þÿIncreasing self other similarity modulates ethni
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# Increasing self–other similarity modulates ethnic bias in sensorimotor resonance to others' pain

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## Abstract

The tendency to simulate the pain of others within our own sensorimotor systems is a vital component of empathy. However, this sensorimotor resonance is modulated by a multitude of social factors including similarity in bodily appearance, e.g. skin colour. The current study investigated whether increasing self–other similarity via virtual transfer to another colour body reduced ingroup bias in sensorimotor resonance. A sample of 58 white participants was momentarily transferred to either a black or a white body using virtual reality technology. We then employed electroencephalography to examine event-related desynchronization (ERD) in the sensorimotor beta (13–23 Hz) oscillations while they viewed black, white and violet photorealistic virtual agents being touched with a noxious or soft object. While the noxious treatment of a violet agent did not increase beta ERD, amplified beta ERD in response to black agent's noxious *vs* soft treatment was found in perceivers transferred to a black body. Transfer to the white body dismissed the effect. Further exploratory analysis implied that the pain-related beta ERD occurred only when the agent and the participant were of the same colour. The results suggest that even short-lasting changes in bodily resemblance can modulate sensorimotor resonance to others' perceived pain.

Key words: vicarious pain; beta desynchronization; sensorimotor resonance; virtual reality; ethnicity; ingroup bias

## Introduction

Empathy signifies an ability to both understand and resonate with the innate states of others (e.g. Davis, 1983; Eres and Molenberghs, 2013; Cuff *et al.*, 2016). It is particularly well captured by vicarious pain experience as observing others in pain activates parts of the same neural network in the observer as when experiencing pain themselves (e.g. Lamm *et al.*, 2011). The network involves substrates related to affective and sensory components of pain (e.g. insula, cingulate and somatosensory cortices; Botvinick *et al.*, 2005; Benuzzi *et al.*, 2008; Akitsuki and Decety, 2009) as well as those associated with reasoning upon others' mental state and motives (i.e. medial prefrontal cortex, temporoparietal junction and superior temporal sulcus; Decety *et al.*, 2013). Intriguingly, the simulation of others' pain the network produces is not equal in all circumstances but varies as a function of social factors such as perceived similarity between oneself and the victim (Dopierała *et al.*, 2017; Han, 2018). For example, using functional magnetic resonance imaging (fMRI)

and electroencephalography (EEG), researchers have shown that people exhibit greater empathic resonance to victims with a similar skin colour (Xu *et al.*, 2009; Avenanti *et al.*, 2010; Perry *et al.*, 2010; Sheng and Han, 2012; Contreras-Huerta *et al.*, 2013; Luo *et al.*, 2015).

Traditionally, victim's ethnic outgroup membership has been associated with reduced responsivity in areas related to affective processing of pain such as anterior cingulate and insular cortices (e.g. Xu *et al.*, 2009; Contreras-Huerta *et al.*, 2013) and theory-of-mind-related areas such as medial prefrontal cortex and temporoparietal junction (Mathur *et al.*, 2010; Fourie *et al.*, 2017). More recently, however, studies using transcranial magnetic stimulation (TMS) and EEG/magnetoencephalography (MEG) have shown that not only the affective processing of vicarious pain is biased but the bias extends also to sensorimotor processes such as motor preparation and simulation of the tactile sensation (Avenanti *et al.*, 2010; Riečanský *et al.*, 2015, 2020; Zhou and Han, 2021). Riečanský *et al.* (2015), for instance, measured

event-related desynchronization and synchronization (ERD/ERS, also called as event-related spectral power perpetuation, ERSP) of white participants while showing them videos of painful needle injections of black and white people. Greater sensorimotor beta ERD (i.e. event-related decrease in beta power) was observed when a white person's hand was injected than when the victim was black. Intriguingly, this ethnicity bias occurred in response to the approaching needle but not to the injection itself, which suggests that, on the sensorimotor level, the intergroup bias may lie either in the anticipation of tactile sensation or in the expectation of defensive motor movements.

Ethnic bias in empathic resonance to pain is likely to play a role in the persistent racial and ethnic disparities in the assessment and treatment of pain seen across the Western world, with non-white patients often being undertreated for pain (Kaseweter *et al.*, 2012; Tait and Chibnall, 2014; Mende-Siedlecki *et al.*, 2021). It also closely resembles other forms of intergroup biases demonstrated by decades of social psychological experiments. For example, just temporarily categorizing people into separate groups causes favouritism towards one's ingroup, even if the categorization is based on completely arbitrary criteria such as eye colour (Tajfel *et al.*, 1971; e.g. Balliet *et al.*, 2014). Moreover, in the implicit association test (IAT; Greenwald *et al.*, 1998), people have been shown to associate positive words more readily to the ethnic ingroup than outgroup (e.g. Maina *et al.*, 2018). While the causal link between implicit biases and real-world discriminative behaviours remains to be debated (Greenwald *et al.*, 2009; Oswald *et al.*, 2013; Carlsson and Agerström, 2016), there is an agreement on the importance of affective and empathy-related processes in fostering positive group relations and reducing prejudice (e.g. Pettigrew and Tropp, 2008).

In recent years, various innovative approaches have been developed to reduce such ethnicity-related biases by momentarily increasing perceived similarity between the self and outgroup members. This has been achieved, for example, by similar clothing (e.g. wearing shirts of the same colour; Sheng and Han, 2012) or by transferring people to virtual bodies of a different skin colour by means of virtual reality technology (Farmer and Maister, 2017). The effectiveness of increasing resemblance via virtual body transfer (also called racial embodiment) in reducing negative implicit associations towards ethnic outgroup members has been demonstrated in several studies (e.g. Farmer *et al.*, 2012, 2014; Maister *et al.*, 2013; Peck *et al.*, 2013). While there have been some contradicting results, particularly in studies utilizing more complex social settings (Groom *et al.*, 2009; Hasler *et al.*, 2017), it has also been shown that when high-accuracy motion-tracking systems are used, the effect of a relatively short embodiment period on implicit racial bias is evident and lasts for several days (Banakou *et al.*, 2016).

