

A neuroimaging meta-analysis on social impression formation of stable characteristics

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The dense and rapidly changing information conveyed through social interactions must be processed efficiently, allowing individuals to form impressions of others that guide social behavior. The present study summarizes over 100 functional magnetic resonance imaging studies on social impressions concerning stable attributes, highlighting overlapping and specific neural mechanisms for their different sub-types. We identified an extensive network involved in forming social impressions, including areas associated with person perception and emotional processing, alongside the mentalizing system in the medial prefrontal cortex and the semantic control network in the inferior frontal gyrus (IFG) and the pre-supplementary motor area. Implicit judgments appear to activate areas related to person perception such as the middle occipital cortex alongside the fusiform gyrus, while explicit judgments engage nodes of the mentalizing and the semantic control systems. Evaluating warmth involves the right IFG, possibly supporting the translation of inferences about others' warmth into social behavior. Additionally, attractive faces recruit the reward system. Psychological attributions involve left-hemispheric sectors of the mentalizing network, while physical attributions engage areas related to social categorization. Both physical and psychological attributions involve the insula, highlighting its potential role in the emotional facet of prejudice. The present results may guide the design of neuromodulation treatments.

Keywords attractiveness, competence, neuroimaging meta-analysis, social impression, warmth

Introduction

Social interactions represent a source of highly complex information that needs to be rapidly processed to meet the demands of the immediate situation. This requirement is supported by humans' ability to automatically generate a social impression when they see or hear someone (Belin et al. 2017; Mileva and Lavan 2023), and even brief exposures to (apparently) neutral faces evoke threat (Bar et al. 2006), attractiveness and competence (Willis and Todorov 2006) judgments.

Social impressions typically arise from two key types of inferences about others: those concerning temporary states like intentions, emotions or goals, and those related to enduring characteristics such as personality traits (Van Overwalle 2009; Tamir and Thornton 2018;). In recent years, neuroimaging meta-analyses have synthesized the brain regions recruited by evaluating temporary mental states, intentions, and emotions (Schurz et al. 2021; Xu et al. 2021; Arioli et al. 2021a, 2023). Instead, to date, no meta-analysis has comprehensively examined the brain regions that have been consistently associated with forming social impressions of others' traits and stable attributes.

To fill this gap, the present study complements research on personality trait inferences (Diveica et al. 2021) in two ways. First, we integrated previously reported evidence on brain activations associated with judgments about physical characteristics (eg sex and age; Ito et al. 2022; Sakano et al. 2021), which appear to strongly modulate social impression formation (Jaeger and Jones 2022). Second, we explored the specific and overlapping patterns of brain activity associated with distinct types of inferences concerning stable attributes. While previous neuroimaging meta-analyses have primarily examined specific social judgments (eg trustworthiness, Santos et al. 2016; attractiveness, Ueda 2022), none have provided such an extensive and comprehensive summary of the specialized and overlapping brain areas underlying different processes of social impression formation.

Social impression formation of stable characteristics

In general, forming social impressions is considered to engage two main networks associated with semantic control and mentalizing (Diveica et al. 2021).

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The former underpins the retrieval and selection of conceptual-level knowledge (such as knowledge about known others, social categories and the associated stereotypes; [Binney and Ramsey 2020](#); [Freeman and Johnson 2016](#); [Greven et al. 2016](#)), allowing to understand, and respond appropriately to, specific social signals according to the context ([Lambon Ralph et al. 2017](#)). Since retrieving unnecessary data is both inefficient and potentially counterproductive, a semantic control system is required to ensure that only information relevant to the current social context is activated ([Diveica et al. 2021](#)). This network comprises the anterior sector of the inferior frontal gyrus (IFG; pars orbitalis and pars triangularis), the supplementary motor area (SMA) and pre-SMA, the dorsomedial prefrontal cortex (dmPFC), and the middle and inferior temporal gyrus ([Diveica et al. 2021](#); [Jackson 2021](#)). Among these regions, the IFG supports semantic control in different social domains, ranging from mentalizing to moral reasoning and inferring others' personality traits ([Diveica et al. 2021](#)). Instead, the possible involvement of the parietal cortex in this network is still debated ([Jackson 2021](#)).

In addition, forming social impressions requires the ability to reason about other's mental states and personal characteristics, ie "mentalizing" ([Schurz et al. 2021](#)). The latter relies on a widespread network including the middle cingulate, precuneus, medial prefrontal (mPFC) and lateral temporal cortex, as well as the temporoparietal junction (TPJ) ([Molenberghs et al. 2016](#); [Arioli et al. 2021a](#)). Among these regions, the mPFC is considered to play a key role in attributing enduring traits, while the TPJ is mainly related to inferring others' temporary goals, intentions, and beliefs ([Van Overwalle and Heleven 2021](#)).

Forming social impressions may additionally engage brain regions underlying social perception, such as the posterior superior temporal sulcus (pSTS) and the amygdala. The former is considered a hub of social perception ([Pitcher and Ungerleider 2021](#)), processing facial expressions ([Sliwinska et al. 2020](#)), eye gaze ([Baseler et al. 2014](#)), bodies ([Li et al. 2023](#)), biological motion ([Gilaie-Dotan et al. 2013](#)), voices ([Schall et al. 2015](#)) and the audiovisual integration of speech ([Venezia et al. 2017](#)). The pSTS is spatially contiguous to the TPJ, and the TPJ-pSTS cluster has been widely implicated in tasks involving the representation of others' states and characteristics ([Thornton et al. 2019](#); [Chwe et al. 2024](#)). Moreover, the pSTS was found to support the communication between the mentalizing network and the amygdala ([Yang et al. 2015](#)). The amygdala is widely recognized as a crucial structure for forming both implicit and explicit social impressions ([Bzdok et al. 2011](#); [Mende-Siedlecki et al. 2013](#); [Santos et al. 2016](#))—including "race" judgments ([Bagnis et al. 2020](#))—and for processing social comparisons ([Swencionis and Fiske 2014](#)) as well as social status and hierarchies ([Koski et al. 2015](#); [Mattan et al. 2017](#)). Recent theories highlight the possible role of amygdala in constantly evaluating and integrating sensory information to code their valence, intensity, and approachability, thereby supporting the quick formation of social impressions ([Šimić et al. 2021](#)).

Based on this previous evidence, we expected to identify a comprehensive network underlying the formation of social impressions, including the mentalizing network and key hubs of the "social brain" ([Arioli et al. 2018](#)), such as the pSTS and the amygdala. As detailed below, we additionally predicted the involvement of specific structures in processing the following selective facets of social impressions.

Implicit and explicit judgments

Explicit social impressions are typically assessed by asking participants to self-report their evaluation of another person, while implicit

impressions are revealed through unrelated tasks with participants kept blind as to the target feature ([Siddique et al. 2022](#)). Previous studies have shown that these experimental designs can influence the neural representation of social impressions (eg [Bzdok et al. 2011](#); [Izuma et al. 2019](#)). Specifically, the core "mentalizing" areas such as the TPJ and the mPFC seem to be recruited during implicit trait processing; whereas explicit trait inferences appear to engage additional areas such as the precuneus alongside premotor and parietal cortex, possibly supporting more complex strategies required to re-evaluate and flexibly adjust social judgments ([Ma et al. 2011](#); [Van Overwalle and Vandekerckhove 2013](#)).

However, the specific effect of task instructions on the neural representation of social impressions remains unclear, particularly concerning the role of amygdala. While [Bzdok et al.'s \(2011\)](#) meta-analysis revealed a consistent bilateral involvement of the amygdala for both explicit and implicit facial judgments, [Kaul et al. \(2010\)](#) reported that implicit facial gender recognition recruits various regions but not the amygdala. Nonetheless, single-neuron recordings in neurosurgical patients suggest that the amygdala plays a role in implicitly encoding femininity and warmth during facial processing ([Cao et al. 2021](#)).

This controversial evidence highlights the need to identify the brain structures that have been consistently associated with the formation of implicit and/or explicit social impression formation.

The Big Two and attractiveness

Warmth and competence are the core dimensions driving judgments about others, to the extent that they are widely considered the "Big Two" of social perception ([Abele and Hauke 2020](#)). When assessing whether someone has good or bad intentions, warmth judgments prompt impressions about friendliness, helpfulness, sincerity, trustworthiness and morality ([Fiske et al. 2007](#); [Halkias and Diamantopoulos 2020](#)). The competence dimension rather refers to whether a person can act in line with their intentions ([Fiske et al. 2007](#); [Halkias and Diamantopoulos 2020](#)), through judgments about ability, intelligence, efficacy, and socio-economic status ([Fiske 2018](#); [Yzerbyt et al. 2022](#)). The available evidence suggests that warmth and competence engage two main hubs ([Kobayashi et al. 2022](#)), ie the TPJ/pSTS supporting person perception and mental state attribution ([Arioli et al. 2021a](#)), and the orbitofrontal cortex to enable social inferences for decision-making ([Xia et al. 2015](#); [Chwe et al. 2024](#)). Moreover, both dimensions appear to involve the role of ventromedial prefrontal cortex in affective mentalizing ([Kestemont et al. 2016](#); [Ma et al. 2016](#)).

These findings were only partially addressed by meta-analytic evidence. Indeed, previous neuroimaging meta-analyses on competence judgments have primarily focused on social hierarchies ([Yaple and Yu 2020](#); [Li et al. 2021](#)), without considering variables such as intelligence or efficacy. Regarding the warmth dimension, the available neuroimaging meta-analyses focused selectively on the evaluation of facial trustworthiness ([Bzdok et al. 2011](#); [Santos et al. 2016](#)), without considering moral attributes or impressions based on someone's voice.

However, mixed results have been reported concerning the overlapping vs. distinctive neural correlates of the Big Two. Key nodes of mentalizing such as dmPFC and TPJ were more strongly associated with warmth than competence, with no significant evidence for the opposite comparison ([Lan et al. 2022](#)), but the opposite pattern was also reported, with a selective stronger parietal activation for competence compared with warmth ([Van Overwalle et al. 2016](#)).

