Enhanced self-reported affect and prosocial behaviour without differential physiological responses in mirror-sensory synesthesia

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Abstract

Mirror-sensory synesthetes mirror the pain or touch that they observe in other people on their own bodies. This type of synesthesia has been associated with enhanced empathy. We investigated whether the enhanced empathy of people with mirror-sensory synesthesia influences experience of situations involving touch or pain, and whether it affects their prosocial decision making. Mirror-sensory synesthetes ($N=18$, all female), verified with a touch-interference paradigm, were compared to a similar number of age-matched control individuals (all female). Participants viewed arousing images depicting pain or touch; we recorded subjective valence and arousal ratings, and physiological responses, hypothesizing more extreme reactions in synesthetes. The subjective impact of positive and negative images was stronger in synesthetes than in control participants; the stronger the reported synesthesia, the more extreme the picture ratings. However, there was no evidence for differential physiological or hormonal responses to arousing pictures. Prosocial decision making was assessed with an economic game assessing altruism, in which participants had to divide money between themselves and a second player. Mirror-sensory synesthetes donated more money than non-synesthetes, showing enhanced prosocial behaviour, and also scored higher on the Interpersonal Reactivity Index as a measure of empathy. Our study demonstrates the subjective impact of mirror-sensory synesthesia and its stimulating influence on prosocial behaviour.

Keywords: mirror-touch synesthesia, mirror-pain synesthesia, empathy, altruism, stress response, prosocial behaviour

Introduction

In mirror-sensory synesthesia, people feel touch or pain on their own bodies when seeing someone else being touched or being in pain [1, 2]. It is one of the most prevalent forms of synesthesia, estimated to affect 1.6% of the general population [3]. A proposed mechanism that may underlie mirror-sensory synesthesia is hyperactivity in the somatosensory mirror-system, causing observed touch or pain to be consciously perceived in synesthetes [2, 4-9].

Normally, observed touch is subconsciously represented in this ‘tactile mirror system’ in somatosensory cortex to facilitate understanding of touch in others [10-13]. Observed pain is represented in the ‘pain matrix’, a system of both (somato)sensory and affective brain regions that reflect the sensory intensity and the affective impact of pain inflicted upon others, respectively [7, 14-16]. Enhanced responses in the tactile mirror-system in non-synesthetes have been related to enhanced empathy ratings [5, 17], suggesting that the more sensitive the tactile mirror system is, the more empathic individuals are. It is therefore not surprising that mirror-sensory synesthesia is related to enhanced empathy [1, 18, 19]. Because of enhanced socio-cognitive abilities [20], atypical self-other representations have also been proposed as the main mechanism of mirror-sensory synesthesia [21, 22], with more inclusive representations of the ‘self’ facilitating the incorporation of others’ experiences into their own body [23].

In mirror-sensory synesthesia, stronger empathy is expected because synesthetes experience on their own body any unpleasant sensation they observe on others: being more sensitive to other people’s misfortunes, they would be more motivated to relieve others’ suffering [24]. Heightened empathy in mirror-sensory synesthetes [1, 18, 19, 25] has mainly been reported on the Emotional Reactivity subscale of the Empathy Quotient (EQ) questionnaire [26]. Ward et al. [19] also report marginal correlations of mirror-sensory synesthesia scores with the Personal Distress and Empathic Concern subscales of the Interpersonal Reactivity Index [27]. The subscores are relevant because empathy has both emotional and cognitive components: shared feelings and emotions, and reasoning about others’ mental states and perspective taking, respectively. The questionnaire results for mirror-sensory synesthesia point to enhanced emotional aspects of empathy. One study failed to find enhanced empathy in mirror-sensory synesthesia [28] (using the EQ). However, mirror-sensory synesthetes in that study were not verified with an objective procedure, but only assessed via self-report.

As far as we know, empathy in mirror-sensory synesthesia has only been assessed with questionnaires. It has not yet been tested in experimental settings in which empathy may influence one's experience of situations involving touch or pain [16, 29, 30], or one's prosocial decision making [e.g. 24, 31, 32]. We hypothesised that mirror-sensory synesthesia may affect these processes. We conducted two experiments for which the rationale is described in the next sections.

Subjective impact of mirror sensory synesthesia

Mirror-sensory synesthetes report that mirror-sensory synesthesia can be unpleasant when observing others in a painful situation. Given their 'mirroring' of pain and heightened empathy, it is expected that for mirror-sensory synesthetes the subjective impact of seeing other people being touched or in pain is enhanced, leading to greater emotional arousal when observing others in a painful situation. The extent to which the subjective judgment of unpleasant situations of mirror-sensory synesthetes is affected by their synesthesia has been tested empirically only in vicarious pain responders, as far as we are aware [25]. In this study, individuals experiencing vicarious pain viewed video clips containing fear, pain, or positive emotion, and physiological reactivity was measured. Vicarious pain responders had a lower respiration rate than controls for all emotional stimuli, suggesting distress, but this effect was associated with heightened trait anxiety. No group differences were found on the subjective ratings of the video clips (e.g. arousal, emotional state). Here, we test the subjective impact of seeing (un)pleasant touch/pain in mirror-sensory synesthetes (mainly those who experience mirror-touch) and relate this subjective impact to measures of synesthetic strength, measures of empathy, and measures of physiological changes in the body accompanying empathic responses [e.g. 33].

Normally, when encountering unpleasant situations, we respond with changes in our behaviour, and autonomic and neuroendocrine parameters also change [34]. If mirror-sensory synesthetes indeed experience stronger emotional arousal when observing painful situations, this may in turn lead to stronger autonomic nervous system activity, as is reported for arousing stimuli [34-36], and to increased stress responses [37]. Autonomic nervous system responses to negative situations include increases in physiological parameters like heart rate, pupil dilation, and skin conductance [34, 35]. The concept of *stress* refers to the physiological mechanisms necessary to maintain and restore the balance after perturbation. One of the main stress-coping strategies involves the hypothalamic-pituitary-adrenal (HPA) axis, which culminates in the release of glucocorticoids, principally cortisol [38]: the 'stress hormone'.

The concentration of cortisol in the blood (plasma or serum) is an indication of the size of the stress response and the measurement of salivary cortisol can be used as a surrogate for free serum/plasma cortisol [39]. Autonomic physiological responses and the release of cortisol are not necessarily correlated [40, 41].