While there is evidence that cognitive perspective taking can reduce racial bias in pain perception (Drwecki *et al.*, 2011), no previous studies have examined whether increasing bodily resemblance between the observer and the victim also reduces ethnicity bias in vicarious pain response. However, a handful of studies suggests this could be the case. For example, Farmer *et al.* (2012) showed that synchronous visual-tactile stimulation of participant's own hand and a different colour rubber hand led to experienced body ownership of a rubber hand (i.e. rubber hand illusion) and increased the participants' skin conductance responses to painful treatment of the different colour rubber hand. More recently, Riečanský and colleagues (2020) showed that increasing bodily overlap between the observer and the victim increased the observer's mu and beta ERDs to noxious treatment

of the victim's hand and diminished previously observed ethnicity bias in beta ERD. The bodily overlap was increased presenting the victim's hand on top of the observer's corresponding hand.

Based on the aforementioned studies, it is, however, premature to conclude that increased bodily resemblance decreases ethnicity bias in empathy for pain as the obtained effects may well be explained in terms of increased self-relevance rather than empathy. That is, in both studies, the treatment was presented in the participants' first-person's perspective. Therefore, in the present study, we investigated whether increasing perceived bodily resemblance decreases ethnicity bias in vicarious pain when the bodies of the observer and the victim are clearly separate. The vicarious pain response was measured using self-reports and sensorimotor beta ERD. While both sensorimotor mu and beta ERDs have been shown to be responsive to vicarious pain stimuli in previous studies (Mu *et al.*, 2008; Perry *et al.*, 2010; Riečanský *et al.*, 2015, 2020; Zhou and Han, 2021), the ethnicity bias has been supposed to be limited to modulations in the beta-band (Riečanský *et al.*, 2015; but see Zhou and Han, 2021). Based on these findings, we hypothesized (H1) that people would show lower empathic resonance to ethnic outgroup members' than ingroup members' pain as measured with self-reports and sensorimotor beta ERD (Riečanský *et al.*, 2015, 2020). More precisely, we hypothesized stronger sensorimotor ERD in the beta (ca. 13–30 Hz) frequency band in response to noxious treatment of ingroup as compared to outgroup members.

As our second hypothesis (H2), we assumed virtual transfer to other-ethnicity bodies to decrease the ethnicity-related bias in vicarious pain responses as measured with self-reports and beta ERD. To be precise, the participants (all of whom self-identified as white) were assumed to show stronger sensorimotor resonance to white agent's than black agent's noxious treatment when embodying a white body but show reduced ingroup bias when being transferred to a black body. Moreover, recent findings suggest the ingroup bias in sensorimotor resonance to occur mainly at the anticipatory phase, before the actual noxious contact (Riečanský *et al.*, 2015). The present study further investigated this possibility by analysing the anticipation (object approaching the hand) and the contact phase (object touching the skin) separately.

## Methods

This section contains detailed descriptions of the procedure and stimulus material and brief descriptions of the sample, apparatus, EEG pre-processing and measures. Descriptions that are more detailed can be found in the Supplementary Methods. The hypotheses and methods were pre-registered in Open Science Framework prior data collection (https://osf.io/5khw4/). The data are available on Open Science Framework (https://osf.io/wd86b/).

### Participants

The sample consisted of 58 right-handed healthy adult volunteers (35 females, 21 males and 2 others) recruited via University of Helsinki student organization email lists. They were aged from 18 to 52 years (M = 26.21, s.d. = 6.44). Fifty-six of them were Finnish and the two others were from other European countries. All self-reported their skin colour as white. The experiment was conducted following the guidelines stated in the Declaration of Helsinki and was approved by the Research Ethics Committee of University of Helsinki.
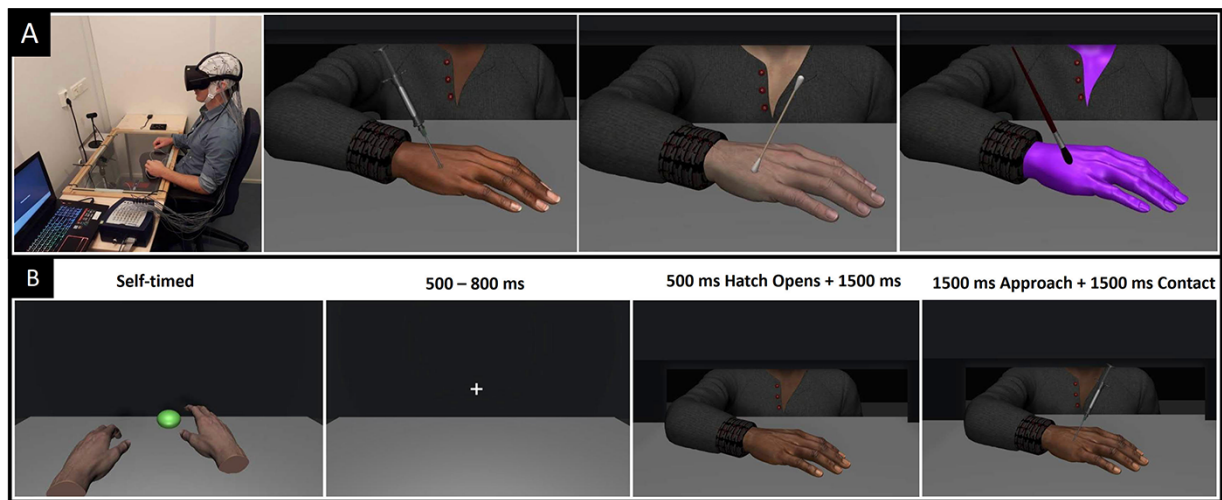
**Fig. 1.** Panel A shows the physical settings, tracking devices, HMD and the black, white and violet empathized agent in a noxious or soft contact condition. Panel B presents temporal flow of the trials (from left to right). The motor task was self-timed and the fixation cross was shown for 500–800 ms (randomized) followed by 500 ms of hatch opening in front of the participant, 1500 ms passive presentation of the agent, 1500 ms of an object approaching the agent's hand and 1500 ms of the object touching the agent.