Moreover, warmth and competence may be biased by the “attractiveness stereotype” (Dion et al.’s (1972) “What is beautiful is good”), ie the tendency to deduce someone’s personality and moral attributes from their physical attractiveness (Cheng et al. 2022; Lan et al. 2022). Previous neuroimaging meta-analyses focused on the association between facial attractiveness and facial trustworthiness (Bzdok et al. 2011; Mende-Siedlecki et al. 2013), while relatively little is known about the association between the Big Two and attractiveness. The impression of attractiveness has been found to be more strongly associated with warmth than competence, with this link possibly originating from common activity in the TPJ and dmPFC (Lan et al. 2022).

Based on this debated evidence, we took a meta-analytical approach to delve into the shared and specific neural bases of judgments on attractiveness, competence, and warmth.

Psychological and physical attributions

Despite the growing literature on their importance in social cognition, preliminary evidence suggests that the Big Two might not be sufficient, and that further dimensions are required, to grasp the complexity of social impressions (Lin et al. 2021; Cao et al. 2023). To account for these novel high-dimensional models of social impression formation (Connor et al. 2024), we further aim to examine the perception of psychological vs. physical characteristics (Lindner et al. 2008) besides inferences on warmth and competence. We define psychological attributions as the perception of people’s inner characteristics (eg trustworthiness and intelligence), whereas physical attributions refer to the impressions of external and physical characteristics (eg a person’s height, sex, or age).

Psychological attributions likely require mentalizing abilities (Schurz et al. 2021; Van Overwalle 2009; Van Overwalle and Vandekerckhove 2013). Some psychological and physical attributions may recruit similar brain structures, such as the STS that has been previously associated with trustworthiness evaluation and gender perception (Dzhelyova et al. 2011). However, psychological attributions tend to be subjective, whereas physical characteristics can often be read off directly (Lindner et al. 2008). Physical attributions might thus be related to more perceptual areas, such as the occipital face area (OFA) and the fusiform face area (FFA) (Tsantani et al. 2021) as well as regions encoding social categories (eg in-group vs. out-group; Merritt et al. 2021; Saarinen et al. 2021).

On this basis, we expected psychological and physical attributions to recruit the mentalizing network and perceptual regions, respectively.

Person perception

A fundamental prerequisite for forming social impressions is person perception, ie the ability to distinguish between inanimate objects, governed by physical laws, and human beings, whose inner experiences make their behavior less predictable (Vogeley 2017; Arioli et al. 2018). This distinction constitutes a critical first step in social impression formation. Indeed, only after recognizing an entity as adopting an intentional stance can we begin to infer their transient mental states (eg desires and emotions) or their stable traits (eg competence and attractiveness). To better understand the neural mechanisms underlying person perception during social impression formation, we carried out a separate meta-analysis of experiments that included non-social or non-human control conditions. Based on previous findings,

we expected to find an extensive network involving both mentalizing and perceptual areas such as FFA and OFA (Binney and Ramsey 2020).

Aim of the study

For over 100 years, social impressions and their formation have received considerable scientific interest (Nicolas et al. 2024). The reviewed neuroimaging studies highlight several gaps in our understanding of the common and specific neural bases underlying different types of social impressions related to stable characteristics. Additionally, the current literature lacks an up-to-date and detailed synthesis. To fill these gaps, we therefore aimed to identify the brain structures that have been consistently associated with social impressions of stable characteristics and their main forming pillars.

Methods

Rationale of the meta-analytic approach

We aimed to provide an overview of the functional magnetic resonance imaging (fMRI) literature on social impressions, and to identify the overlapping and specific brain structures that have been consistently associated with the formation of different types of social impressions. This goal was pursued with activation likelihood estimation (ALE), a meta-analytic approach employing coordinates of peak locations to summarize published findings (Turkeltaub et al. 2002; Eickhoff et al. 2017; Müller et al. 2018). Besides a general meta-analysis on social impression formation, we investigated the common and specific activations for (i) implicit and explicit judgments, (ii) warmth, competence and attractiveness judgments, and (iii) psychological and physical attributions. In addition, we performed a meta-analysis on person perception.

To increase the generalizability of our results within the constraints of our research questions (Radua and Mataix-Cols 2012), we investigated brain activations associated with the formation of social impressions independent of the sensory modality (eg visual or auditory) and the stimulus type (eg photos, videos, verbal materials, sounds). All the inclusion criteria were selected by the first (E.M.W.K) and second (M.A.) authors to reduce the chances of selection bias (Müller et al. 2018).

Literature search and study selection process

We searched for publications in PubMed (<https://pubmed.ncbi.nlm.nih.gov/>) and Web of Science (<https://www.webofscience.com/wos/woscc/basic-search>) using the following keywords: “fMRI”, “competence”, “intelligence”, “trustworthiness”, “aggressiveness”, “attractiveness”, “face processing”, “voice processing”, “appearance”, “social evaluation*”, “social attitude”, “social judgment”, “social judgment”, “social impression” and “impression formation” (see [Supplementary Materials](#) for details). After removing duplicates, the titles and abstracts of the remaining 1,420 articles were screened according to the following criteria (see Fig. 1):

- 1) Published in English;
- 2) Empirical fMRI studies to ensure a comparable spatio-temporal resolution;
- 3) Results reported as whole-brain coordinates in the Montreal Neurological Institute (MNI) (Evans et al. 1994) or Talairach (Talairach and Tournoux 1988) atlases, excluding those obtained with small volume correction (SVC), regions of interest (ROI), or connectivity analyses (Müller et al. 2018);

- 4) Samples with human adults between 19 and 65 years;
- 5) Experiments measuring typical performance (eg not influenced by external manipulations such as placebo or brain stimulation);
- 6) Non-clinical and drug-free samples with at least seven participants (Tahmasian et al. 2019);
- 7) Contrasts isolating brain regions involved in social impression formation, eg analyses focusing on the correlation between social impressions and brain activity (eg Peer et al. 2021), or contrasts comparing a social impression to a condition unrelated to social impressions (eg Wen et al. 2017). In this regard, we excluded contrasts aimed to detect person recognition (eg Bicanski and Burgess 2019) or the perceiver's relationship with a close other, as these tasks might activate unrelated processes (Platek and Kemp 2009). Moreover, we focused on monotonic effects, namely linear (Engell et al. 2007) or quasi-exponential relationships (eg Tsukiura and Cabeza 2011), while excluding—for instance—quadratic effects (eg Verosky and Todorov 2010) to avoid the inclusion of contrasts focusing on different patterns of brain activity. Additionally, we excluded experiments requiring participants to iteratively update impressions of the same stimulus (eg Mende-Siedlecki and Todorov 2016);
- 8) To avoid the inclusion of opposite contrasts in the same analysis, while increasing the chances of identifying many studies (Bzdok et al. 2011; Mende-Siedlecki et al. 2013; Bagnis et al. 2020), we chose to focus on contrasts with: (i) a “positive valence”, eg highly beautiful vs. not beautiful instead of not beautiful vs. highly beautiful (eg Yang et al. 2022), (ii) comparisons in which a stable characteristic was contrasted to a neutral baseline, eg aggressive vs. a neutral condition (eg Ceravolo et al. 2016), (iii) contrasts referring to the subject itself, eg own age group vs. other age group (eg Ito et al. 2022).

In addition, we established further specific criteria for different meta-analyses.

Concerning the **general meta-analysis on social impression formation**, we included all studies on social impressions regarding stable traits and attributes. Notably, we excluded contrasts comparing different types of social impression formation regarding stable characteristics, which led to exclude seven experiments from the general meta-analysis. However, if the contrast compared a psychological attribution with a physical one, eg “trustworthiness ratings > age ratings”, we included this contrast in the meta-analysis about psychological attributions. Similarly, if an implicit judgment was compared with an explicit judgment, we included it in the meta-analysis on implicit impressions. The same logic was applied to the study selection for the meta-analyses on physical attributions as well as explicit, warmth, competence and attractiveness judgments.

The **meta-analysis on explicit impressions** included experiments in which participants were instructed to form social impressions while in the fMRI scanner (Santos et al. 2016). In contrast, the **meta-analysis on implicit impressions** included fMRI experiments in which the in-scanner task was independent of the social impression under investigation (Bzdok et al. 2012). We thus used in-scanner task instructions to distinguish studies investigating the neural bases of implicit vs. explicit impressions. This distinction aligns with Bzdok et al.'s (2011) methodology, and is consistent with well-established approaches in cognitive neuroscience (eg Arioli et al. 2026).

The **meta-analysis on warmth** included studies on social impressions concerning how well-intentioned a person appears, such as in terms of their pleasantness (eg Murakami et al. 2018) and morality (eg Luo et al. 2019). In contrast, the **meta-analysis on competence** included experiments on social impressions assessing the perceived ability to translate intentions into effective action, ranging from inferences about intelligence (eg Wen et al. 2017) to dominance (Quirin et al. 2013) and socio-economic status (eg Barth et al. 2020). Experiments on impressions related to attractiveness—such as beauty (eg Yang et al. 2022), aesthetics (Di Dio et al. 2011), and photogenic appearance (Morita et al. 2008)—were included in the **meta-analysis on attractiveness**.

The meta-analysis on **psychological attributions** included experiments addressing evaluations of stable characteristics that might be related to impressions of someone's inner and psychological traits, such as personality trait judgments (eg Stanfield et al. 2017). As to the **physical attribution**, we included experiments on social impression of external and physical characteristics, eg a person's height (Kedia et al. 2013) and age (Yin et al. 2017). Importantly, physical attributions do not refer to the actual attributes of the perceived individuals. The idea of biologically defined *homo sapiens* “races” is inadequate from a biological, anthropological, and genetic perspective (Heinz et al. 2014; Gokumen 2018; Templeton 2023; Kim et al. 2023a). Although only racism, rather than human “races”, exists, we classified studies on this topic under “physical attributions”, as external attributes such as eye shapes and skin tones, have been previously associated with the outdated concept of the human “race” (Heinz et al. 2014). Furthermore, the term sex regards biological attributes, whereas gender refers to the socially constructed behaviors, identities and roles of male, gender-diverse, and female individuals (Heidari et al. 2016). Our meta-analysis does not regard a person's actual sex or gender, but how others perceive the person. Since in some languages in which the participants were tested the same word is used for gender and sex (eg Koppe et al. 2015), and because some of the included studies used gender- and sex-related terms inconsistently, we assigned experiments on both sex and gender to the meta-analysis on physical attributions. We excluded experiments on attractiveness from the classification between psychological and physical attributions because, across studies, attractiveness impressions have been described as both physical (Kedia et al. 2014; Jankowiak-Siuda et al. 2015) and psychological (Bzdok et al. 2011).