In this study we investigated whether viewing (un)pleasant situations of touch and/or pain led to enhanced subjective emotional arousal and more extreme valence ratings in mirror-sensory synesthetes compared to controls, and whether this (enhanced) emotional arousal was accompanied by physiological autonomic and stress responses. We asked our participants to subjectively rate pictures with physical context (negative, positive, and neutral) for valence and arousal while measuring their heart rate, pupil dilation, and skin conductance as measures of autonomic activity, and salivary cortisol levels as an index of stress. Eye movements during picture viewing were recorded to assess whether synesthetes showed differential viewing durations and fixation patterns for pictures of different physical context. Stimulus conditions with emotional pictures were added in which there was no physical context. These served as stimulus conditions in which it was mainly affective, not physical context that would cause emotional reactions.

Empathy, theory of mind, and altruism in mirror-sensory synesthesia

It has not been addressed in the literature whether enhanced empathy in mirror-sensory synesthetes affects prosocial decision making. Several studies do report on the relation between mirror-sensory synesthesia and social skills. Banissy et al. [20] and Ward et al. [19] showed that mirror-sensory synesthetes are better at judging subtle facial expressions, but not at recognition of faces, consistent with the idea that enhanced mirror-abilities in the somatosensory system can improve social perception through simulation. In another study by Baron-Cohen et al. [28] however, synesthetes did not perform better on the Reading the Mind in the Eyes test, an assessment of ‘theory of mind’ abilities and social understanding [42], and they scored lower on the Social Skills component of the Empathy Quotient. In Santiesteban et al. [43], mirror-touch synesthetes also did not perform differentially on a test of theory of mind, the movie for the assessment of social cognition (MASC, [44]). It is possible that the lower social abilities reported in the Baron-Cohen et al. study can be explained by a high occurrence of autism (30%) among the included mirror-sensory synesthetes. Summarizing, although mirror-sensory synesthetes have enhanced abilities to recognize facial expressions and theory of mind abilities appear not to be altered, it is not clear whether other aspects of

social or prosocial behaviour are changed. We assessed this question with an experiment to test altruistic behaviour.

Conclusions about human altruism can be drawn from observing human behaviour after natural disasters, in everyday life or through simulations of everyday situations. To stimulate altruistic behaviour in the laboratory, economic games based on game theory are often used [45]. The basic idea involves one player dividing a sum of money between himself or herself and a second player. In a ‘Dictator’s game’ [46] the second player just has a passive role. The behaviour of people who donate large amounts of money in this game is interpreted as altruistic. To assess altruism in mirror-sensory synesthetes, our participants played such a one-shot Dictator’s game [46]. Empathy is considered one of the main reasons why people adopt prosocial, altruistic behaviour [47], hence we expected heightened altruism in mirror-sensory synesthesia. We hypothesized that individuals with mirror-sensory synesthesia would donate larger amounts of money than non-synesthetes and that prosocial behaviour would be linked to empathy scores on either the Empathy Quotient or the Interpersonal Reactivity Index. Synesthetes additionally performed the Reading the Eyes in the Mind test to assess theory of mind abilities.

Approach

In this study we tested the impact of mirror-sensory synesthesia on viewing pictures with arousing context, collecting data on subjective picture ratings, physical responses, and eye movements, as well as assessing altruistic behaviour, empathy, and theory of mind skills in mirror-sensory synesthetes. Mirror-sensory synesthesia was confirmed with an established behavioural vision-touch interference paradigm (Banissy & Ward, 2007). We hypothesized that people with mirror-sensory synesthesia would be more affected than non-synesthetes while viewing pictures with arousing physical context, and would have larger physiological responses and develop higher cortisol levels related to stronger emotional arousal. We specifically predicted that individuals with more extreme subjective negative arousal ratings would display more physiological stress activity. Moreover, we predicted that individuals with mirror-sensory synesthesia would score higher on tests assessing empathic-altruistic behaviour than control participants without mirror-sensory synesthesia, because the synesthetes are more sensitive to other people’s state.

Methods

Participants

Synesthetes were recruited through announcements on campus and in the media and underwent structured interviews via email prior to inclusion. We asked about the manifestation of mirror-sensory synesthesia for pain and/or touch, whether they had consistently experienced this all of their lives (consistency and developmental criterion), for examples of synesthetic inducers (verifying specificity to observed touch and/or pain, and excluding emotions as inducers), and about age and general condition. Only synesthetes who experienced the observed pain and touch on their own body at the same location as in the observed situation were invited to our laboratory, excluding individuals who experienced whole-body sensations or sensations at another location (seemingly) unrelated to the observed touch. Control participants were recruited through the university recruitment platform and printed announcements on campus, and screened for neurological and psychiatric conditions prior to inclusion.

After the abovementioned screening, 36 individuals, i.e. 18 synesthetes ($M_{\text{age}}=43.6$, $SD=13.9$, range 24-63) and 18 control participants ($M_{\text{age}}=42.6$, $SD=14.40$, range 20-68), all female, took part in the study. We did not have any gender exclusion criteria during participants' recruitment, but many more female than male synesthetes responded to our call for participants. Because we anticipated that we would only be able to include a very limited number of male synesthetes we decided to include only females to obtain a homogeneous sample population. The synesthete and control group did neither differ in age ($t(34)=0.20$, $p=.84$) nor educational level ($t(19)=-.52$, $p=.61$, not reported by everyone). Participants were mostly educated at the applied university or university level. All participants received information about the study prior to participating and gave informed written consent. Ethics approval was obtained from the local Ethics Committee of the Faculty of Social Sciences (ECSS) of Radboud University Nijmegen.

Procedure

During a 2-hour laboratory visit, participants completed a mirror-touch synesthesia verification experiment, an arousing pictures experiment, and a one-shot Dictator's game. First, in the arousing pictures experiment, participants rated pictures for valence and arousal while their heart rate, skin conductance, and pupil dilation were recorded to monitor stress

responses. Because this experiment was hypothesised to affect the overall mood and stress response of the participants, before and after the experiment saliva samples for cortisol assessment were collected and a mood questionnaire completed. Laboratory timeslots were at 1:30 PM and at 4 PM, as cortisol levels are generally stable at this time of day with no significant changes due to circadian rhythm effects [48]. Next, a verification task was completed to confirm the presence of mirror-touch synesthesia by means of an established vision-touch interference paradigm [1]. This verification task and its results are described in the Supplementary Material. Finally, participants completed an exit questionnaire with questions on the experienced synesthesia during the experiments. At the very end of the lab visit the third experiment was conducted: participants played a one-shot Dictator's game to assess altruistic behaviour. Additional empathy and theory of mind questionnaires were completed online from home. We now turn to each experiment in detail.