## Procedure

After signing the informed consent, a set of EEG electrodes was applied on the participants' scalp. Thereafter they were assisted with putting on the head-mounted display (HMD) and immersed in virtual reality (see Figure 1, panel A). Upon entering the virtual reality (VR) environment, the participants were asked to move their virtual hands freely to acquire a sense of body ownership. After a 10 s delay, a ball appeared in front (Figure 1, panel B) and touching it led to another ball to show in another location. Six balls were to be touched. A questionnaire on body ownership followed this task (for further details of the questionnaire, see Supplementary Methods), after which the hands were removed from the view and a white fixation cross appeared on a surface in front (Figure 1, panel B, second picture from the left). Following a fixation duration of 500–800 ms, the surface was gradually lifted in 500 ms revealing a small hatch. Through the hatch, the participant saw a human agent. Only the agent's torso and right hand were visible (Figure 1, panel B, third picture). After 1500 ms, a noxious (syringe, scalpel, construction knife) or soft object (cotton tip applicator, paintbrush, feather) started to approach the agent's hand reaching it after another 1500 ms (Figure 1, panel B, fourth picture). The contact lasted for still another 1500 ms. The agent's hand was stationary throughout the scenario. The hatch was then closed.

The next trials started after a 500 ms delay with the participant's hands coming to view and a ball emerging again at a random location on the table (location randomized between trials). Touching this single ball relaunched the trial procedure described above. At the end of 36 pseudo-randomized trials (3 per each of the 12 conditions), the participants were asked to rate how painful the preceding treatment looked like (i.e. how much pain the other person would feel due to the presented treatment) and how unpleasant it was to watch it (for further details, see Supplementary Methods). The body ownership questionnaire was presented only in the first trial of each block consisting of 120 trials each. The participant's skin colour was kept the same throughout each of these blocks to maximize the salience of the body transfer. The skin colour and treatment type were randomly varied within the four blocks of 120 trials (4 × 120 = 480 trials in

total, 40 trials per each condition). To increase the variation in the stimuli material and prevent habituation, the system randomly varied the soft and noxious objects (soft: brush, feather and cotton stick; noxious: scalpel, syringe and construction knife) as well as the agent's gender and the direction from which the object approached (left *vs* right upper corner).

## Apparatus and stimuli

The VR-EEG set-up developed by our lab (Harjunen *et al.*, 2017; Ravaja *et al.*, 2017) is described in detail in Supplementary Methods. The set-up (see Figure 1) consisted of an Oculus Rift HMD connected to a gaming laptop and a Leap Motion tracking the user hand movements underneath a class table surface. The hand movements were projected on photorealistic 3D hands offered by the Leap Motion program (Supplementary Figure S1, left panel). The same hands were customized and integrated in male and female Genesis 2 characters offered by Daz Studio. Non-corporeal contents including contact objects (Supplementary Figure S1, right panel), surroundings (table, wall and hatch) and treatment animations were created using the Unity3D and Blender software. The Unity3D platform was used to collect self-reports, ensure timing accuracy and send triggers via parallel port to the EEG amplifier.

## EEG data acquisition and pre-processing

The EEG signal was recorded at a 2000 Hz sample rate from 32 equidistant electrodes, down-sampled offline to 256 Hz and pre-processed using the EEGLAB software (Delorme and Makeig, 2004). Independent component analysis was used for artefact correction. The reconstructed and cleaned continuous data were segmented to 5500 ms epochs time-locked to object approach onset. To avoid the impact of volume conduction from distant sources (McFarland, 2015), the epoched EEG data were transferred to reference-free current source density (CSD). The ERD/ERS of the CSD signal was then calculated for each subject, experimental condition, and channel overlying the sensorimotor cortex (FC1, FC2, C3, C4, CP1 and CP2) with respect to a pre-stimulus baseline from −2500 to −2000 ms (the last 500 ms of the fixation cross) using the fast Fourier transform method. The channel-

**Table 1.** Effects of agent skin colour and virtual body transfer on self-reported painfulness and unpleasantness of a vicarious pain experience

| Effect | Painfulness | | | Unpleasantness | | |
|---|---|---|---|---|---|---|
| | df | F | $\eta_p^2$ | df | F | $\eta_p^2$ |
| Skin colour | 1.98, 112.98 | 4.15[*] | 0.07 | 1.84, 104.77 | 1.95 | 0.03 |
| Body transfer | 1, 57 | 0.03 | <0.001 | 1, 57 | 0.65 | 0.01 |
| Skin colour × body transfer | 1.87, 106.67 | 1.81 | 0.03 | 1.79, 101.78 | 1.05 | 0.02 |

$N = 63$ for all ANOVA models. F-tests conducted with type-III sum of squares. The Greenhouse–Geisser correction method was used to adjust for the lack of sphericity.
[*]$P < 0.05$.

level CSD activity was averaged over left (FC1, C3, CP1) and right (FC2, C4, CP2) hemispheric regions of interest (ROIs). Finally, the average beta ERD of the CSD activity in the two temporal phases was calculated for each subject, condition and hemisphere using subject-specific time–frequency windows (see Section EEG data). The averaged ERD/ERS data were then subjected to statistical testing.

## Design and analysis

The study followed a repeated measures design with treatment (noxious *vs* soft), agent skin colour (white *vs* black *vs* violet) and body transfer (transfer to white *vs* black body) as factors. To test hypotheses H1 and H2 regarding the self-reported vicarious pain, we conducted a three-way full-factorial repeated measures analysis of variance (rmANOVA) separately for self-reported painfulness and unpleasantness. The agent skin colour (black *vs* white *vs* violet), treatment (painful *vs* soft) and body transfer type (ingroup *vs* outgroup body) were set as factors. The ERD/ERS at the beta-band was analysed with similar rmANOVAs in two separate temporal phases (i.e. approach and contact phase) resulting in two rmANOVAs. In each one, hemisphere, treatment (noxious *vs* soft), skin colour (white *vs* black *vs* violet) and body transfer (white *vs* black) were set as factors and the average beta ERD as the outcome. F-tests with type-III sum of squares and planned pairwise comparisons between soft and noxious treatment were used to test the interaction effects between agent skin colour and treatment (H1) and among agent skin colour, treatment and body transfer (H2). The planned pairwise comparisons were calculated using the 'pairs' and 'contrast' functions of the 'emmeans' (Russell, 2020) package in R. The functions operate on estimated margin means (EMMs) and pooled variances, which are based on fitted ANOVA models fitted on the full data. For this reason, the degrees of freedom and other t-statistics of 'emmeans' pairwise comparisons are different from those obtained using paired sample t-tests based on the selected portions of the raw data.

