the bodily self. While it is an initial step in the experimental study of this link, our study might support a link between altered self-related auditory vocal processing and bodily self-consciousness. Furthermore, this experimental setup could easily be combined with existing visuo-tactile (e.g., Lenggenhager et al., 2007) and motor-tactile (Blanke et al., 2014; Orepic et al., 2021; Salomon et al., 2020) manipulations of bodily self-consciousness to further understand the link and potentially enhance the effect of these other interventions.

It has been argued that experimentally induced alterations of bodily self-consciousness as is the well-replicated rubber hand illusion (Botvinick & Cohen, 1998) might actually be describing responses based on suggestion and demand characteristics (Dieguez, 2018; Lush, 2020; Roseboom & Lush, 2020). However, not only are these illusions of clinical relevance (e.g., Brugger & Lenggenhager, 2014) but they offer opportunities to modulate cognitive, motor, emotional and social processes (Dijkerman & Lenggenhager, 2018; Roel Lesur et al., 2018). Moreover, similar illusions have been elicited in other species such as mice (Wada et al., 2016) and monkeys (Shokur et al., 2013), which arguably would be less susceptible to such demand characteristics. In the case of our study, while we cannot fully discard that there might be a degree of suggestibility, we would not expect participants to have a systematic *a priori* idea of how they should react to each of the conditions. Especially for the spatial perception task, we believe that there is no reason why naive participants would follow a specific pattern of responses due to demand characteristics.

8. Limitations and outlook

It should be noted that, besides the small sample of hallucinators tested, we assessed the participants' hallucinatory history with a limited measure, consisting of only two questionnaire items (Johns et al., 2002). Thus, despite the strong differences found between groups, our findings should be considered with caution. Future studies are advised to use more robust psychometrics to assess proneness to hallucinations in healthy individuals and aim for a larger sample size (e.g., Bentall & Slade, 1985; Launay & Slade, 1981). Another potential confound in our study might be that in the self-conditions, given that participants were actively involved in the generation of the stimuli, there could have been a potential auto-noetic effect. For example, the fact that participants actually moved and spoke while recording might have had an effect while listening back and arguably memorizing such actions. A potential way to control for this would be to use deep neural network techniques for generating enunciations based on the participants' own voice (e.g., Arik et al., 2018) and subsequent digital manipulations (such as head-related transfer functions; HRTF; Gamper, 2013; Roel Lesur & Lelo de Larrea Mancera, 2014) to create the spatially accurate allocentric cues. However, from exploratory phenomenal piloting with our team, digital signal processing for generating spatial sound (HRTF) does not seem to create an effect as strong as recording binaurally inside the same room where the stimuli are presented.

The last point worth mentioning is that the participants' weight, height, clothing (including shoes), and even certain vocal attributes (e.g., pauses, expressiveness) were not controlled for during the recording. This might have yielded important individual differences in the stimuli that could have influenced the results. While we would not expect a systematic modulation stemming from these variations, future studies might consider controlling for such cues.

9. Conclusion

Our findings point at a replicable, acoustically generated autoscopia-like experience in healthy volunteers. Participants reported feeling their own presence in extracorporeal space, which was, however, not mimicked in our physiological measures. Our findings further suggest altered space perception when participants heard themselves allocentrically. They located their own sounds closer to themselves compared to when hearing another person. For participants with previous hallucinatory experiences, the opposite pattern was unexpectedly found. These later findings concerning hallucinators should be considered cautiously and replicated in a larger sample using a more robust measure of hallucination proneness. While audition has been relatively neglected in accounts of autoscopia

and out-of-body experiences, acoustic phenomena are frequent and reports of auditory doubles exist even in non-clinical populations (Lukianowicz, 1958; Posey & Losch, 1983). This paradigm adds up to existing literature pointing at the role of acoustic bodily cues for bodily self-consciousness (Tajadura-Jiménez et al., 2012, 2017; 2018), and importantly extend it by linking it to auditory-verbal aspects that are often altered in clinical populations. This investigation thus offers new ways to manipulate and study the relation between auditory-verbal hallucinations and bodily self-consciousness both in health and disease, potentially serving as a bridge between clinical and experimental knowledge in the field.

CRedit authorship contribution statement

Marte Roel Lesur: Conceptualization, Data curation, Investigation, Methodology, Project administration, Formal analysis, Visualization, Software, Writing – original draft, Writing – review & editing. **Elena Bolt:** Investigation, Writing – review & editing. **Gianluca Saetta:** Formal analysis, Software, Data curation, Writing – review & editing. **Bigna Lenggenhager:** Conceptualization, Methodology, Project administration, Funding acquisition, Resources, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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