Finally, the meta-analysis on **person perception** included studies using control conditions with non-human and non-social stimuli, such as rectangles. We excluded, for instance, control conditions with stimuli that were somehow associated with the perception of others' emotions or intentions, such as animals (Kedia et al. 2014), emoticons (Kim et al. 2016), and sculptures of humans (Di Dio et al. 2011), as we assumed that brain activations underlying their processing might reflect the engagement of mentalizing (Arioli et al. 2021a).

After screening titles and abstracts, we excluded 1,185 articles and read the full text of the remaining 235 articles. Fifteen of them were excluded because they lacked whole-brain results, and 79 because they focused on unrelated topics, or reported inappropriate contrasts. Since the coordinate-based ALE algorithms cannot incorporate insignificant findings (Müller et al. 2018), 2 studies fell into the category of “inappropriate contrasts or focus on unrelated topics” because their fMRI results about social impressions did not reach statistical significance. In addition, we excluded 7 studies because their samples

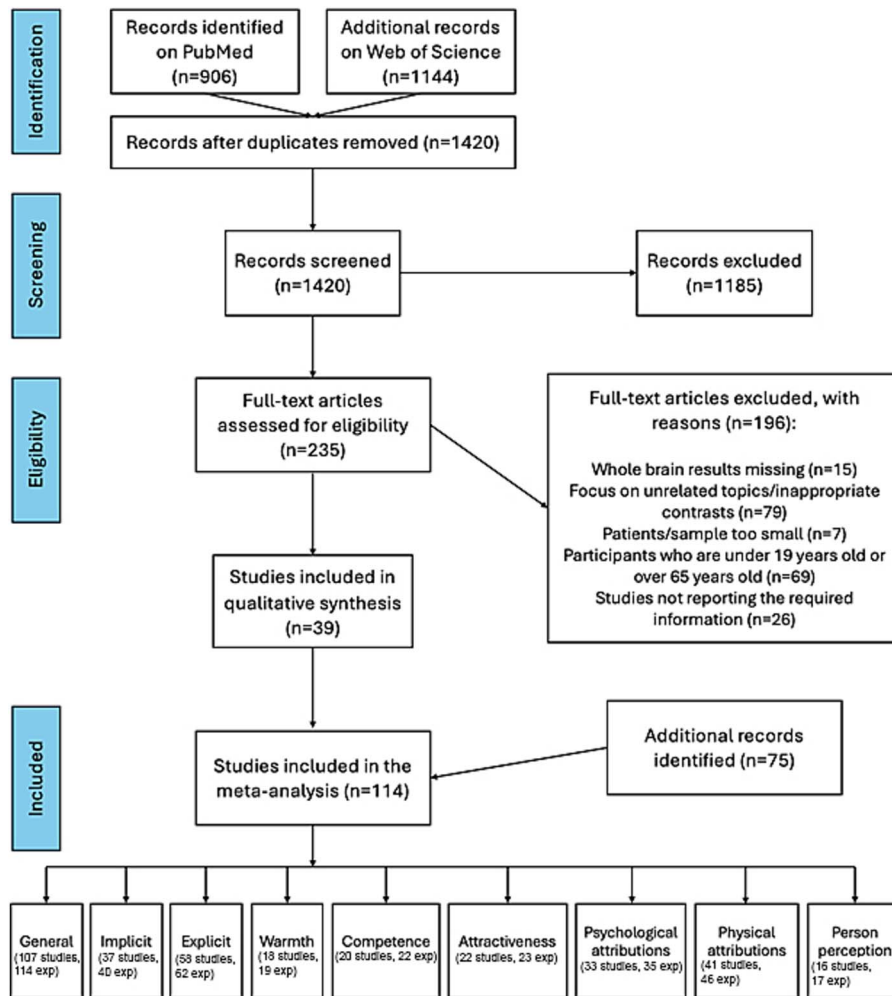


Figure 1 The figure represents the preferred reporting items for systematic reviews and meta-analyses (PRISMA) flowchart (Moher et al. 2009) reporting all steps of the study selection process. Abbreviations: exp: experiments.

included patients or the sample was too small, and other 69 because they involved subjects aged under 19 or over 65 years. Moreover, 26 studies were excluded because they did not report the required information. The remaining 39 articles fulfilled our inclusion criteria. By inspecting their references and the studies that cited these articles and by reading 36 previously published meta-analyses, reviews and comments about social impressions (see [Supplementary Materials](#) for the complete list of references), we identified further 75 studies.

Overall, we therefore included 114 studies in our analyses. From this general database, 107 studies (resulting in 114 experiments with 2,613 subjects and 1,293 foci of activation) were selected for the general meta-analysis on social impression formation (see [Table S1](#)). The meta-analysis on implicit impression encompassed 37 studies (resulting in 40 experiments with 911 participants and 401 foci), while the meta-analysis on explicit impressions included 58 studies (resulting in 62 experiments with 1,411 subjects and 666 foci) (see [Tables S2, S3](#)).

We identified 18 studies (resulting in 19 experiments with 460 subjects and 129 foci) for the meta-analysis on warmth (see [Table S4](#)). Twenty studies (resulting in 22 experiments with 502 subjects and 211 foci) were eligible for the meta-analysis on competence (see [Table S5](#)). Moreover, we assigned 22 studies (resulting in 23 experiments with 599 subjects and 201 foci) to the meta-analysis on attractiveness (see

[Table S6](#)). Furthermore, 33 studies (resulting in 35 experiments with 733 subjects and 389 foci) were assigned to psychological attributions, while the meta-analysis on physical attributions includes 41 studies (resulting in 46 experiments with 1,066 subjects and 353 foci) (see [Tables S7, S8](#)).

The meta-analysis on person perception includes 16 studies, resulting in 17 experiments with 342 subjects and 346 foci (see [Table S9](#)). Overall, the number of included experiments aligns with common recommendations, suggesting a minimum of 17 experiments for sufficient power to detect smaller effects (Eickhoff et al. 2016; Müller et al. 2018; Yeung et al. 2023).

E.M.W.K. and M.A. chose the selection criteria, and read all the retained studies to ensure their adherence to the selected criteria. We extracted the foci manually (E.M.W.K.) and double-checked them (E.M.W.K. and M.A.). Coordinates reported in Talairach were automatically converted to the MNI atlas with the software GingerALE (Fox et al. 2013). Including multiple contrasts/experiments from the same participants can generate dependence across experiment maps, decreasing the validity of meta-analytic results. Therefore, for each meta-analysis we adjusted for within-group effects by pooling the coordinates of all relevant contrasts from a study into one experiment (Turkeltaub et al. 2002).

Data analysis

ALE meta-analyses were performed using the GingerALE 3.0.2 software (Eickhoff et al. 2017), to identify the most consistent brain activations across different experiments (Müller et al. 2018). For all analyses, we used the most conservative (smaller) anatomical mask. In the GingerALE framework, each activation coordinate is initially interpreted as the center of a three-dimensional Gaussian probability distribution, to capture the spatial uncertainty of each coordinate. Then, GingerALE combines these three-dimensional probabilities of all coordinates for each voxel, creating a modeled activation (MA) map. ALE scores are generated by combining the MA maps to evaluate the convergence of results for each brain voxel (Turkeltaub et al. 2002). The ALE scores are then compared to a null distribution to discriminate significant convergence from random convergence (Eickhoff et al. 2012). Namely, the actual ALE scores were tested against the random ALE scores at a threshold of $P < 0.05$, corrected for cluster-level family wise error (FWE) (1,000 permutations), with a $P < 0.001$ cluster-forming threshold (as in Arioli et al. 2022, and in line with Müller et al.'s (2018) recommendations).

GingerALE was also used to unveil common and specific activations across the different meta-analyses. For each comparison, a conjunction image alongside two contrast images are created. The input is represented by the ALE images resulting from the two separate individual meta-analyses, plus a third meta-analysis merging the coordinates of the two individual ones. GingerALE randomly divides the coordinate foci of the two original datasets into two new datasets, preserving their sizes. For each of the new datasets, an ALE image is created, which is then subtracted from the other one and compared with the original data. Following Sacheli et al. (2022), the significance level for the contrast analysis was defined at an uncorrected threshold of $P < 0.001$, with 1,000 permutations and a minimum cluster size of 20 mm^3 . It is common practice to use the uncorrected p-value because GingerALE does not correct for multiple comparisons for contrast analyses (Arioli et al. 2022).

The significant clusters were anatomically localized with GingerALE (Fox et al. 2013), and the SPM Anatomy Toolbox (version 2.2b; Eickhoff et al. 2005) was used to double-check the reported localizations.

Results

General meta-analysis on social impression formation

The general meta-analysis on social impressions highlighted a variety of cortical and subcortical brain structures (see Fig. 2; Table 1), including areas traditionally associated both with mentalizing, such as the mPFC (Arioli et al. 2021a), and to semantic control, such as the IFG and the pre-SMA (Diveica et al. 2021; Jackson 2021). Further activations involved the anterior insula bilaterally, the left amygdala and the left thalamus, likely associated with the emotional evaluation of social stimuli (Šimić et al. 2021), alongside the occipital cortex and fusiform gyrus, possibly supporting their visual processing (Kaul et al. 2010; Brooks et al. 2021).