## Results
### Behavioural data

Ratings of body ownership and vicarious pain experience were examined first. When estimating their sense of body ownership over the virtual hands on a 19-point Likert scale, the participants reported moderate levels of body ownership ($M = 12.94$, s.d. $= 2.92$). There were no differences in the ownership between the white and black body transfer conditions, $t(57) = -0.46$, $P = 0.647$. Substantial effects of treatment on painfulness, $F(1, 57) = 993.30$, $P < 0.001$, $\eta_p^2 = 0.946$, and unpleasantness ratings were found, $F(1, 57) = 75.95$, $P < 0.001$, $\eta_p^2 = 0.571$, indicating that the noxious contact was rated as more painful ($M_{noxious} = 7.25$, SE $= 0.13$; $M_{soft} = 1.35$, SE $= 0.13$) and unpleasant
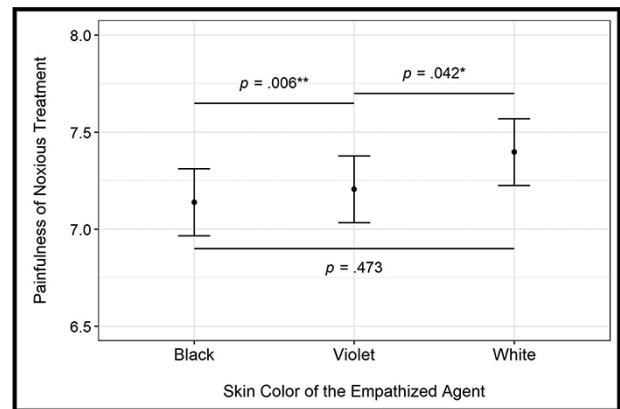


**Fig. 2.** Effect of agent skin colour on perceived painfulness of noxious treatment. Error bars indicate standard errors of EMMs.

($M_{noxious} = 4.00$, SE $= 0.24$; $M_{soft} = 1.43$, SE $= 0.24$). Given that a strong floor effect was present in the soft contact (i.e. soft being rated as not at all painful or unpleasant), further examination was limited to the noxious contact alone (for ANOVA with the treatment included as a factor, see Supplementary Table S1).

As shown in Table 1, the effect of skin colour on painfulness ratings of noxious contact was significant ($P = 0.019$). In line with H1, noxious treatment of white agents was perceived as more painful ($M = 7.40$, SE $= 0.17$) than similar treatment of black ($M = 7.14$, SE $= 0.17$, $t[114] = -2.78$, $P = 0.006$, $d = -0.52$) violet agents ($M = 7.21$, SE $= 0.17$, $t[114] = -2.06$, $P = 0.042$, $d = -0.38$, see Figure 2). In relation to H2, neither the effect of body transfer nor the interaction between skin colour and body transfer was found to predict painfulness ratings (Table 1). Moreover, there were no significant main or interaction effects of skin colour and body transfer on self-reported unpleasantness ($P$ values>0.151).

### EEG data

Approaching objects resulted in sustained beta ERD. Across all conditions, the beta ERD emerged at 700 ms after the object approach onset and gradually diminishing 700 ms after a contact was established (Figure 3, panel A). The ERD was present in all ROIs but was stronger on the left hemisphere. A weak mu ERD was also observed parallel with the beta ERD (Figure 3, panel B). Its occurrence was, however, less consistent across participants and in approximately half of participants no clear mu ERD was found from a subject-specific grand-average ERD/ERS image. Inspection of subject-specific grand-average ERD/ERSs within the sensorimotor ROIs also revealed that while the temporal dynamics of beta ERD was stable across participants, there were substantial individual differences in the frequency ranges
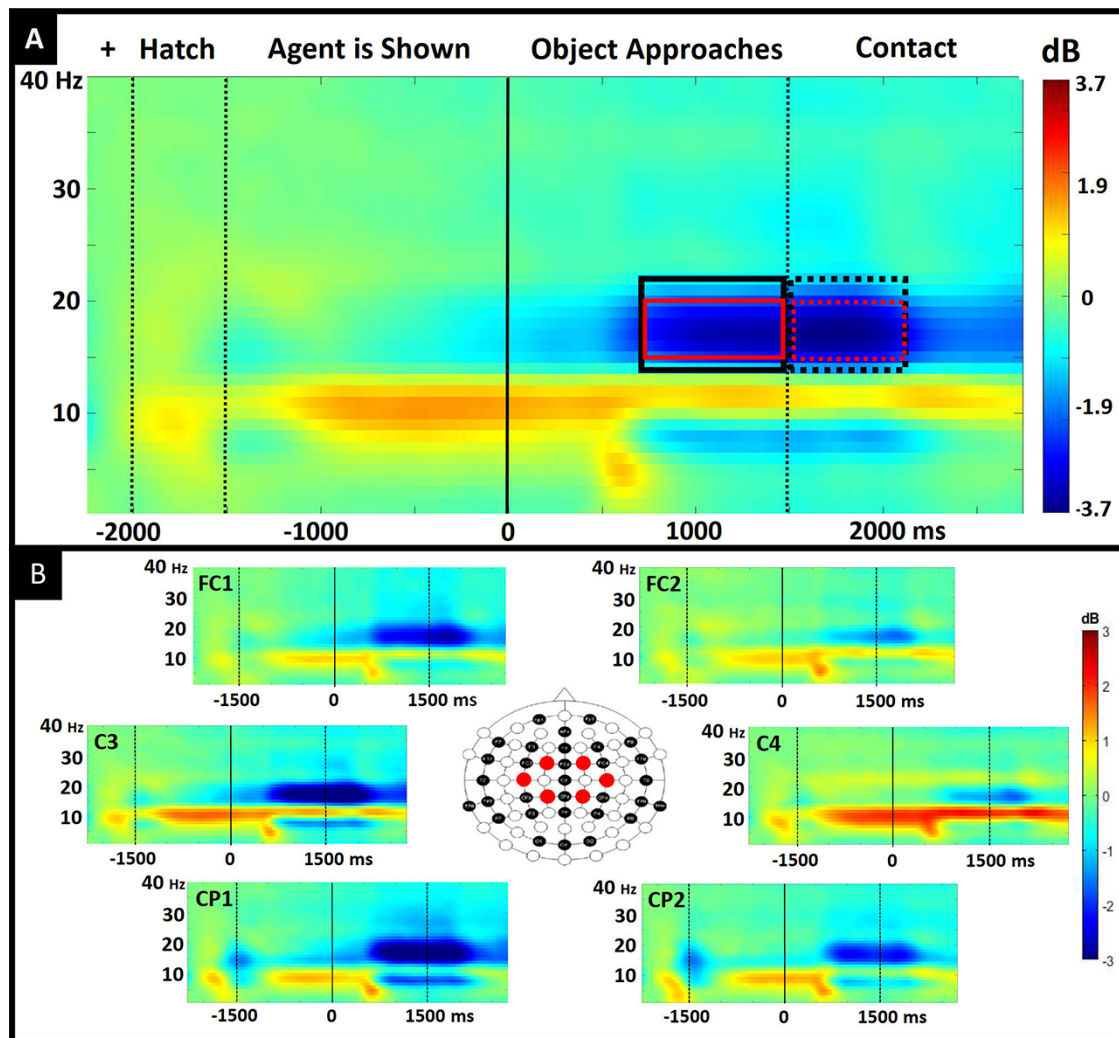
**Fig. 3.** Panel A: grand-average CSD ERD/ERS activity at channel C3. Black rectangles: time–frequency windows for the mu and beta ERD/ERS activity. Red rectangles: subject-specific frequency ranges used to extract the mu and beta ERD/ERS averages of each participant, condition and channel. Solid line: approach phase windows. Dashed line: contact phase windows. Panel B: grand-average ERD/ERS activity in each ROI.