Mirror-sensory synesthesia verification experiment

In this vision-touch interference paradigm [1], participants were asked to report the location of actual touch applied to their cheeks by an electrical tactile device while observing videos of another person or object being touched. For mirror-sensory synesthetes, the additional experience of synesthetic touch leads to more errors in situations where the actual touch and touch as observed in the video do not match. Following the approach of the original study, the presence of this synesthetic interference was verified at the group level. Here we additionally explored the interference at an individual level for each participant. For details on how this experimental synesthesia verification task was run see the Supplementary Methods and for the paradigm see Supplementary Figure S1.

Arousing pictures experiment

Participants rated pictures for arousal and valence while physiological responses and eye-movements were recorded. At specific timepoints before and after the experiment, cortisol levels and mood state were assessed.

Stimuli. There were five stimulus categories: pictures with positive, negative, or neutral physical context ($N=20$ per condition), and emotional pictures with faces of positive or negative context ($N=15$ per condition). A picture from the negative physical condition would show injuries or painful events involving touch (e.g. an injection), while the positive physical pictures included pleasant sensations of touch (e.g. soft materials, see Fig. 1 for example

stimuli). Neutral physical pictures included everyday tasks involving touch like washing dishes or reading (as in Fig. 1). Finally, the emotional pictures included close-ups of people with either negative (e.g. sad, angry, nervous) or positive (e.g. smiling, laughing) facial expressions.

Fifty-four pictures were selected from the International Affective Picture System (IAPS) database for affective stimuli [49, 50] and 36 were created by us. For the stimuli that we created ourselves valence and arousal ratings were not yet available, and so 14 volunteers (aged 21-64, nine females) rated them online (presented in Limesurvey, <https://www.limesurvey.org/>) using the Self-Assessment Manikin (SAM) scales (1 to 9) for valence and arousal [51]. For the final stimulus selection, we included pictures with the following mean ratings (derived from the IAPS database or our pilot ratings) for valence: $M_{\text{neg}}=2.8\pm0.52$, $M_{\text{pos}}=6.9\pm0.52$, $M_{\text{neu}}=5.5\pm0.56$, $M_{\text{emo_neg}}=3.5\pm1.2$, $M_{\text{emo_pos}}=6.7\pm1.1$; and for arousal: $M_{\text{neg}}=5.9\pm0.64$, $M_{\text{pos}}=4.3\pm1.2$, $M_{\text{neu}}=3.7\pm0.41$, $M_{\text{emo_neg}}=4.8\pm0.95$, and $M_{\text{emo_pos}}=3.7\pm0.67$.

We controlled for orientation of the pictures (landscape/portrait), the sex of actors, and picture luminance across conditions. Picture dimensions were 1024 x 768 pixels and all images subtended 28 x 21 degrees of visual angle, presented on a Benq XL2420Z 24" monitor with a refresh rate of 120 Hz.

< insert figure 1 here >

Subjective ratings procedure. Initially each picture was presented for 6 seconds, after which the SAM scale for valence appeared below the picture and participants entered their response [51]. Next, the SAM scale for arousal appeared and was completed. If trial duration at that point was still less than 20 seconds, a fixation cross was presented until a trial duration of 20 s was reached; otherwise the next trial started immediately. The long interval between the presentation of two pictures was necessary to allow the skin conductance to return to baseline.

Before the actual experiment, participants familiarised themselves with the task through 5 practice trials, and were allowed to ask questions. A chin rest was used and participants were instructed to move as little as possible in order to avoid motion artifacts in the physiological measurements.

Physiological responses: measurements. Heart activity (electrocardiogram, ECG), skin conductance, and pupil dilation were recorded for the duration of the entire experiment. Heart activity (mV) and skin conductance (delta microsiemens) were measured with BioPac Student Lab (<https://www.biopac.com/education/>) software using a sampling frequency of 1000 Hz. For the heart activity three electrodes were used, two on the participant's wrists and one on the right ankle. For the skin conductance two electrodes were placed on the middle finger and index finger of the non-responding hand. Gel was applied at the touching points to facilitate ion conductance. For the pupil dilation assessment and eye-movement recording a SatoriMotorInstruments (<http://www.smivision.com/en.html>) Red 3 eye tracker was used with a sampling rate of 500 Hz.

Physiological responses: data analysis. All physiological data were analysed by in-house routines in Matlab 2013a (MathWorks) and averaged values were obtained for each stimulus condition and participant. Participants with insufficient amounts of artifact-free data were removed from analysis (less than 40 trials remaining).

Pupil dilation. Relative pupil dilation was determined for the stimulus period (0-6 s picture presentation) by dividing by the prestimulus baseline pupil dilation (-1 until 0 s). Trials on which activity during the initial 200 ms of the trial (0-200 ms) dropped below or exceeded the baseline value by 10% were excluded from analysis. On average, $M=73$ ($SD=13.7$) trials remained for each participant. We compared pupil dilation during 2-6 seconds after picture onset, when the pupils had stabilised after the initial response to luminance change.

Heart rate. Raw ECG traces were epoched into segments of 6 seconds from picture onset until picture offset. Trials on which the heart signal exceeded 0.2 mV on average or sunk below -0.2 mV on average for more than two seconds during picture presentation were excluded from analysis. ECG data for the remaining trials were detrended and the peaks detected in order to calculate the number of beats per minute. Peak detection was manually checked for each participant. On average, $M=71.7$ ($SD=15.3$) trials remained for each participant.

Skin conductance. Relative changes in skin conductance were computed as the difference between the amplitude of the peak (occurring within 8 seconds after picture onset) and the onset value of each trial. Trials in which the peak occurred within 500 ms of trial onset, exceeded the baseline value by 10%, exceeded the value 4 or where there was a large jump in the value (>0.2) were excluded from analysis.

Correlation analysis. We assessed whether subjective valence and arousal ratings correlated with the physiological measures obtained in the arousing pictures experiment on a trial-to-trial basis. For each group and each stimulus condition, bivariate Pearson correlations were run across all available variables. Bonferroni correction for multiple comparisons across groups and conditions was applied on the obtained statistics.

Eye movements. For the three physical picture categories, we analysed the number of fixations and the time spent looking at pre-defined Regions of Interest (ROIs) containing the area(s) of physical touch. For details on the procedure see the Supplementary Methods.