Implicit and explicit judgments

The meta-analysis on implicit social impressions unveiled consistent activations encompassing the fusiform gyrus and middle occipital gyri as well as the cerebellum (see Fig. 3; Table 2), previously

associated with person perception (Arioli et al. 2018). Instead, explicit impressions recruited the IFG and pre-SMA, implicated in semantic control (Diveica et al. 2021; Jackson 2021), alongside the frontal pole and the anterior cingulate cortex (ACC) hub of the mentalizing network (Arioli et al. 2021a) (see Fig. 3; Table 3). Explicit judgments additionally recruited the intraparietal sulcus, alongside the bilateral anterior insula and medial thalamus.

There were no common activations to implicit and explicit judgments (see Fig. 3; Table 4), nor regions that were more consistently associated with implicit than explicit judgments. Instead, the opposite comparison highlighted four clusters that were specifically associated with explicit judgments, mainly involving the right IFG (see Fig. 3; Table 4).

The Big Two and attractiveness

While warmth judgments were associated with consistent activity in the pars orbitalis of the right IFG (see Fig. 4, Table 5), no cluster was specifically associated with impressions of competence. The perception of attractiveness was associated with activity in the left caudate—likely reflecting the reward inherent in processing pleasant faces (Chuan-Peng et al. 2020)—alongside the frontal pole and ACC that may underpin mentalizing on their, or one's own, states (Arioli et al. 2021a) (see Fig. 4, Table 6). However, neither overlapping nor specific activations were found for warmth vs. attractiveness judgments.

Psychological and physical attributions

The meta-analysis on psychological attributions highlighted regions involved in mentalizing (precuneus and ventral part of the posterior cingulate cortex; Arioli et al. 2021a) and emotional processing (right anterior insula and left IFG; Jabbi and Keysers 2008) (see Fig. 5; Table 7). Instead, physical attributions were associated with the right IFG and intraparietal sulcus, previously associated with social categorization (Merritt et al. 2021; Saarinen et al. 2021), alongside the right fusiform gyrus, left anterior insula and right cerebellum, possibly underlying their emotional processing (see Fig. 5; Table 8). A conjunction analysis confirmed the common involvement of the right anterior insula for both psychological and physical attributions (see Fig. 5; Table 9). Contrast analyses highlighted a stronger involvement of the left mPFC, precuneus and temporal pole—possibly underlying mentalizing (Arioli et al. 2021a)—for psychological compared with physical attributions (see Fig. 5; Table 9), while the opposite comparison unveiled a stronger engagement of the right fusiform gyrus for physical compared with psychological attributions (see Fig. 5; Table 9).

Person perception

Person perception was associated with the consistent involvement of an extensive set of regions that have been previously implicated in socio-cognitive processing (see Fig. 6, Table 10). In particular, this meta-analysis highlighted the inferior temporal gyrus and fusiform gyri, the intraparietal sulcus, as well as the IFG, the SMA and pre-SMA and the anterior insula bilaterally, plus the right cerebellum.

Figure 7 depicts the anatomical overlap between the brain structures resulting from the meta-analysis on person perception and general social impression formation (based on MRIcron, v1.0.20190902). Both processes engaged the fronto-insular cortex bilaterally, alongside the posterior fronto-medial cortex (pre-SMA), the right fusiform gyrus and the right intraparietal sulcus. Person perception specifically

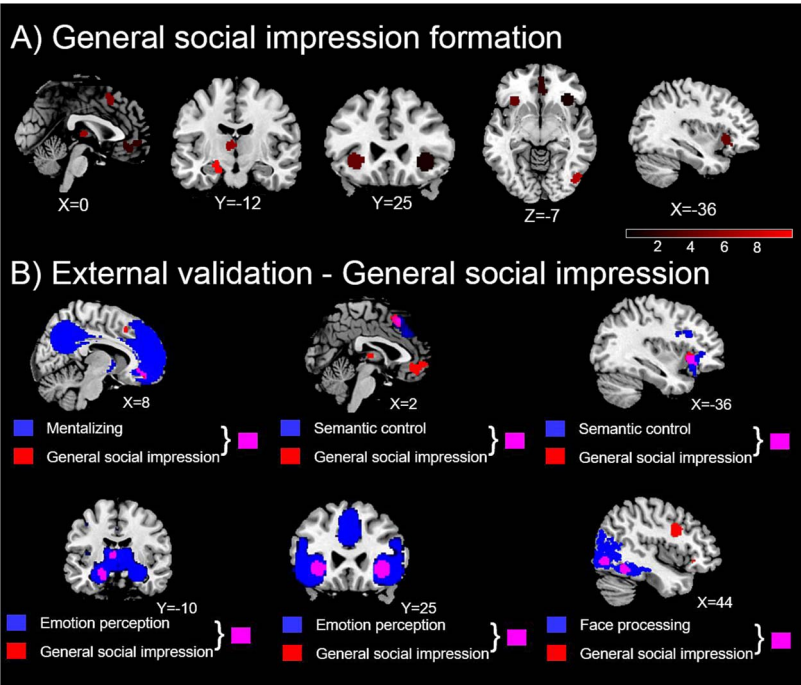


Figure 2 The top part of figure A) illustrates the brain structures whose activations were significantly associated with social impression formation. For this analysis, we adopted a cluster-level $P < 0.05$ with FWE correction (1,000 permutations), and a $P < 0.001$ cluster-forming threshold. The bottom part of the figure B) reports the anatomical overlaps between the brain structures that have been consistently associated with general social impression formation and mentalizing (Schurz et al. 2021), semantic control (Jackson 2021), face processing (Rosenke et al. 2021) as well as emotion perception (Kuhnke et al. 2023).

Table 1 Neural bases of social impression formation (114 experiments with 2,613 subjects and 1,293 foci).

Cluster #	Volume (mm ³)	x	y	z	Brain regions	Contributing experiments	Z-values
1	2,896	36	26	-2	right IFG/right insula	19	8.34
2	2,504	4	42	-14	area Fo1 (mPFC)	17	5.34
		4	38	-10	rectal gyrus		5.14
		0	52	-4	area Fp2 (frontal pole)		4.44
3	2,208	46	8	28	right IFG	15	6.12
4	2,104	-32	22	-2	left IFG/left insula	13	6.48
		-38	28	-10	left IFG		3.24
5	1,712	2	18	50	posterior-medial frontal area (pre-SMA)	10	4.58
		-4	16	48	superior medial frontal gyrus		4.50
		8	20	44	right middle cingulate cortex		3.85
6	1,288	-6	-12	6	left thalamus	9	4.72
		-2	-16	6	thalamus		4.72
7	1,192	46	-74	-6	right area hOc4Ia	11	5.54
8	984	44	-52	-14	right area FG4	6	4.47
9	944	32	-58	46	right intraparietal sulcus	8	4.74
10	912	-20	-10	-16	left amygdala	8	4.99

Note: The number of the cluster (#), their volume, the MNI coordinates of local maxima, the corresponding brain structure, the contributing experiments and Z-value are listed from the left to the right columns. We adopted an FWE-corrected cluster level $P < 0.05$ (1,000 permutations) and a $P < 0.001$ cluster-forming threshold.

recruited the left intraparietal sulcus and the cerebellum (lobule VI), whereas impression formation on stable traits involved the left amygdala and thalamus alongside the frontal pole and right occipital cortex.

External validation

To support our interpretations of the functional role of the identified brain networks, we used MRICron (v1.0.20190902) to assess the anatomical overlap between our meta-analytic results and functional

maps of relevant cognitive systems. Specifically, we used published maps for mentalizing (Schurz et al. 2021), emotion perception (Kuhnke et al. 2023), semantic control (Jackson 2021), face processing (Rosenke et al. 2021), and reward processing (Martins et al. 2021).

This external validation supports our interpretations regarding the recruitment of:

- The mentalizing (mPFC), semantic control (pre-SMA and IFG), face processing (fusi-form gyrus) and emotion perception (amygdala)