of the beta ERD. Previously, the interindividual variation in frequency peaks has been linked to genetic factors (Landolt, 2011; Smit *et al.*, 2012) and GABA concentration (Muthukumaraswamy *et al.*, 2009). To account for the variation, we extracted average ERD/ERSs at beta range using frequency ranges defined individually for each participant (Cohen, 2014, pp. 499–501, for further details, see Supplementary Methods). The subjects' beta ranges were defined within a 13–25 Hz group-level range (see Figure 3, panel A, black rectangles). The approach phase was defined starting from 700 ms and ending at 1500 ms and the contact phase starting from 1500 ms and ending at 2200 ms. The effects of all factors on beta ERD/ERSs were then tested separately on the two temporal phases.

Finally, to ensure that the pattern seen in channels overlying the sensorimotor region was distinct from the ERD/ERS activity captured by occipital sites, the ERD/ERS images at the occipital electrode sites were inspected. As shown in Supplementary Figure S2, a distinct activity pattern marked by sustained ERD between 10 and 13 Hz was found across the occipital channels. This higher alpha ERD peaked first in response to the presentation of an agent and then again in response to the treatment animation. Due to the applied spatial filtering (CSD) and clearly

distinct activity pattern between the occipital electrode sites and the ROIs, confounding volume conduction from occipital sources was deemed unlikely.

### Beta ERD/ERS activity in the approach phase

Beta-band ERD/ERSs in the approach phase were examined with similar full-factorial rmANOVAs as the behavioural responses but adding hemisphere as a factor (for full ANOVA results, see Supplementary Table S2). Beta ERD/ERS was significantly different between the hemispheres, $F_{(1, 57)} = 154.06$, $P < 0.001$, $\eta^2_p = 0.730$, with a stronger ERD on the left ($M = -2.55$, $SE = 0.19$) than on the right ($M = -1.17$, $SE = 0.19$). The main effect of skin colour was likewise significant, $F_{(1.82, 104.00)} = 4.18$, $P = 0.021$, $\eta^2_p = 0.068$, as were the interactions between treatment and ethnicity, $F_{(1.94, 110.64)} = 3.13$, $P = 0.049$, $\eta^2_p = 0.052$, and among hemisphere, treatment and body transfer, $F_{(1, 57)} = 5.98$, $P = 0.018$, $\eta^2_p = 0.095$. The three-way interaction among treatment, skin colour and body transfer was trending towards significance ($P = 0.062$).

To better understand the interactions, separate ANOVAs for each hemisphere were calculated (for the full ANOVA table, see
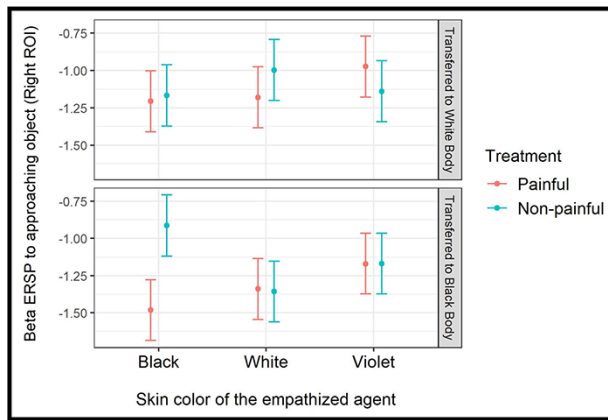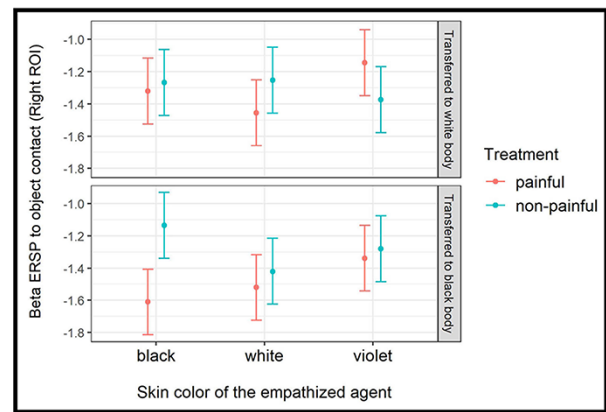
**Fig. 4.** Interaction effect of treatment, skin colour and body transfer on beta ERD (in the right-side ROIs) induced by an approaching object. Error bars indicate standard errors of EMM.



**Fig. 5.** Interaction effect of treatment, skin colour and body transfer on beta ERD (in the right-side ROIs) induced by object contact. Error bars indicate standard errors of EMM.