Assessing cortisol levels and mood state. Saliva samples for obtaining cortisol levels were collected at the start of the arousing pictures experiment, 25 minutes after completion of the arousing pictures experiment, and at home several days after the laboratory experiments (baseline measure). The mood state of the participants was assessed along with the cortisol measurements, i.e. before and after the arousing pictures experiment (as well as a baseline measure at home) using the Positive and Negative Affect Schedule (PANAS) questionnaire [52]. Participants were asked to rate to which extent they experienced 20 different emotions on a 5-point Likert Scale with (1) being “very slightly” and (5) “very much”. The time point of the second saliva sample was chosen as such because cortisol has its peak 20-30 minutes after the induction of stress [53] and it takes a few minutes for cortisol to diffuse from the blood into the saliva. The baseline sample collection (and mood state questionnaire completion) at home was done at exactly the same time of day (hour and minute) as the first measurement at the laboratory, and participants sent an email to the experimenters just after collecting the sample at home to verify that they completed the task at the indicated time. The saliva samples were mailed back to us via post. For details on the procedure for collecting the cortisol samples see the Supplementary Methods.

Dictator’s game

A one-shot Dictator’s game was played [46, 54] to assess altruistic behaviour. Participants were given a folder, containing instructions and two envelopes: one envelope contained ten 1-euro coins and the other was empty. Participants were told to open the folder and follow the instructions while the experimenter left the room. They were instructed that they were to be Player A in a game. Participants always had the role of Player A in the game but they were informed that the role was assigned by a random draw. As Player A, the participant had the

opportunity to either keep the full amount of money in the envelope or to give some of it to Player B. The only information that participants had about Player B was that he or she was also someone participating in a research experiment and that his or her role had also been assigned randomly. The participants were reassured that their response would be completely anonymous as neither the experimenters nor Player B would learn about their identity or about the amount that they had donated. After making their decision on how much money to donate to player B, participants had to place the money to be given away in one of the envelopes and put it in a cardboard box that was placed in the laboratory for this purpose. They could keep the rest of the amount in the second envelope and take it with them. Participants did not know beforehand that the Dictator's game was part of the experiment and were only told about it at the moment that the Dictator's game was to take place.

Questionnaires

Exit laboratory questionnaire. Before leaving the laboratory (and before playing the Dictator's game), participants completed an exit questionnaire rating the intensity of the synesthetic touch (and/or synesthetic pain) as experienced during the two behavioural experiments on a 5-point Likert scale with (1) being "very slightly" and (5) "very much". They additionally completed questions about their menstrual cycle, relevant for the cortisol assessments.

Online questionnaires assessing empathy and theory of mind. Participants were emailed a link to several online questionnaires to be completed at home, presented with LimeSurvey software (<https://www.limesurvey.org/>). One questionnaire was about synesthetic experiences, history of neuropsychiatric disorders, medication use, etc; additionally empathic behaviour was assessed with the Empathy Quotient [26] and the Interpersonal Reactivity Index [27] questionnaires. Theory of mind abilities were probed with the Reading the Mind in the Eyes test [42]. Detailed descriptions of the questionnaires are provided in the Supplementary Methods.

Results

Of the 18 synesthetes and 18 controls, one control dropped out: she stopped participating during the arousing pictures experiment due to an inability to stay still, and as the amount of available data was too low for inclusion this participant was excluded from all analyses.

Furthermore, heart rate and skin conductance data of one synesthete and two controls were lost due to a technical failure of the automatic data storage. For one synesthete, failure of the eye-tracker halfway through the measurements led to the loss of half of the pupil and eye-movement data. In statistical analyses where the assumption of non-sphericity was violated (Mauchly's Test of Sphericity), Greenhouse-Geisser correction was applied.

Apart from the frequentist statistics, Bayesian statistics [55] are additionally reported for each negative result, since they allow disentangling between the absence of evidence and evidence of absence. Bayesian statistics assess the likelihood of the data under both the null and the alternative hypothesis. Here we report BF_{10} , corresponding to the $p(\text{data}|H_1)/p(\text{data}|H_0)$. A BF between 0.3 and 3 indicates that the data is similarly likely under the H_1 and H_0 , and that the data thus does not adjudicate which is more likely. A BF_{10} below 0.3 or above 3 is interpreted as supporting H_0 and H_1 , respectively [56]. BF were calculated using JASP [57] and the default priors implemented in JASP.

A power calculation [58] indicates that with a minimum of 30 participants left in the analyses and a power of 0.80, we should be able to detect between-within interaction effects with a small effect size ($\eta_p^2 \approx .050$), and between-groups effects with a slightly higher but still intermediate effect size ($\eta_p^2 \approx .16$). For two-sample t-tests, effect sizes are reported as Hedges' g as we often had different samples sizes for each group [59]. Hedges' g follows Cohen's d in its interpretation (0.2 = small effect, 0.5 = medium effect, 0.8 = large effect).

Mirror-sensory synesthesia verification experiment

Data from 16 synesthetes and 17 controls were analysed. Two synesthetes did not follow the instructions correctly and their data were not analysed further, and their synesthesia was thus solely verified by subjective report. Detailed results are presented in the Supplementary Results section, Supplementary Figure S6, and Supplementary Tables S1.1 and S1.2: the results concur with earlier reports of more 'mirror touch errors' at the group level in the incongruent and no-touch conditions of this set-up [1]. We report increased reaction times and increased errors (Fig. S6) for synesthetes for the incongruent condition, in a group analysis of the person videos.

When considering the individual data, for 8 out of 16 synesthetes significantly increased errors for incongruent versus congruent trials were present at the individual level (Supplementary Table S1.1), verifying the subjective reports of mirror-touch synesthesia. All

synesthetes who did not show a congruency effect at the individual level reported experiencing synesthetic sensations for touch and/or pain during the pictures experiment, as indicated in the exit questionnaire. Most of these individuals reported strong synesthetic sensations of pain (3, 4, or 5 on a scale from 1 to 5); pain stimuli were not included in the verification experiment but they were present in the pictures experiment. Thus, after considering individual error rates and subjective reports, all synesthetes were retained in the sample. We would like to point out that subjective reports of synesthetic experiences are also used to verify mirror-touch synesthesia in other studies [19, 28]. For details on the individual data of the control participants please see the results section of the Supplementary Material.

Arousing pictures experiment

Subjective ratings. Subjective ratings for the arousing pictures were computed from 16 synesthetes and 14 controls. Apart from the one control who did not finish the experiment, three controls were excluded as they did not make correct use of the arousal rating scales (failing to interpret number 5 as the middle (neutral) of the scale). Two synesthetes were excluded as they reported having autistic traits (including them did not change the main findings). Data from the physical stimulus conditions were analysed separately from the data of the emotional stimuli to allow us to assess whether physical stimuli would lead to different effects from those seen for emotional stimuli.