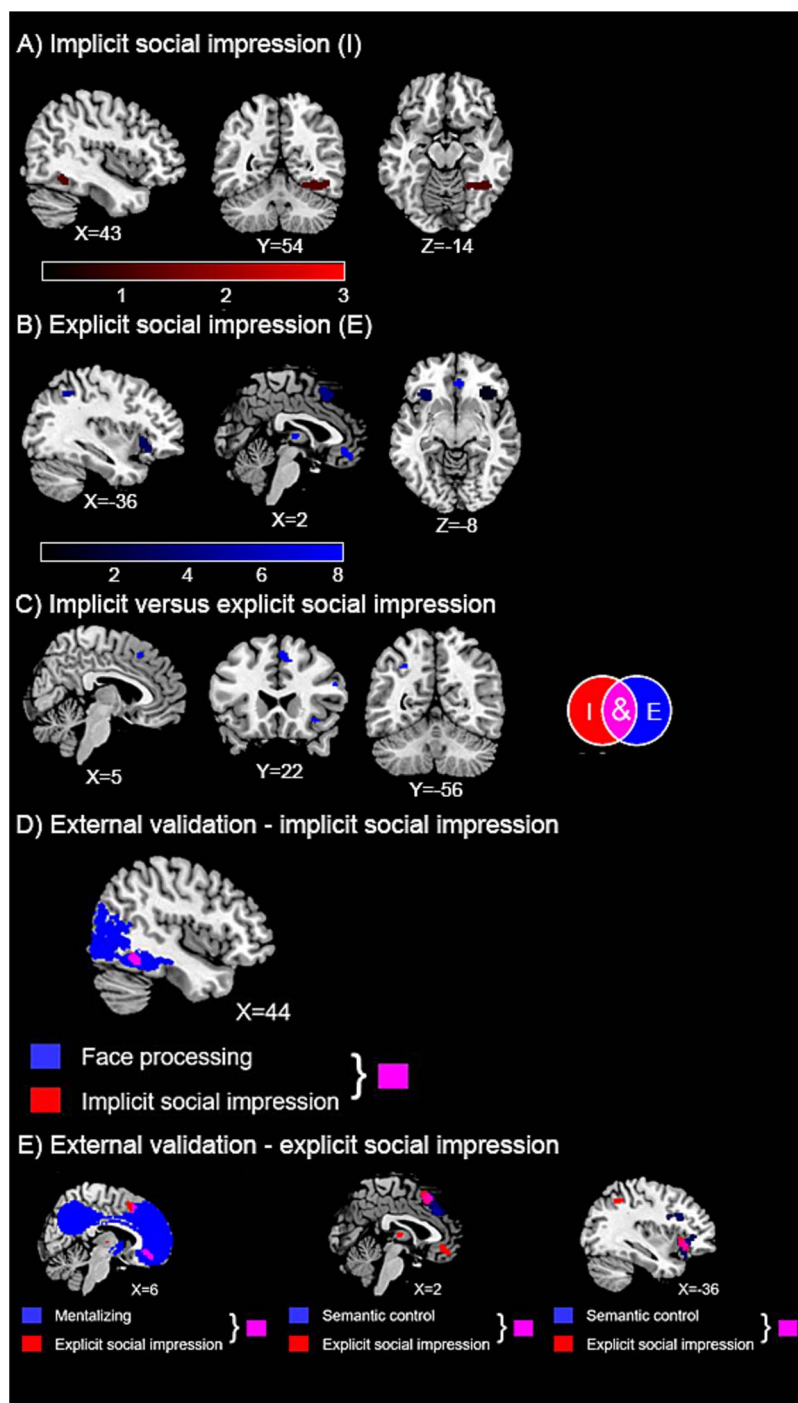


Figure 3 The top part of the figure illustrates the brain areas associated with implicit judgments A), explicit judgments B), and their common and specific activations C). For the two separate meta-analyses, we adopted a cluster-level $P < 0.05$ with FWE correction (1,000 permutations), and a $P < 0.001$ cluster-forming threshold. For the contrast analysis, we adopted an uncorrected $P < 0.001$ with 1,000 permutations and a minimum cluster size of 20 mm^3 . Moreover, the bottom part of the figure reports the anatomical overlaps between the brain structures that have been consistently associated with implicit social impression formation and face processing (Rosenke et al. 2021; D) and with explicit social impression formation and mentalizing (Schurz et al. 2021) as well as semantic control (Jackson 2021; E).

and insula) systems for general social impression formation (Fig. 2);

- The face processing system (fusiform gyrus) for implicit social impression formation (Fig. 3);
- The semantic control (pre-SMA and IFG) and mentalizing (mPFC) systems for explicit social impression judgments (Fig. 3);

- The reward (caudate) and mentalizing (mPFC) systems for attractiveness judgments (Fig. 4);
- The mentalizing system (precuneus/cingulate cortex) for psychological attributions (Fig. 5); and
- The face processing system (fusiform gyrus) for physical attributions (Fig. 5).

Table 2 The neural bases of implicit social impressions (40 experiments with 911 participants and 401 foci).

Cluster #	Volume (mm ³)	x	y	z	Brain regions	Contributing experiments	Z-values
1	1,456	44	−52	−14	right area FG4	8	4.49
		34	−52	−14	right area FG3		4.23
		24	−54	−14	right cerebellum (lobule VI)		3.70
2	744	−28	−92	2	left area hOc4Ia	5	4.34

Note: The number of the cluster (#), their volume, the MNI coordinates of local maxima, the corresponding brain structure, the contributing experiments and Z-value are listed from the left to the right columns. We adopted an FWE-corrected cluster level $P < 0.05$ (1,000 permutations) and a $P < 0.001$ cluster-forming threshold.

Table 3 The neural bases of explicit social impressions (62 experiments with 1,411 subjects and 666 foci).

Cluster #	Volume (mm ³)	x	y	z	Brain regions	Contributing experiments	Z-values
1	3,040	34	26	−4	right IFG/right insula	14	8.21
2	2,680	46	6	28	right IFG	14	5.10
		44	26	20	right IFG		4.45
		52	24	22	right area 45		3.60
3	2,152	−30	22	−4	left IFG/left insula	11	5.63
		−38	26	−10	left IFG		3.59
		−38	24	−18	left IFG		3.25
4	2,104	2	18	50	posterior-medial frontal area (pre-SMA)	12	5.32
5	1,112	−28	−58	46	left intraparietal sulcus	5	4.06
		−36	−52	44	left intraparietal sulcus		3.80
		−36	−48	44	left intraparietal sulcus		3.65
6	1,008	32	−60	46	right angular gyrus	7	4.94
7	936	4	36	−8	area s32 (ACC)	7	4.75
		4	44	−16	area Fo1 (mPFC)		4.19
8	928	−4	−12	8	thalamus	7	4.41

Note: The number of the cluster (#), their volume, the MNI coordinates of local maxima, the corresponding brain structure, the contributing experiments and Z-value are listed from the left to the right columns. We adopted an FWE-corrected cluster level $P < 0.05$ (1,000 permutations) and a $P < 0.001$ cluster-forming threshold.

Table 4 Common and specific activations for implicit vs. explicit social impressions.

Implicit & explicit judgments (conjunction): not significant

Implicit > explicit judgments: not significant

Explicit > implicit judgments:

Cluster #	Volume (mm ³)	x	y	z	Brain regions	Z-values
1	264	6	22	48	superior medial frontal area (pre-SMA)	3.09
2	248	35	27	−12	right IFG	3.29
		33	23	−8	right IFG	3.09
3	104	−29	−57	41	left intraparietal sulcus	3.29
4	88	53	24	24	right area 45	3.29
		51	20	23	right IFG	3.09

Note: The number of the cluster (#), their volume, the MNI coordinates of local maxima, the corresponding brain structure and Z-value are listed from the left to the right columns. We applied a minimum cluster size of 20 mm³ and a statistical threshold of $P < 0.001$ with 1,000 permutations.

Table 5 The neural bases of warmth judgments (19 experiments with 460 subjects and 129 foci).

Cluster #	Volume (mm ³)	x	y	z	Brain regions	Contributing experiments	Z-values
1	720	54	26	−2	right IFG	3	4.91

Note: The number of the cluster (#), their volume, the MNI coordinates of local maxima, the corresponding brain structure, the contributing experiments and Z-value are listed from the left to the right columns. We adopted an FWE-corrected cluster level $P < 0.05$ (1,000 permutations) and a $P < 0.001$ cluster-forming threshold.

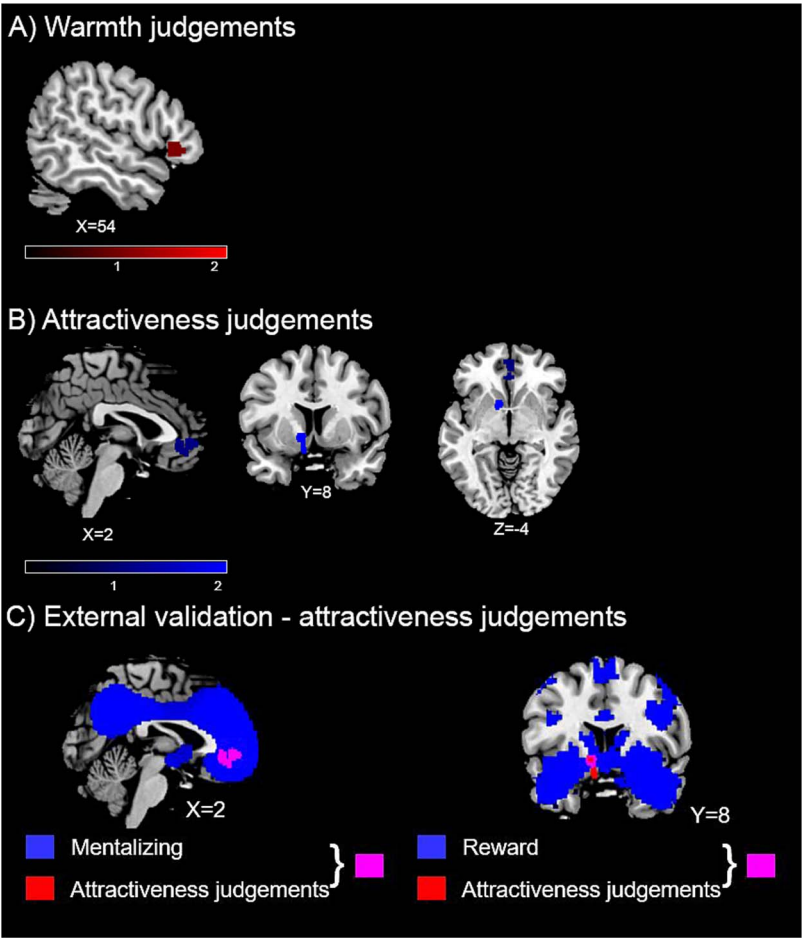


Figure 4 The top of the figure illustrates the brain structures whose activations were significantly associated with warmth A) and attractiveness judgments B). We adopted a cluster-level $P < 0.05$ with FWE correction (1,000 permutations), and a $P < 0.001$ cluster-forming threshold. The meta-analytic comparison of warmth and attractiveness judgments did not reach significance. Moreover, the bottom part of the figure C) reports the anatomical overlaps between the brain structures that have been consistently associated with attractiveness judgments and mentalizing (Schurz et al. 2021) as well as reward processing (Martins et al. 2021).

Table 6 The neural bases of attractiveness judgments (23 experiments with 599 subjects and 201 foci).

Cluster #	Volume (mm ³)	x	y	z	Brain regions	Contributing experiments	Z-values
1	1,400	2	48	−4	area fp2 (frontal pole)	7	4.36
		0	36	−4	area s32 (ACC)		3.93
2	664	−10	8	−4	left caudate nucleus	5	4.34
		−8	8	−16	left caudate nucleus		3.71

Note: The number of the cluster (#), their volume, the MNI coordinates of local maxima, the corresponding brain structure, the contributing experiments and Z-value are listed from the left to the right columns. We adopted an FWE-corrected cluster level $P < 0.05$ (1000 permutations) and a $P < 0.001$ cluster-forming threshold.