Supplementary Table S3). The left side ERD was affected only by skin colour, $F(1.90, 108.37) = 7.30$, $P = 0.001$, $\eta^2_p = 0.114$. Objects approaching black ($M = -2.64$, $SE = 0.20$) and white ($M = -2.60$, $SE = 0.20$) agents resulted in stronger beta ERD than objects approaching violet agents ($M = -2.41$, $SE = 0.20$, pairwise comparisons: $P$ values $<0.012$). On the right, interactions between ethnicity and treatment, $F(1.94, 110.40) = 5.11$, $P = 0.008$, $\eta^2_p = 0.082$, and among ethnicity, treatment and body transfer, $F(1.99, 113.19) = 3.27$, $P = 0.042$, $\eta^2_p = 0.054$, were found. As shown in Figure 4, there was no difference between the noxious and soft treatment of black agents when embodying a white body, $t(330) = 0.292$, $P = 0.770$, but the effect was clear when transferred to a black body, $t(330) = 4.269$, $P < 0.001$. A trend of similar congruency effect occurred when witnessing a white agent's treatment, although the pairwise comparisons between noxious and soft treatment were not significant ($P$ values $>0.171$). Noxious objects approaching a violet agent did not amplify beta ERD in either condition of body transfer.

### Beta ERD/ERS activity in the contact phase

The contact-related beta ERDs were examined with rmANOVAs similar to those used in the approach phase (see Supplementary Table S2 for full-factorial solutions). First, significant effects of hemisphere, $F(1, 57) = 139.33$, $P < 0.001$, $\eta^2_p = 0.710$, and skin colour, $F(1.99, 113.24) = 5.18$, $P = 0.007$, $\eta^2_p = 0.083$, were found, indicating stronger ERD on the left ($M = -2.68$, $SE = 0.19$) than the right hemisphere ($M = -1.34$, $SE = 0.19$), and when observing white ($M = -2.09$, $SE = 0.18$) and black ($M = -2.03$, $SE = 0.18$) than the violet agent ($M = -1.90$, $SE = 0.18$). Interactions between hemisphere and skin colour ($P = 0.017$), among hemisphere, treatment and skin colour ($P = 0.043$) and among hemisphere, treatment and body transfer ($P = 0.010$) were likewise significant. Examining the hemispheres separately (see Supplementary Table S4) revealed an interaction between treatment and skin colour on the right ROIs, $F(1.93, 110.03) = 4.26$, $P = 0.018$, $\eta^2_p = 0.070$, indicating that noxious treatment of black agents resulted in stronger beta ERD than soft treatment of black agents, $t(167) = 2.892$, $P = 0.004$. While a similar trend was observed in response to a white agent's noxious treatment, $t(167) = 1.661$, $P = 0.099$, the effect was completely absent in violet agent conditions, $t(167) = -0.936$, $P = 0.350$ (see Supplementary Figure S3). Finally, treatment and body transfer were found to interact, $F(1, 57) = 5.29$, $P = 0.025$, $\eta^2_p = 0.085$, indicating overall stronger ERD response to noxious *vs* soft treatment

when transferred to a black virtual body (Supplementary Figure S4).

The two significant two-way interactions described above both involved treatment but the three-way interaction was non-significant. To see if the beta ERD responded completely differently in the contact than in the approach phase, we also plotted the mean ERDs based on the non-significant three-way interaction (see Figure 5). Based on the EMMs, the pain-related beta ERD was still the strongest when the agent's skin colour matched the observer's black body colour, similarly as in the approach phase. On the left hemisphere, an effect of ethnicity was again found, $F(2.00, 113.87) = 8.39$, $P < 0.001$, $\eta^2_p = 0.128$, but the other effects were non-significant ($P$ values $>0.155$, see Supplementary Table S4).

### Exploratory analysis: beta ERD/ERS and skin colour congruency

An exploratory analysis was then conducted examining whether the modulatory influence of body transfer on ethnic bias in pain-related beta ERD translated into a significant interaction when limiting our focus to black and white skin colour conditions. The rationale for this examination was that the participants saw themselves in a black and white body but were never transferred to a violet body. Therefore, the influence of body transfer on the sensorimotor resonance to violet agents' treatment could be different from the other two skin colour conditions. Two rmANOVA models were built separately for the ERD/ERS activity of the approach and contact phases with hemisphere, treatment, skin colour (black *vs* white) and body transfer as factors in both models (see Supplementary Table S5 for full-factorial solutions). In the approach phase, significant main effects of hemisphere ($P < 0.001$), treatment ($P = 0.042$) and significant interactions among hemisphere, treatment and body transfer ($P = 0.002$), and treatment, skin colour and body transfer ($P = 0.010$) were found. The former interaction indicated that beta ERD to noxious *vs* soft approaching object was mainly present in the right hemisphere when transferred to a black body ($t(179) = 2.83$, $P = 0.005$). The latter interaction indicated that the pain-related beta ERD occurred similarly in the black and white skin colour conditions when the perceiver's and agent's skin colours were congruent (see Figure 6, left panel).

A similar pattern of results was observed in the contact phase (Supplementary Table S5). Besides the main effects of
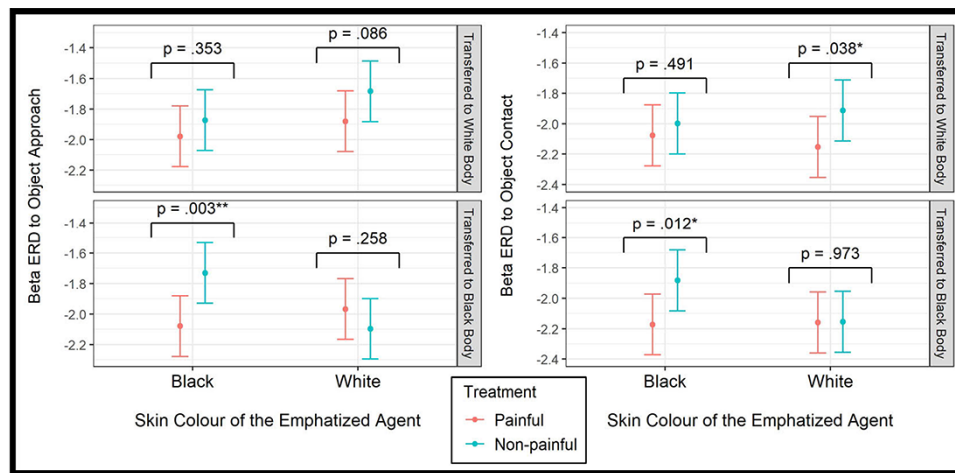
**Fig. 6.** Interaction effect among treatment, agent skin colour and body transfer on beta ERD in the approach phase (left panel) and the contact phase (right panel). The y-axes represent average CSD ERD/ERS activity at the contact phase across all ROIs. Error bars indicate standard errors of EMMs. The *P* values are related to the planned pairwise comparisons of EMMs.