Physical stimulus conditions. In a repeated measures ANOVA with the within-subject factor Physical Context (negative, positive, neutral physical picture context) and the between-subject factor Group (synesthetes, controls) a significant interaction between Physical Context x Group was found for both valence ($F(2,56)=10.2$, $p<.001$, $\eta_p^2=0.27$ and (in a separate repeated measures ANOVA) for arousal ($F(2,50)=8.23$, $p=.001$, $\eta_p^2=0.25$). Regarding valence (Fig. 2A), posthoc independent samples t-tests revealed that there was an effect of Group for each stimulus condition, with synesthetes rating negative pictures as more negative than controls (2.2 vs 2.7, $t(28)=-2.08$, $p=.046$, $g=0.76$) and positive and neutral pictures more positive (6.7 vs 5.9, $t(28)=3.33$, $p=.002$, $g=1.22$ and 5.5 vs 5.0, $t(28)=2.65$, $p=.013$, $g=0.97$ respectively). For arousal (Fig. 2B), the interaction was driven by the negative context (7.2 vs 6.1, $t(25)=3.48$, $p=.002$, $g=1.35$) in which synesthetes rated the pictures as more arousing than controls, while there was no group effect for the positive context (4.2 vs 4.7, $t(25)=-1.61$, $p=.12$, $g=0.62$) nor the neutral context (4.7 vs 4.3, $t(25)=1.18$, $p=.25$, $g=0.46$) with the Bayesian statistics providing inconclusive evidence ($BF_{10}=.92$ and $BF_{10}=.60$ respectively). As

expected, the results showed that synesthetes were influenced more by the context of negative and positive pictures, rating them more extremely than control participants did, also on the arousal scale.

Emotional faces conditions. A repeated measures ANOVA with the within-subject factor Emotional Context (positive, negative emotional faces) and the between-subject factor Group (synesthetes, controls) revealed a significant interaction between Emotional Context x Group ($F(1,28)=17.0, p<.001, \eta_p^2=0.38$) for the valence ratings (Fig. S2). The interaction was driven by more positive ratings of synesthetes than controls for the positive emotional faces context (7.2 vs 6.1, $t(28)=4.02, p<.001, g=1.47$) while there was no effect for the negative context (3.3 vs 3.6, $t(28)=-1.6, p=.12, g=0.60$) where Bayesian statistics provided inconclusive evidence ($BF_{10}=0.92$). For arousal, there was no significant interaction between Emotional Context and Group ($F(1,25)=1.44, p=.24, \eta_p^2=.054$), with the Bayesian version of the same ANOVA resulting in a $BF=.46$ limiting the interpretability of the effect. A main effect of condition was observed with both groups rating the negative emotion condition as more arousing than the positive condition (ratings 5.6 vs 4.7, $F(1,25)=11.1, p=.003, \eta_p^2=0.31$). The results mirror those of the physical stimulus conditions except that there was no effect on the arousal measure.

< insert figure 2 here >

Physiological responses. Pupil dilation. Pupil dilation data from 16 synesthetes and 17 controls with the required amount of artifact-free trials (>40) were analysed.

Physical stimulus conditions. Pupil dilation in the negative condition was larger than in the positive and neutral conditions (Fig. 3). In a repeated measures ANOVA with the within-subject factor Physical Context (negative, positive, neutral picture context) and the between-subject factor Group (synesthetes, controls), a significant effect of Physical Context was found ($F(2,62)=9.63, p<.001, \eta_p^2=0.24$). There was no interaction between Physical Context x Group ($F(2,62)=.201, p=.82, \eta_p^2=.006$) which was also confirmed by the Bayesian version of the same ANOVA with a $BF=.21$ and there was no Group effect ($F(1,31)=.088, p=.769, \eta_p^2=.003$) observed with frequentist statistics, while Bayesian statistics provided inconclusive evidence with a $BF=.36$. Post-hoc paired sample t-tests showed that the positive and neutral condition pupil dilation did not significantly differ from each other (0.89 vs 0.90, $t(32)=-0.97, p=.34, d=.12, BF_{10}=0.28$) while the pupil dilation in the negative condition significantly differed from the positive and neutral condition (0.89 vs 0.93, $t(32)=-4.33, p<.001, d=.70$ and

0.90 vs 0.93, $t(32)=-2.97$, $p=.006$, $d=0.52$, respectively). Summarising, we observed the expected effect of the physical picture context, with negative pictures inducing increased pupil dilation compared to positive and neutral ones, pointing to stronger autonomic activity. We did not, however, observe a difference in pupil dilation responses between synesthetes and controls and Bayesian statistics support the evidence for no group by condition interaction for pupil dilation.

Emotional faces conditions. For the emotional faces conditions, the results were highly similar to the results from the physical stimulus conditions (Fig. S3). A repeated measures ANOVA with the within-subjects factor Emotional Context (positive, negative emotional faces) and the between-subject factor Group (synesthetes, controls) revealed a significant effect of Emotional Context on pupil dilation ($F(1,31)=17.6$, $p<.001$, $\eta_p^2=0.36$). No interaction between Emotional Context x Group ($F(1,31)=1.37$, $p=.25$, $\eta_p^2=0.043$) and no Group effect were found ($F(1,31)=.354$, $p=.56$, $\eta_p^2=0.011$). The Bayesian version of the ANOVA provided inconclusive evidence with $BF=.78$ and $BF=.60$ for the last two findings, respectively. Pupil dilation in the negative emotional condition was larger than in the positive emotional condition.

< insert figure 3 here >

Heart rate. There were 14 controls and 16 synesthetes remaining in this analysis: data of one synesthete and two controls were lost due to technical failure of the automatic data storage; for one synesthete, too few trials remained after artifact rejection (29 trials) and for one control the data were too noisy for reliable peak detection.

Physical stimulus conditions. A repeated measures ANOVA with the factors Physical Context (negative, positive, neutral picture context) and the between-subject factor Group (synesthetes, controls) revealed a marginal Group by Physical Context interaction ($F(2,56)=2.84$, $p=.067$, $\eta_p^2=.092$, $BF=.36$) and no effect of Physical Context ($F(2,56)=1.78$, $p=.18$, $\eta_p^2=.060$), which in the equivalent Bayesian ANOVA was confirmed by a $BF=.017$ (Fig. 4). No Group effect was found ($F(1,28) = 2.82$, $p=.10$, $\eta_p^2=.091$), on which the Bayesian results were inconclusive ($BF=.42$). Thus, although heart rates for the synesthetes were higher overall, this group difference did not reach significance.