Discussion

Previous trans-disciplinary research has highlighted the societal relevance of social impressions (Volk and Quinsey 2002; Todorov et al. 2015; Piva and Rovelli 2023; Han et al. 2024; Kukkonen et al. 2024). The present study synthesizes a large body of research investigating the neural basis of forming social impressions of “stable characteristics”. We identified an extensive network of areas underlying this ability, with further specialized neural systems supporting its constituent properties such as implicit and explicit impressions, warmth and attractiveness judgments, psychological and physical attributions, as well as person perception.

The widespread “social impression” network

The formation of social impressions likely starts with early visual analyses in the occipital cortex, supporting the processing of others’ visual features (Brooks et al. 2021), while the FFA may support the representation of social content such as sex (Kaul et al. 2010) and external physical attributes (Contreras et al. 2013). In addition, subcortical areas such as the amygdala, the thalamus and the insula enrich this sensory processing of social stimuli with cues on their emotional value (Šimić et al. 2021), possibly motivating approach-avoidance responses (Abivardi et al. 2020; Hulsman et al. 2024). Then, cognitive inferences about others’ traits and stable personal characteristics

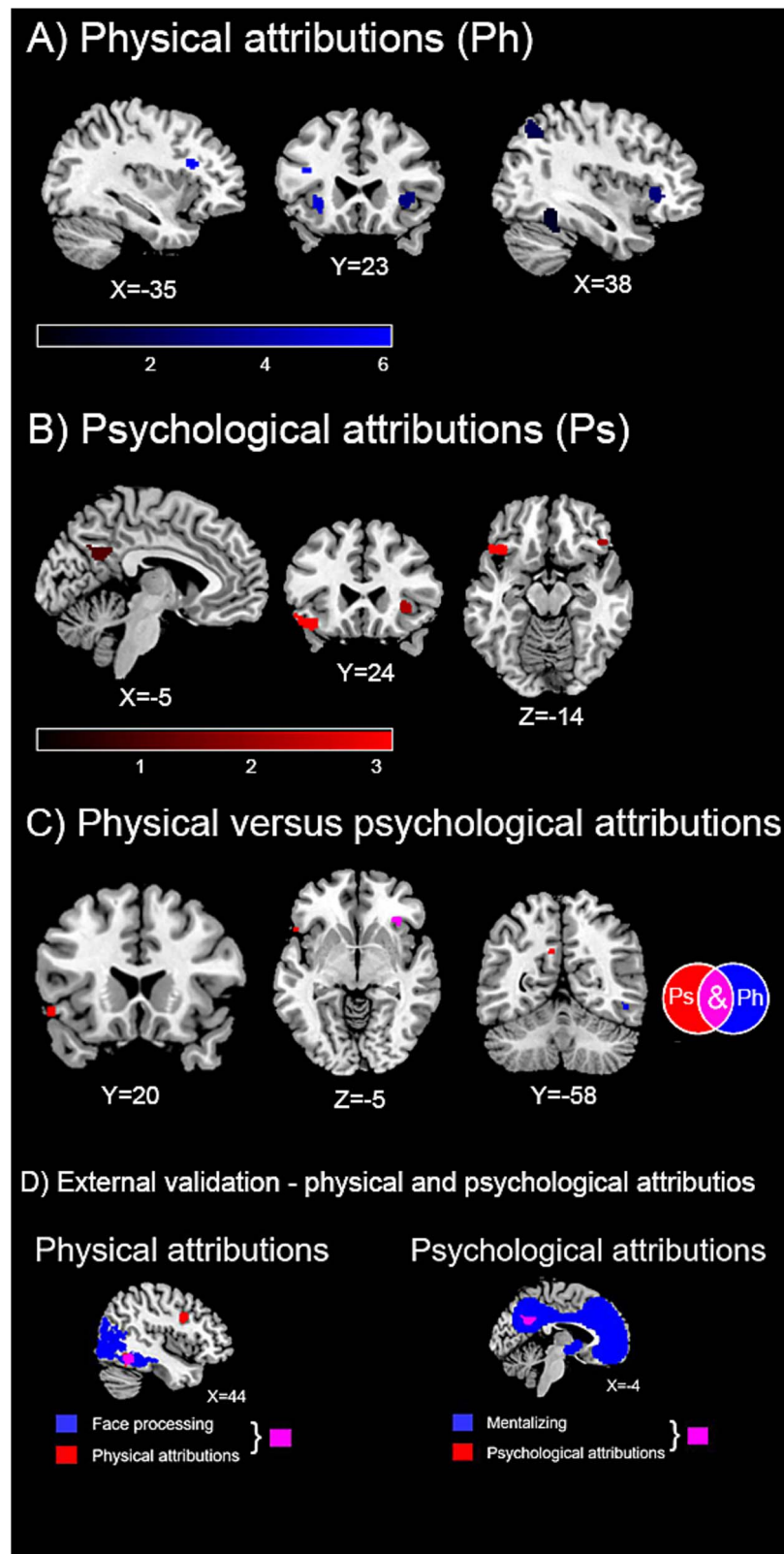


Figure 5 The top part of the figure reports the brain areas associated with physical attributions A), psychological attributions B), and their common and specific activations C). For the two separate meta-analyses, we adopted a cluster-level $P < 0.05$ with FWE correction (1,000 permutations), and a $P < 0.001$ cluster-forming threshold. For the contrast analysis, we adopted an uncorrected $P < 0.001$ with 1,000 permutations and a minimum cluster size of 20 mm^3 . The bottom part of the figure reports the external validation D). Specifically, the figure reports the anatomical overlaps between the brain structures that have been consistently associated with physical attributions and face processing (Rosenke et al. 2021) and with psychological attributions and mentalizing (Schurz et al. 2021).

Table 7 The neural bases of psychological attributions (35 experiments with 733 subjects and 389 foci).

Cluster #	Volume (mm ³)	x	y	z	Brain regions	Contributing experiments	Z-values
1	1,640	-4	-56	28	posterior cingulate cortex	7	4.65
		-10	-66	36	left precuneus		3.57
2	1,272	34	26	-2	right IFG/right insula	8	5.27
		46	28	-14	right IFG		4.03
3	1,160	-38	22	-16	left temporal pole/IFG	5	5.21
		-46	22	-14	left temporal pole/IFG		4.01
		-52	20	-8	left temporal pole/IFG		3.71

Note: The number of the cluster (#), their volume, the MNI coordinates of local maxima, the corresponding brain structure, the contributing experiments and Z-value are listed from the left to the right columns. We adopted an FWE-corrected cluster level $P < 0.05$ (1,000 permutations) and a $P < 0.001$ cluster-forming threshold.

Table 8 The neural bases of physical attributions (46 experiments with 1,066 subjects and 353 foci).

Cluster #	Volume (mm ³)	x	y	z	Brain regions	Contributing experiments	Z-values
1	2,312	44	-52	-14	right area FG4	9	4.64
		38	-50	-26	right cerebellum (lobule VI)		3.76
2	1,736	32	-60	48	right intraparietal sulcus	7	5.36
3	1,088	36	28	-2	right IFG/right insula	6	5.49
4	824	46	6	30	right IFG	5	4.81
5	784	-30	26	-6	left IFG/left insula	5	4.14
6	776	-40	18	22	left IFG	3	4.55

Note: The number of the cluster (#), their volume, the MNI coordinates of local maxima, the corresponding brain structure, the contributing experiments and Z-value are listed from the left to the right columns. We adopted an FWE-corrected cluster level $P < 0.05$ (1000 permutations) and a $P < 0.001$ cluster-forming threshold.

Table 9 Common and specific activations for psychological vs. physical attributions.

Psychological & physical attributions (conjunction):

Cluster #	Volume (mm ³)	x	y	z	Brain regions
1	696	34	26	-2	right IFG/right insula

Psychological > physical attributions:

Cluster #	Volume (mm ³)	x	y	z	Brain regions	Z-values
1	120	-52	19	-8	left temporal pole	3.09
2	80	-8	-57	31	left superior medial frontal area	3.29
3	24	-9	-64	34	left precuneus	3.29

Physical > psychological attributions:

Cluster #	Volume (mm ³)	x	y	z	Brain regions	Z-values
1	72	46	-56	-8	right inferior temporal	3.29
		49	-58	-11	right area FG4	3.09

Note: The number of the cluster (#), their volume, the MNI coordinates of local maxima, the corresponding brain structure and Z-value are listed from the left to the right columns. We applied a minimum cluster size of 20 mm³ and a statistical threshold of $P < 0.001$ with 1,000 permutations.

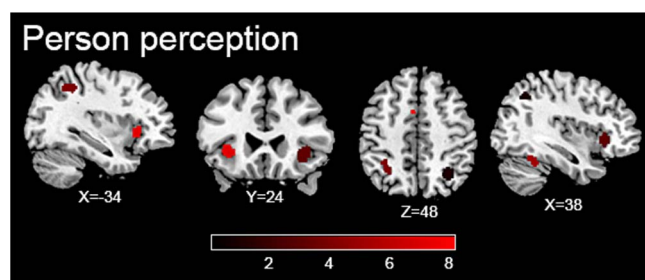


Figure 6 The figure illustrates the brain structures whose activations were significantly associated with person perception. We adopted a cluster-level $P < 0.05$ with FWE correction (1000 permutations), and a $P < 0.001$ cluster-forming threshold.

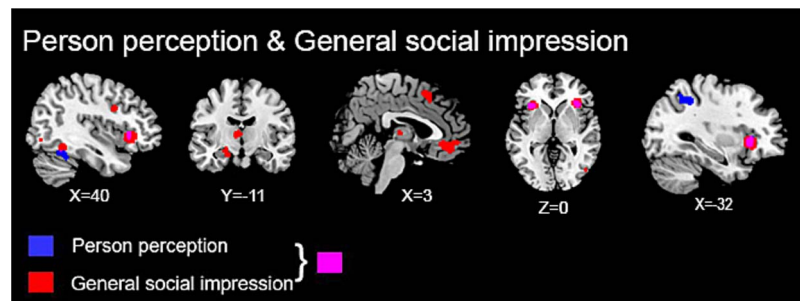
are implemented in the mPFC (Van Overwalle and Heleven 2021; Wagner et al. 2019). Finally, forming social impressions recruits areas in charge of semantic control, such as the IFG and the pre-SMAs, underlying the retrieval and selection of social knowledge about the other (Binney and Ramsey 2020; Balgova et al. 2024). This final step is fundamental for generating an appropriate social response considering the perceiver's goals alongside the contingent counterpart and their social context (Diveica et al. 2021).