hemisphere ($P < 0.001$) and treatment ($P = 0.014$), similar interactions were found among hemisphere, treatment and body transfer ($P = 0.007$) and among treatment, skin colour and body transfer ($P = 0.041$). Again, no significant higher-level interaction effects were found. As Figure 6 (right panel) shows, the non-lateralized pain-related ERD in the contact phase occurred only when the perceiver was transferred to the same colour body as the agent, similarly to the approach phase. This implies that the modulatory influence of body transfer on empathic resonance to similar looking targets continues from the approach phase to the contact and is visible across the ROIs when limiting the examination to black and white skin colour conditions.

## Discussion

We investigated whether increasing bodily resemblance between the observer and the victim by means of virtual transfer to a different colour body increases the observer's sensorimotor resonance to ethic outgroup member's pain. In accordance with the first hypothesis (H1), the participants estimated noxious treatment of white agents as more painful-looking than similar treatment of black agents. However, contrary to H2, transfer to a black body did not mitigate this ingroup bias in self-reported vicarious pain. Concerning ERD/ERSs, beta rhythms in the right ROIs exhibited enhanced desynchronization in response to noxious objects approaching and touching the black agent's hand. The pain-related beta ERD was further dependent on which colour body the participants were transferred to: Being in a black body resulted in amplified beta ERD in response to black agent's painful treatment, whereas embodying a white body dismissed the pain-related beta ERD to black agent's pain. This modulatory effect of body transfer was visible also in the contact phase. Exploratory analysis focusing solely on the black and white skin colour conditions indicated a non-lateralized effect of skin colour congruency between the perceiver and the agent on pain-related beta ERD. This effect was present both when being in a black body and seeing a black agent in pain and when being in a white body and seeing a white agent being hurt. Overall, the results give support for H1 in terms of self-reports but speak against H2 according to which increasing self–other similarity would reduce ethnicity

bias in vicarious pain. Instead, pain-related alterations in sensorimotor beta seemed to be limited to situations in which the skin colour of the empathized target matched the participant's own skin colour. In the following paragraphs, we will elaborate the findings and their implications in more detail.

In consistency with previous reports (Montalan *et al.*, 2012; Trawalter *et al.*, 2012; Riečanský *et al.*, 2015), black agents' painful treatment was perceived as less painful-looking than similar treatment of white agents that represented participants' ingroup. Such ingroup bias has previously been demonstrated in studies utilizing pictures (e.g. Montalan *et al.*, 2012) and video clips (e.g. Riečanský *et al.*, 2015) of painful needle injections and has suggested to drive the persistent racial and ethnic disparity in medical treatment of pain (Kaseweter *et al.*, 2012; Tait and Chibnall, 2014; Mende-Siedlecki *et al.*, 2021). Here, we replicated this effect presenting virtual human agents as targets of various kinds of painful treatments. Contrary to H2, however, transfer to a black body did not mitigate the ingroup bias in self-reported vicarious pain. The result suggests that in case virtual body transfer does modulate ethnicity-related bias in vicarious pain, the modulatory influence occurs outside of consciousness.

With regard to the neural responses, our findings extend the current understanding of sensorimotor processes involved in empathy for pain. Witnessing a tactile stimulation of another person's skin is known to activate the observer's somatosensory cortex (Keysers *et al.*, 2010). This sensorimotor resonance, as manifested in ERD in cortical beta and mu oscillations (e.g. Perry *et al.*, 2010; Riečanský *et al.*, 2015), was also observed in the current study. Similar to previous studies (Riečanský *et al.*, 2015, 2020), an approaching tactile contact induced beta ERD. Contrary to some other studies (e.g. Riečanský *et al.*, 2015), however, we found the ERD being stronger on the left hemisphere. This lateralization was unanticipated but could be due to the fact that the stimulation was systematically targeted to the agents' right hand. That is, while the direction of the approaching object was randomized and the contact point was centralized, the targeted hand was always agent's right hand orienting towards the right side of the participant's peripersonal space. The hand orientation could have resulted in anticipatory sensorimotor activity contralateral to the oriented side given that spatial attention is associated with

a lateralization of mu and beta ERD when anticipating a painful stimulus (May *et al.*, 2012).

Regarding pain-related resonance, we found beta ERD on the right hemisphere to be strengthened by noxious *vs* soft object approaching and touching black agent's hand. While a similar trend was observed on the right hemisphere when a white agent was touched, no difference was observed between the noxious and soft object when a violet agent was the target. Intriguingly, this effect was further dependent on which colour body the observers themselves were embodying: seeing a black agent being hurt amplified beta ERD in the right sensorimotor sites only when the participants themselves were in a black body. A trend of selective beta ERD to a white agent's pain while being in a white body was also observed but the pairwise comparisons between the noxious and soft treatment did not reach statistical significance on the right hemisphere. However, exploratory analyses focusing solely on the black and white skin colour conditions revealed that the effect of congruent skin colour on pain-related beta ERD was not entirely lateralized as a non-lateralized effect of skin colour congruency could be observed in both black–black and white–white agent-perceiver conditions. Somewhat similar results have been reported earlier by Riečanský *et al.* (2015) who found white participants' sensorimotor beta ERD to increase in response to noxious treatment of white but not black targets. However, Riečanský *et al.* (2015) reported the beta ERD occurring bilaterally and only in the approach phase. In the current study, the ERD extended from the approach phase to contact phase, the modulatory effect being lateralized to the right particularly in the black skin colour condition. While the reason for these differences remains unclear, they could well be explained by the orientation of the target hand and other low-level perceptual differences between the stimuli.