Emotional faces conditions. For the emotional faces manipulation a repeated measures ANOVA with the factors Emotional Context (negative, positive emotional faces) and the

between-subject factor Group (synesthetes, controls) yielded no significant effects (Emotional Context: $F(1,28)=.544$, $p=.47$, $\eta_p^2=.019$, $BF=.37$; Group $F(1,29)=2.3$, $p=.14$, $\eta_p^2=.076$, $BF=.48$; Group x Emotional Context $F(1,29)=.001$, $p=.98$, $\eta_p^2=.00$, $BF=.14$, see Fig. S4).

< insert figure 4 around here >

Skin conductance. After cleaning of the raw data, there were 7 synesthetes and 3 controls who retained a sufficient number of trials ($N>40$) for statistical analyses. In rejected trials a reliable skin response was not detected. We did not consider this limited amount of data sufficient for analysis.

Correlations of subjective ratings with pupil dilation and heart rate. To assess whether subjective ratings were related to physiological responses, subjective valence and arousal ratings were correlated with pupil dilation and heart rate on a trial-by-trial basis, for each group and stimulus condition separately (Table S2). For synesthetes, valence and arousal ratings correlated negatively in all three physical stimulus conditions and in the negative emotions condition, in line with the notion that high valence pictures are generally calming and pictures with low valence are arousing. Valence ratings were negatively correlated with pupil dilation in the positive physical condition, indicating more narrow pupils for pictures with high valence ratings, in line with calming effects. Arousal ratings were negatively correlated with heart rate for the neutral physical condition. Interestingly, pupil dilation and heart rate correlated positively in the positive physical stimulus condition in synesthetes, illustrating their covarying nature. For controls, only correlations between valence and arousal ratings reached significance: in the negative physical condition these were negatively correlated, as for the synesthetes, but in the positive physical condition there was a positive correlation.

Cortisol measurements. Cortisol results were obtained for 18 synesthetes and 16 controls; one control dropped out of the experiment and another control did not provide sufficient data. Baseline saliva cortisol levels (at home) did not differ between synesthetes and controls ($F(1,29)=1.26$, $p=.27$, $\eta_p^2=.042$, $BF=.32$, Fig. 5). A repeated measures ANOVA was run with the within-subject factor Timepoint (before and after the arousing pictures experiment) and the between-subject factor Group (synesthetes, controls), and menstrual phase (1-5, for definition see methods) as a covariate of no interest. A marginal effect of Timepoint was observed ($F(1,29)=3.40$, $p=.075$, $\eta_p^2=.011$) while the Bayesian analysis

supported the presence of an effect ($BF=25.5$): cortisol values were lower after the experiment (see Fig. 5). No interaction between Timepoint and Group was observed ($F(1,29)=.010$, $p=.75$, $\eta_p^2=.003$) and no Group effect ($F(1,29)=.398$, $p=.53$, $\eta_p^2=.014$). The results from the equivalent Bayesian ANOVA for the Timepoint x Group interaction and for Group were inconclusive ($BF=.37$ and $BF=.36$). It is unexpected that the cortisol values after the experiment were lower than before the experiment, because we hypothesized that the arousing pictures would increase cortisol levels. Furthermore, we found no increased cortisol levels for synesthetes as compared to non-synesthetes. Across participants, there was no significant correlation of the obtained cortisol values before or after the experiment with subjective ratings of arousal (all $p>0.18$).

< insert figure 5 here >

Mood state. In a repeated measures ANOVA with the within-subject factors Mood (positive mood score, negative mood score) and Timepoint (before and after the arousing pictures experiment, baseline measurement) and the between-subject factor Group (synesthetes, controls), main effects of Mood and Timepoint were found ($F(1,29)=161$, $p<.001$, $\eta_p^2=0.85$; $F(2,58)=4.88$, $p=.011$, $\eta_p^2=0.14$, respectively) as well as an interaction of Mood x Timepoint ($F(2,58)=4.67$, $p=.013$, $\eta_p^2=0.14$). Positive mood scores were reduced after the arousing pictures experiment and negative mood scores enhanced. Baseline measurements did not differ significantly between groups ($t(30)=.072$, $p=.94$, $g=0.026$, $BF=.19$) nor from the other time points (all $p>.05$). There were no main or interaction effects of Group (Group effect $F(1,29)=1.06$, $p=.31$, $\eta_p^2=.035$, Timepoint x Group $F(2,58)=2.26$, $p=.12$, $\eta_p^2=0.07$) while the Bayesian equivalent ANOVA was inconclusive, but close to supporting the absence of effects Group and Timepoint x Group ($BF=.32$ and $BF=.32$, respectively). This is not in line with our hypothesis, as we were expecting that the synesthetes' mood would be more affected by the presentation of pictures with negative arousing context than the mood of the controls.

Eye movements. For detailed analyses see the Supplementary Results. The eye-movement data reflected the results of the pupil dilation data: also here, the negative condition elicited the strongest reaction, and there is no indication that synesthetes differed from controls (see Figure S5).

Dictator's game

Data from 17 synesthetes and 13 controls were included in the analysis (age did not differ between these samples, $t(28)=.229$, $p=.82$, $g=.084$). Four controls and one synesthete were excluded because they misinterpreted the instructions and did not return the envelope with the money to the box as instructed. An independent samples t-test revealed a significant difference in the amount of money donated by synesthetes and controls ($t(28)=2.45$, $p=.021$, $g=.90$) with synesthetes on average donating larger amounts of money (6.71 ± 2.66 vs 3.69 ± 4.07 euros). Thus, as predicted, the Dictator's game suggests heightened altruism in mirror-sensory synesthetes.

Questionnaire results

The battery of online questionnaires on empathy and theory of mind was completed by eleven synesthetes and six controls (age did not differ between these samples, $t(15)=-.351$, $p=.73$, $g=.18$). No group differences were found on the Empathy Quotient (EQ) (nor its subscales) nor the Reading the Mind in the Eyes test (all $.45 < BF_{10} < .69$, inconclusive). Synesthetes scored higher on the Empathic Concern subscale of the IRI ($M_s = 16.4$, $M_c=11.7$; $F(1,13)=5.16$, $p=.041$, $\eta_p^2=0.28$) and on the total IRI score (IRI Total $M_s = 79.1$, $M_c = 61.0$; $F(1,11)=6.42$, $p=.028$, $\eta_p^2=0.37$).

Scores from the online questionnaires were additionally correlated in an exploratory manner with the experimental outcomes of all three experiments. It was found that the more empathic a participant was according to subscale empathy questionnaire scores, the more extreme the subjective ratings scores in the arousing pictures experiment, while for the pupil dilation responses, a reversed effect was found (see SI for the details of these exploratory analyses).