As expected, this general meta-analysis highlighted the involvement of mPFC, likely underpinning a neural representation of others' stable characteristics within the mentalizing system (Welborn and Lieberman 2015; Van Overwalle and Heleven 2021). Instead, we did not detect a consistent engagement of TPJ/pSTS, likely because these

Table 10 The neural bases of person perception underlying social impression formation (17 experiments with 342 subjects and 346 foci).

Cluster #	Volume (mm ³)	x	y	z	Brain regions	Contributing experiments	Z-values
1	1,824	32	−58	46	right intraparietal sulcus	7	5.94
2	1,568	48	6	34	right IFG	6	5.29
3	1,440	34	26	−4	right IFG/right insula	6	5.90
4	1,200	−34	−46	46	left intraparietal sulcus	5	4.40
		−32	−52	44	left intraparietal sulcus		4.04
		−30	−56	50	left intraparietal sulcus		3.80
5	1,176	50	−54	−24	right area FG4	6	4.05
		38	−50	−26	right cerebellum (lobule VI)		4.02
		42	−56	−22	right area FG4		3.79
6	1,056	−46	6	30	left area 44	4	4.47
		−48	10	30	left area 44		4.36
7	928	−32	22	−2	left IFG/left insula	4	4.42
8	664	−6	−4	56	posterior-medial frontal area (SMA and pre-SMA)	5	4.53
		−4	4	48	middle cingulate		3.29
					cortex/posterior-medial frontal area (SMA and pre-SMA)		

Note: The number of the cluster (#), their volume, the MNI coordinates of local maxima, the corresponding brain structure, the contributing experiments and Z-value are listed from the left to the right columns. We adopted an FWE-corrected cluster level $P < 0.05$ (1,000 permutations) and a $P < 0.001$ cluster-forming threshold.

**Figure 7** The figure shows the brain structures that have been consistently associated with person perception (blue), general social impression formation (red), or both (violet).

regions preferentially encode transient mental states such as beliefs, emotions, intentions, and goals (Van Overwalle 2009; Long et al. 2020). This interpretation aligns with the well-established role of the STS in gaze processing (Carlin and Calder 2013) and of the TPJ in attention allocation (Krall et al. 2015). Both processes appear more critical for evaluating context-dependent mental states than for processing stable, enduring traits. As our study focused exclusively on social impressions of stable attributes, we did not compare these inferences with evaluations of others' transient mental states. Accordingly, further research is needed to delineate the distinct neural representations of stable vs. transient traits. In particular, future studies should clarify the specific contributions of the pSTS/TPJ and mPFC to these social-cognitive processes.

From an evolutionary perspective, an extensive brain network underlying the formation of social impressions may have evolved to cope with the demands of increasingly complex societies ("Social intelligence hypothesis"; Speechley et al. 2024). This hypothesis fits with the notion that, in vertebrates, brain size is associated with the size of their social groups and pair bonding (Dunbar and Shultz 2007). Social impressions are indeed crucial for a timely understanding of social inputs, and for fostering group cohesion, building relationships, and enabling effective social behavior, all vital skills for surviving and thriving in a complex world (Ashton et al. 2018; Johnson-Ulrich 2021). Importantly, however, fast social impressions can also result in

inaccurate judgments, as in the case of facial stereotyping, ie inferences on personality traits based on facial appearance (Foo et al. 2022; Chwe et al. 2024).

It is worth noting that most of the studies included in this meta-analysis used faces as stimuli (see Supplementary Materials). Thus, whether we identified a network reflecting the formation of social impressions in general, or rather specifically tuned to facial appearance, remains unclear. Future research may fill this gap by investigating the regions underlying the processing of social impressions based on information other than appearance, such as somebody's reputation or behavior (Ames et al. 2010). In the present study, this analysis was not feasible because less than 10 studies explicitly examined the neural bases of social impression with videos or sentences depicting positive and negative moral actions (Cloutier et al. 2012; Cloutier and Gyurovski 2013, 2014; Englander et al. 2012; Harada et al. 2009; Luo et al. 2019; Spiers et al. 2017).

Moreover, our literature search highlighted a gap concerning the formation of social impressions based on non-visual sensory modalities. In particular, we identified only one study using body odors (McGlone et al. 2013), seven studies with contrasts based on auditory or audiovisual stimuli (Sokhi et al. 2005; Englander et al. 2012; Junger et al. 2013; Quirin et al. 2013; Hensel et al. 2015; Ceravolo et al. 2016; Smith et al. 2019), and no studies on social impressions elicited by touch and taste. This gap is particularly relevant because, although

humans are primarily visual animals, our brain is also highly sensitive to social information from other sensory channels (Aglioti and Paz-zaglia 2011; Groyecka et al. 2017). Moreover, an extensive literature on blind individuals highlights an effective “social brain” even in the absence of visual information (Gougoux et al. 2009; Fairhall et al. 2017; Arioli et al. 2021b).

Implicit and explicit social impressions

The meta-analysis on implicit social impressions identified activations in areas underlying person perception (Arioli et al. 2018), extending from the middle occipital to the fusiform gyrus. These areas have been suggested to underpin the perceptual analysis of social stimuli in tasks eliciting implicit impressions (Geday et al. 2003). Conversely, explicit impressions engaged multiple regions usually ascribed to networks in charge of semantic control (pre-SMA) and mentalizing (mPFC) (Diveica et al. 2021). The involvement of such an extensive network may reflect the larger cognitive load required by explicit impressions (Cunningham and Zelazo 2007; Ma et al. 2011), while implicit judgments may rely on reflexive and automatic processes associated with the fusiform gyrus (Yang et al. 2015). We observed no common activations to implicit and explicit impressions, supporting the idea that these judgments engage different neuro-cognitive mechanisms (Kurdi et al. 2019).

Against our expectations, both meta-analyses failed to detect a consistent involvement of the amygdala in association with implicit or explicit social judgments. While this negative finding may be partially ascribed to methodological limitations that will be discussed below, it might also suggest that the amygdala is activated only in response to specific social judgments, regardless of the task instructions. For example, recent evidence suggests that the amygdala is mainly active in response to multiple types of cues signaling untrustworthiness (Santos et al. 2016; Sladky et al. 2021). In line with this interpretation, previous meta-analyses (Bzdok et al. 2011) reported amygdala activation during both explicit and implicit tasks when analyses were restricted to judgments of trustworthiness and attractiveness. Moreover, the amygdala comprises multiple nuclei with distinct functional specializations (ranging from valence and reward to visceral processing; Gothard 2020). This internal heterogeneity may preclude the identification of a singular neural representation for the diverse social impressions examined in our study, especially when they are categorized only by task type (implicit vs. explicit) rather than by the specific social judgment required.

Importantly, our findings might be biased by the unequal distribution of studies addressing psychological attributions among implicit and explicit impression studies. Indeed, 17 out of 62 experiments ($\approx 27\%$) included in the meta-analysis on explicit judgments examined psychological attributions, whereas only 7 out of 40 experiments ($\approx 17\%$) in the meta-analysis on implicit judgments focused on psychological attributions. Although small, this difference may in principle bias the chances of detecting the involvement of the mentalizing network for implicit judgments.

The Big Two and attractiveness

Concerning the Big Two, while the meta-analysis on competence did not provide significant findings, consistent activations for warmth judgments were found in the pars orbitalis of the right IFG. Clues into the role of this area in impressions about warmth come from previous

reports of its engagement as a crucial hub for moral judgment (Carlson and Crockett 2018; Tassy et al. 2012), reputation formation (Knoch et al. 2009), processing of affective gesture (Lotze et al. 2006), and empathic response to others' emotional states (Schulte-Rüther et al. 2008). These findings suggest that the IFG pars orbitalis integrates affective and moral inferences regarding others' warmth into consistent social decision-making and behavior (Xia et al. 2015; Kobayashi et al. 2022).

Different reasons could explain the absence of consistent activations for impressions of competence. First, the latter involve highly heterogeneous processes, such as the perception of intelligence, financial status, strength, and dominance, possibly requiring a larger number of studies to identify convergent brain activations (Müller et al. 2018). In particular, in our dataset (see [Supplementary table S5](#)), the 22 experiments included in the meta-analysis on competence focused on socio-economic status ($n = 6$), dominance ($n = 2$), hierarchy ($n = 5$), and intelligence ($n = 7$), as well as specific combinations of socio-economic status and physical power ($n = 1$) and general competence ($n = 1$). Although all these experiments clearly targeted the evaluation of competence (ie whether a person can act in line with their intentions; Fiske et al. 2007; Fiske 2018), the specific cognitive and neural processes involved—for example, in representing intelligence vs. hierarchy—may recruit distinct brain networks. For example, intelligence judgments have been associated with a specific engagement of the dorsolateral prefrontal cortex (Hall et al. 2010), whereas hierarchy appears to recruit a more ventral portion of the prefrontal cortex, extending into the orbitofrontal cortex (Farrow et al. 2011). However, given the number of experiments focusing on different competence subtypes, we could not perform specific meta-analytic comparisons to directly test this interpretation. An alternative interpretation is that this negative finding may also reflect the absence of a dedicated neural substrate selectively specialized for competence judgments, which fits with previous related evidence showing no selective activation for competence vs. warmth (Lan et al. 2022), nor regions associated with the processing social hierarchies (Kim et al. 2023b). However, there is evidence that the neural processing of competence may interact with other dimensions. For instance, the ventromedial prefrontal cortex and the ventral striatum are activated when someone's preferences are congruent with those of hierarchically superior (compared to inferior) individuals (Kim et al. 2023b). Another study found no regions associated with processing a superior vs. inferior status, but in the striatum, amygdala and vmPFC this contrast interacts with the external motivation to respond without prejudice (Mattan et al. 2018). These results suggest that the processing of competence maps onto a specific neural substrate only if other—interacting—determinants of social impressions are considered. Following this consideration, our meta-analysis may have failed to identify consistent neural correlates of competence because it focused exclusively on this trait, without addressing other relevant dimensions that often interact with competence-based judgments. Finally, the lack of significant findings for competence might depend on our exclusion criteria, as a recent neuroimaging meta-analysis on social hierarchies, which also included contrasts based on cultural objects (eg car, uniform) rather than restricting analyses to human stimuli as in the present study, highlighted the significant involvement of insula and TPJ for dominance detection (Li et al. 2021).