A potential explanation for the unexpected observation that sensorimotor empathic resonance was generally stronger to black than white agents' painful treatment could be that the participants experienced the black virtual body as particularly salient and interesting because it differed so drastically from their real bodily appearance. The novelty could have increased attention paid to the treatment, which could have resulted in a stronger pain-related beta ERD in the matching skin colour condition. Another explanation could be that the low-level sensory features of the black body (shading and luminance) were attracting the perceiver's attention more to the animation, resulting in amplified beta ERD. Whether being due to novelty or perceptual salience, further research is needed to replicate and scrutinize the observation.

It is nevertheless evident that seeing another person in pain induces sensorimotor resonance and that this resonance is dependent on the perceived resemblance between the victim and the observer (Avenanti *et al.*, 2010; Riečanský *et al.*, 2015; Zhou and Han, 2021). As a follow up to their 2015 study, Riečanský and colleagues (2020) showed that weakening the bodily boundaries between the observer and the victim increased sensorimotor resonance to the victim's pain and diminished the previously observed ethnicity bias in beta ERD. Contrary to the spatial overlap set-up of Riečanský and colleagues, we kept the observer's body separate from the body of the target and, by momentarily transferring the observer to the same colour body, increased self–other similarity between the observer and the target. With this set-up, we were able to show that the strength of pain-related beta ERD was the strongest when the perceived self–other similarity was high.

Temporarily perceived similarity and bodily overlap may thus boost the desynchronization of beta in response to others' pain.

What remains open, however, is what functional processes the suppression reflects. The two most likely are mirrored anticipatory somatosensation and motor preparation, both of which are associated with beta ERD (van Ede *et al.*, 2010; Pfurtscheller and Da Silva, 2005). Expectations of upcoming tactile stimulations are known to modulate pre-stimulus beta ERD in the somatosensory cortex supposedly reflecting increased excitability of S1 neurons to an incoming sensory signal (van Ede *et al.*, 2010). Moreover, expecting self-targeted painful stimulation results in a stronger pre-stimulus suppression of beta than expecting a non-painful touch (May *et al.*, 2012). From the perspective of mirrored somatosensation, our findings imply that the anticipation of another person's painful treatment causes enhanced somatosensory processing in the observer particularly when there is resemblance between the observer and the victim.

Another possibility is that the observed beta suppression reflects increased readiness for defensive motor response (Riečanský *et al.*, 2015). Beta power is indeed known to decrease before and during movement execution (Pfurtscheller and Da Silva, 2005) and just witnessing a motor movement results in beta suppression (Avanzini *et al.*, 2012). Furthermore, a series of TMS studies have revealed an involvement of the primary motor cortex in vicarious pain (e.g. Avenanti *et al.*, 2005, 2010). It is unclear, however, whether suppression in beta power reflects involvement of the primary motor cortex or some other related areas (for further discussion, see Riečanský *et al.*, 2015).

Further research is thus needed to unravel the functional processes underlying beta suppression in the context of vicarious pain. Here, it is crucial to directly measure observers' readiness for motor movements and use methods with higher spatial resolution such as source-reconstructed MEG or high-density EEG to distinguish between motor and somatosensory sources. Indeed, in a recent study by Zhou and Han (2021), MEG with MRI-based source reconstruction was acquired to examine spatial-temporal neural dynamics of ethnicity-related bias in processing facial expressions of pain. Early mu ERD in response to outgroup member's pain was found and localized at the left and right sensorimotor cortex and the left insular cortex. Intriguingly, reduced self-reported empathy towards outgroup members' suffering predicted decreased functional connectivity between the sensorimotor and insular cortex. A similar approach with a relatively high spatial and temporal resolution would greatly benefit the understanding of the role of sensorimotor beta ERD in vicarious pain experience. It is also crucial to conduct studies aiming at replicating the reported effects. In the current study, large amounts of statistical tests were required to follow the complex interaction effects, which may have increased the risk of type-I error.

These limitations notwithstanding, our results are highly relevant for understanding how bodily resemblance shape intergroup biases in empathy. The modulation of pain-related ERD by virtual body transfer demonstrated here remarkably resembles earlier found effects of body transfer on motor mimicry (Lakin *et al.*, 2003; Farmer *et al.*, 2018). Hasler *et al.* (2017), for example, demonstrated that white participants transferred to a black avatar body showed greater mimicry of a black agent while those participants embodied in a white avatar showed great mimicry of white agents. The influence of bodily resemblance on vicarious pain may thus be limited to certain aspects of empathy, such as motor simulation or mirrored somatosensation, which may be more readily modulated by available sensory feedback. In support of this idea are our findings that virtual body transfer did not influence ingroup bias in self-reported vicarious pain while doing so on the neural sensorimotor level. In addition, our previous findings that virtual

embodiment reduced implicit but not explicit measures of racial bias support this view (Peck *et al.*, 2013).

The conclusion that momentarily increased bodily resemblance selectively shapes sensorimotor but not affective aspects of empathy may, however, be premature since the animated nature of our pain stimuli may have dampened affective resonance to others' suffering. Future studies should therefore examine whether changing the observer's bodily appearance can modulate explicit and implicit vicarious responses to more realistic pain stimuli. Another important avenue for future research is the extent to which virtual embodiment might prove a useful tool in reducing health inequalities. Previous research has employed virtual reality to study medical staff's responses to medial dilemmas (Pan *et al.*, 2016). Using virtual embodiment to increase the similarity between medics and non-white patients might act as a vivid way to highlight inequalities in pain treatment and an ethical way to test whether alterations in self–other similarity could influence real-life treatment decisions.

## Conclusions

The current study provides evidence that perceived bodily resemblance between the observer and the victim increases the observer's sensorimotor resonance to the victim's pain. This influence seems to be transient in its nature as changing flexibly according to changes in the observer's bodily appearance. We therefore demonstrate a novel perceptual intervention technique to battle ethnic ingroup bias in empathic neural resonance, which complements previously developed interventions focusing on higher-level cognitive mechanisms (see Han, 2018). This intervention technique building on virtual body transfer offers an innovative tool for social neuroscience and to uncover the micromechanisms of empathy and intergroup relations.

## Data availability

The data and code used in statistical testing are available at Open Science Framework (https://osf.io/wd86b/). Raw EEG data are available upon request.

## Funding

## Supplementary data

Supplementary data are available at *SCAN* online.

## Conflict of interest

The authors declare that they have no actual or potential conflicts of interest of financial nature concerning this work.

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