Synesthesia strength – as experienced during the arousing pictures experiment and the verification task and reported in the exit questionnaire – correlated with subjective ratings from the arousing pictures experiment: stronger reported synesthesia led to more extreme ratings. For detailed results see the Supplementary Material. There were no correlations of synesthesia strength with physiological measures, the outcomes of the Dictator's game, nor the questionnaire results.

Discussion

We hypothesized that mirror-sensory synesthetes would show enhanced subjective and physical responses to arousing pictures because of their stronger empathic skills. We successfully verified mirror-sensory synesthetes with a vision-touch interference paradigm and found that their subjective ratings of arousing pictures were more extreme than those of controls, for both valence and arousal, especially for pictures with negative physical context. The stronger the synesthetic experience during the experiment, the more extreme the synesthetes' subjective ratings were, demonstrating the impact of mirror-sensory synesthesia on the extent to which synesthetes are affected by other people's state. Although subjective ratings were more extreme in synesthetes, no differences in physiological and autonomic stress responses for synesthetes were observed and there was no evidence that higher subjective arousal ratings were related to stronger physiological responses in synesthetes. We revealed and quantified the subjective impact of mirror-sensory synesthesia in an experimental setting.

The Dictator's game demonstrated enhanced altruistic behaviour in mirror-sensory synesthetes: they donated larger amounts of money than non-synesthetes to an anonymous second player. As far as we know, this is the first report of heightened prosocial behaviour in mirror-sensory synesthesia. Stronger prosocial behaviour in this group fits with the finding that synesthetes are more affected by touch or pain as observed on another person and with reports of enhanced empathy. If you are better able, literally, to feel what other people feel, this may stimulate altruistic behaviour towards other individuals. Relatedly, we found that mirror-sensory synesthetes scored higher than controls on the Empathic Concern subscale of the Interpersonal Reactivity Index (IRI) and on the total IRI score, supporting previous reports of enhanced (emotional) empathy in mirror-sensory synesthetes [1, 18, 19]. We note that all our participants were female; hence, these conclusions concern females.

Our findings provide insight into the subjective impact of mirror-sensory synesthesia on the everyday life of mirror-sensory synesthetes. Images with mildly aversive content or even positive touch were valued in a more extreme manner by the synesthetes. Synesthetes with stronger experiences of synesthetic touch during the arousing pictures experiment and the verification experiment rated the images more extremely, and the negative picture ratings were more negative for individuals with higher total IRI scores, indicating that empathic abilities affect the subjective ratings. Together, the results imply that the more sensitive

synesthetes are to another person's state, the more strongly they are influenced when rating the images, i.e., the more strongly they are affected by everyday situations involving touch. Our rating results therefore suggest mirror-sensory synesthesia and empathy are linked and may be part of a similar mechanism increasing sensitivity to the situation of other people. This is not only in line with earlier reports of enhanced empathy in mirror-sensory synesthesia [1, 18, 19] but also consistent with research that has shown that the more sensitive mirror systems are, the more empathic individuals are [5, 17].

We found no evidence of enhanced physiological responses or stress reactivity accompanying the stronger subjective ratings in mirror-sensory synesthetes. Physiological effects were present in both groups, as pupil dilation was wider for the negative stimulus condition in both synesthetes and controls, but did not differ between groups (the absence of an interaction of group and stimulus condition was confirmed by Bayesian statistics). This pupil dilation effect is in line with previous studies reporting more strongly dilated pupils for arousing content [e.g. 34, 53]. Although wider pupils have also been reported for positive arousal [34], we did not see this effect, concurrent with the neutral ratings of arousal for our positive stimuli, similar to those of the neutral stimuli (Fig. 2). If anything, valence ratings in the positive physical pictures condition were negatively correlated with pupil dilation. The only other significant effect we report was that the arousing pictures experiment as a whole reduced the overall mood of the participants, but there was no other evidence of autonomic physiological effects and no evidence that the subjective experience of synesthesia impacted any of the physiological responses. Eye-movement data revealed that synesthetes did not view the regions of interest in negative images longer than controls or that they fixated them more often. We do have to note that for these null-effects, Bayesian statistics could not confirm the absence of effects, but were inconclusive. Still, altogether the data suggest that the stronger subjective affect reported for synesthetes is not associated with stronger empathy-related physiological responses.

It is possible that the absence of strong physiological effects is because our stimuli were not extreme enough to induce strong physiological responses. Although our pupil dilation results suggest otherwise, the heart rate and skin conductance were not perturbed by the effects of our stimuli. We cannot exclude that we would have observed physiological effects – and also differential effects in synesthetes – if our physical stimuli would have been more extreme, e.g., more negative. For instance, in the study by Young et al. [25] movie clips with strong content were used and differences were found in the respiration rate of vicarious pain responders and controls – the stimuli also all contained respiratory events, which may

have stimulated this effect. In our study, the physical pictures condition resulted in a group effect for the arousal ratings which was absent for the emotional faces condition, suggesting that physical stimuli affect synesthetes differentially while emotional stimuli do not. The fact remains, however, that we did observe a differential effect on the subjective ratings of synesthetes that was induced even in absence of strong physiological effects. Hence, we suggest that in mirror-sensory synesthesia, cognitive processes play a more important role in mediating the impact of synesthesia than physiological mechanisms.

Our results strongly suggest that empathy, the sensitivity to other people's situation, drives the subjective impact of mirror-sensory synesthesia, given that both stronger empathy and stronger synesthesia led to stronger effects on the subjective ratings. Moreover, synesthetes score higher than controls on the total IRI score and the Empathic Concern subscore. This Empathic Concern score indexes compassion and sympathy in response to distress of other people. In Ward et al. [19] mirror-touch synesthetes did not score higher on any of the IRI subscores, but the strength of the synesthetic experience did correlate with the Emotional Reactivity subscore of the Empathy Quotient, in line with previous findings [1, 18]. Similar to the IRI-Empathic Concern subscale, the Emotional Reactivity subscore relates to the emotional aspects rather than the cognitive components of empathy (Theory of mind/Reading the Mind in the Eyes test). EQ-Emotional Reactivity and IRI-Empathic Concern scores have been shown to be correlated [60]. Our results therefore support previous findings of enhanced empathy in mirror-sensory synesthetes.

In Baron-Cohen et al. [28], a large cohort of mirror-touch synesthetes ($N=46$) did not score higher than controls on the Empathy Quotient. However, 30% of the included mirror-touch synesthetes in this study had an autism spectrum disorder (ASD) while rates of ASD for the other two included groups (controls and grapheme-color synesthetes) were not reported, warranting caution when interpreting this result. It is known that synesthesia in general is more prevalent among individuals with autism [61, 62], but rates for mirror-touch synesthesia specifically have not yet been determined. Thus, we do not know whether the percentage of individuals with ASD in the Baron-Cohen et al. study is representative of any possible wider association between ASD and mirror-touch synesthesia. Also, the mirror-touch synesthetes in that study were included on the basis of self-report and did not rate their synesthetic experiences as very strong (1.48 out of 5). In our study, we applied an objective verification test and synesthetes rated their synesthesia as much stronger (3.4 out of 5). These differences offer potential explanations for the discrepancy between results of the different studies.

As far as we are aware, this is the first demonstration that mirror-sensory synesthetes display stronger altruistic behaviour. The stronger sensitivity to other people's situations may aid altruistic tendencies in synesthetes. One theory about altruism is that it is driven by attempts to relieve one's own discomfort (personal distress) when observing others in pain [24]. An alternative view states that empathic emotions and concern regarding the other person predict altruistic behaviour [31, 32]. In our experiments neither the empathy questionnaire scores, nor the strength of the observed synesthetic touch/pain during the arousing pictures experiment (personal distress), nor the subjective ratings correlated with the amount of money that was donated in the Dictator's Game. Hence, our results do not allow us to conclude which mechanism drives altruism in mirror-sensory synesthesia. We do note that the synesthetes did not score higher than non-synesthetes on Personal Distress in the IRI questionnaire. An alternative interpretation for enhanced prosocial behaviour in mirror-sensory synesthesia relates to the reported differential self-other distinction [21, 23, 63]: self-other merging could lead to greater personal discomfort when observing others in pain, in turn accounting for enhanced empathic and altruistic behaviour [64].

Several synesthetes and controls donated more than the expected amount of money in the Dictator's game (5 euros, half the total amount). This generosity could be interpreted as an actual extreme altruistic act, but it could also be interpreted as a denial to fully play the game (e.g., because of a lack of trust in the anonymity of the set-up). We therefore repeated the analysis excluding the participants who donated more than 5 euros as a verification of the robustness of the result. This analysis still resulted in a significant group difference ($t(18)=3.83$, $p=.001$, $d=1.71$) with synesthetes donating 4.7 ± 0.95 euros on average, and controls 1.8 ± 2.20 euros. This demonstrates that the group effect is robust.

The mirror-sensory synesthesia of the synesthetes in our study was successfully verified in a visual-tactile interference paradigm. Synesthetes displayed more errors specifically in the incongruent and no-touch conditions, in which 'mirror-touch errors' were to be expected, than our control participants (in a group analysis). Overall, our synesthetes were slower on the task, possibly reflecting overall harder task difficulty for the synesthetes. One factor could have been that we used videos in the task, diverging from the original set-up by Banissy and Ward (2007). Video stimuli are also used in the screening tool that was recently developed to verify mirror-touch synesthesia online [19]. Similar to Baron-Cohen et al. [28], we also find interference for synesthetes for touch involving objects (compare the left and right panel of Fig. S6A). For eight synesthetes mirror-touch synesthesia could be verified at the individual level by significantly more errors for the incongruent condition compared to

the congruent condition. For verification of the other synesthetes we relied on self-report of synesthetic experiences in the initial screening questionnaire and during the pictures experiment, similar to other studies using self-report as an indication of mirror-sensory synesthesia [1, 28]. We suggest that future studies use a combination of an objective verification paradigm involving touch interference and the analysis of its error rates, and subjective reports by synesthetes to verify the presence of synesthesia.

Conclusion

In this study we have shown that mirror-sensory synesthesia is accompanied by enhanced altruistic behaviour. Mirror-sensory synesthetes tended to be more strongly impacted by positive and negative images than control participants without any measurable differential physiological effects. We confirm reports of enhanced empathy in mirror-sensory synesthetes and propose empathy may be the driving force behind altered prosocial behaviour in mirror-sensory synesthesia.

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Author contributions

K.I. conceived of the project and collected data. K.I. and T.M.v.L. designed experiments, analyzed data, and wrote the paper. S.A.G. & S.E.F. contributed to the cortisol analysis and to

the paper. T.C. conducted the eye movement analysis. R.v.L. contributed to data interpretation and to the paper.

Data accessibility statement

Raw data, scripts, and results files are available from a data repository via the following URL:
[https://data.donders.ru.nl/login/reviewer-](https://data.donders.ru.nl/login/reviewer-74428818/k9yeDeRYE8tJRQDMiTH8Qgich0To1s5kzEs_r-OIVQU)

[74428818/k9yeDeRYE8tJRQDMiTH8Qgich0To1s5kzEs_r-OIVQU](https://data.donders.ru.nl/login/reviewer-74428818/k9yeDeRYE8tJRQDMiTH8Qgich0To1s5kzEs_r-OIVQU)

The stimuli that were shown to the participants are not shared publicly due to constraints in publishing the IAPS images (pictures experiment) and privacy of the movie actors (verification experiment). The code for these experiments is available from the authors upon request.

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Figure captions

Figure 1. Examples of picture stimuli used in the arousing pictures experiment.

Figure 2. Synesthetes display more extreme ratings for arousing picture stimuli with physical context. Box plots summarizing the ratings results of the arousing pictures experiment: both for valence and arousal, synesthetes (Syn – in light grey boxes) rate pictures with arousing physical context as more extreme than control participants (Con– in dark grey boxes). $*p<.05$, $**p<.01$.

Figure 3. Relative pupil dilation for arousing picture stimuli with physical context. Arousing pictures experiment: pupil dilation relative to picture onset for positive (Pos), negative (Neg) and neutral (Neu) images. Traces were smoothed for plotting (100 ms moving average).

Figure 4. Heart rate for picture stimuli with physical context in the arousing pictures experiment. Box plots with the heart rate for synesthetes (Syn – in light grey boxes) and controls (Con – in dark grey boxes) for the three stimulus conditions. $*p<.05$.

Figure 5. Salivary cortisol levels before and after viewing arousing pictures in the arousing pictures experiment. Box plots with cortisol levels for synesthetes (Syn – in light grey boxes) and controls (Con – in dark grey boxes) at the three time points.

Figure 1. Examples of picture stimuli used in the arousing pictures experiment.

Figure 2. Synesthetes display more extreme ratings for arousing picture stimuli

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Figure 4. Heart rate while viewing arousing pictures with physical context

Figure 5. Cortisol levels before and after viewing arousing pictures.