Regarding attractiveness judgments, consistent with prior reports (Mende-Siedlecki et al. 2013; Chuan-Peng et al. 2020), attractiveness judgments engaged the ACC alongside the left caudate. These findings

suggest that meso-cortico-limbic reward circuitry (Smith et al. 2009; Martins et al. 2021) also supports “social” evaluation.

It has been reported that a facial trustworthiness judgment is the best indicator to predict whether someone evaluates a face as attractive (Todorov 2008). In the light of previous meta-analytic evidence of common involvement of the amygdala for facial trustworthiness and attractiveness judgments (Bzdok et al. 2011; Mende-Siedlecki et al. 2013), we expected this subcortical structure to emerge when comparing the neural basis of impressions about attractiveness and warmth. Importantly, however, the present negative findings may be biased both by the nonlinear response of amygdala to facial trustworthiness, and by its prominent role in encoding increasing untrustworthiness (Mende-Siedlecki et al. 2013; Santos et al. 2016). Since we focused on linear effects and contrasts with a positive valence (eg “trustworthy > untrustworthy faces”) to avoid the inclusion of opposite contrasts in the same analysis (see *Methods*), our exclusion criteria likely reduced sensitivity to regions typically engaged by negatively-valenced stimuli such as the amygdala. Indeed, the amygdala is a crucial subcortical structure for the expression and recognition of intense emotions (Barrett et al. 2007; Habel et al. 2007), supporting survival-based fight-or-flight responses (Šimić et al. 2021) and aggressive behavior (Tonnaer et al. 2023). Although robust evidence highlights its involvement in both positive and negative emotions (Smith and Torregrossa 2021), several functional neuroimaging studies show that untrustworthy-looking faces elicit a stronger amygdala response (eg Engell et al. 2007). These findings are further supported by meta-analyses of facial trustworthiness, which emphasize a predominant role of the amygdala in responding to untrustworthy faces (Santos et al. 2016).

Psychological and physical attributions

Psychological attributions preferentially recruited mentalizing- and affect-related regions (posterior cingulate, precuneus, insula; Arioli et al. 2021a), whereas physical attributions engaged a network implicated in social categorization (right IFG, intraparietal sulcus) alongside fusiform and emotion-related structures (insula, cerebellum; Merritt et al. 2021; Saarinen et al. 2021; Xu et al. 2021). This pattern is consistent with the notion that many social categories (eg sex, age, “race”) are rapidly inferred from physical features (Fiske and Neuberg 1990; Todorov 2012) and, crucially, with the close link between physical appearance, categorization, and stereotyping (Fiske and Neuberg 1990; Wheeler and Fiske 2005; Amodio 2014).

Because our physical-attribution dataset included numerous studies on “race”, the observed activations may reflect category-based processes shaped by prejudice and stereotypes rather than purely perceptual analyses. While the notion of biologically discrete human “races” is nowadays untenable on biological, anthropological, and genetic grounds (Heinz et al. 2014; Gokcumen 2018; Templeton 2023; Kim et al. 2023a), discrimination based on visible traits (resulting in racism, sexism, ageism) remains pervasive and may modulate these responses (World Health Organization 2021; Barreto and Doyle 2023).

The right anterior insula, emerging from the conjunction across psychological and physical attributions, may track the affective core of such category-based evaluations. This structure has been indeed implicated in the subjective feelings accompanying prejudiced responses, in conformity to in-group members, and in intergroup empathy, and is recurrently reported in meta-analyses of in-/out-

group processing (Amodio 2014; Cikara and Van Bavel 2014; Lin et al. 2018; Merritt et al. 2021; Saarinen et al. 2021).

Finally, direct comparison highlighted a possible hemispheric dissociation between psychological and physical attributions, with the processing of personality traits involving left-lateralized “mentalizing” regions, while attending to physical characteristics preferentially recruited right-hemisphere structures. This pattern aligns with previous evidence on right-lateralized face processing (Rossion and Lochy 2022) and predominantly left-hemispheric activations for intelligence and trustworthiness judgments (Lindner et al. 2008; Bzdok et al. 2012; Hensel et al. 2015). Since high-dimensional models of social impressions are still emerging, further work is needed to ground this lateralization in a detailed neuro-cognitive characterization of the underlying processes (Connor et al. 2024).

Person perception

The meta-analysis on person perception unveiled an extensive brain network that may underpin the ability to differentiate between humans and objects. This network involves structures that have been previously implicated not only in perceiving other individuals (such as the fusiform gyrus), but also in observing their actions to extract their meaning (pre-SMAs, intraparietal sulcus, the inferior temporal gyrus), and in the emotional processing of their significance (insula and cerebellum). Interestingly, these findings confirm the involvement of cerebellum during person perception and during the processing of others’ stable characteristics (Van Overwalle et al. 2015, 2020).

Building on the premise that person perception (ie discriminating inanimate objects, governed by physical laws, from human beings, whose inner experiences make their behavior less predictable) constitutes a prerequisite for social inferences, we contrasted neural responses to person perception and social impression formation. This comparison aimed to distinguish brain structures involved in the initial recognition of intentional agents from those supporting the attribution of stable traits. Both processes were found to engage an extensive network of regions implicated in the processing of biological and emotional information (Arioli et al. 2018), such as the fronto-insular cortex bilaterally alongside the right fusiform gyrus and intraparietal sulcus. Person perception specifically recruited the left intraparietal sulcus and the cerebellum (lobule VI), likely involved in representing others as intentional agents (Arioli and Canessa 2019). While impression formation was associated with activity in the amygdala and prefrontal cortex, the former likely supports the formation of (predominantly negative) impressions via emotional processing, while the latter integrates this information to build a more comprehensive representation of others’ traits and to support socially appropriate behaviors (Iidaka et al. 2011). Since the person perception dataset constitutes a subset of the general social impression one (see *Supplementary Materials*), the substantial overlap between the two meta-analyses represents a key limitation of this comparison, hindering a clear dissociation between these processes.

Surprisingly, we did not observe a consistent engagement of the pSTS and TPJ during person perception, which were expected based on their well-established role in processing social information (Yang et al. 2015). This negative finding may first reflect their prominent role in processing temporary mental states rather than stable attributes (Van Overwalle 2009). Indeed, although the meta-analysis on person perception included only contrasts comparing human perception with non-human, the initial database was restricted to studies on stable

attributes, which may have limited the detection of brain structures probably more strongly involved in representing transient mental states. In addition, the relatively small sample of this meta-analysis (17 experiments) may have limited the power to detect all relevant nodes of the person-perception network. Further research is needed to clarify the role of pSTS/TPJ in person perception, differentiating the representation of others' temporary mental states vs. stable attributes.

Limitations

In line with well-established methodological recommendations, and given our aim to examine the entire brain rather than specific regions, we included only studies reporting whole-brain activations (Eickhoff et al. 2012), thereby excluding those based on ROI or SVC analyses (Müller et al. 2018). The side effect of this selection is however a sampling bias, leading to exclude 15 experiments based on ROI/SVC analyses, many of which reported the involvement of amygdala and STS/TPJ (Abbatecola et al. 2021; Ai et al. 2018; Cassidy et al. 2013; Kranz and Ishai 2006; Liang et al. 2010; Liu et al. 2015; Quarto et al. 2016; Xie et al. 2021). These regions are often examined with ROI/SVC analyses because of their well-established role in socio-cognitive processing, but since coordinate-based meta-analyses generally exclude such restricted findings, they can paradoxically disappear from meta-analytic results. Importantly, this lack of activation may also reflect other functionally relevant factors. Regarding the amygdala, its preferential processing of negatively-valenced stimuli (Santos et al. 2016), along with the distinct functional specializations of its different nuclei (Gothard 2020), may hinder the identification of a convergent neural representation in our meta-analysis, which primarily focused on positive traits. Regarding the pSTS/TPJ, our null findings might instead reflect their more prominent role in processing transient mental states rather than the stable attributes examined here (Van Overwalle 2009). Further studies are needed to disentangle these possibilities.

To enhance the generalizability of our findings within the constraints of our research questions (Radua and Mataix-Cols 2012), we investigated the neural correlates of social impression formation across different sensory modalities and stimulus types (see Methods). However, the literature remains heavily biased toward visual stimuli, particularly faces (see Supplementary Materials). Given the predominance of studies on facial appearance, the limited availability of non-visual data precluded statistical comparisons across sensory modalities; similarly, we could not contrast brain activity associated with face appearance against that linked to reputation or behavior. This limitation warrants caution regarding the degree of generality of our results. Future research should address this gap by examining social impressions derived from non-visual cues and from behavior or reputation. Finally, since our meta-analysis primarily contrasted positive vs. negative attributes to ensure methodological consistency (ie excluding contrasts in the opposite direction; see Methods), the findings may not fully generalize to social impressions involving exclusively negative traits.

Another significant limitation is that, although we followed methodological guidelines (Müller et al. 2018) and met recommended thresholds for the number of experiments per meta-analysis ($n = 17$; Yeung et al. 2023) and cluster ($n \geq 3$; Janacsek et al. 2020), some datasets showed internal heterogeneity in the constructs of interest. Such diversity in the underlying cognitive processes can hinder the identification of consistent patterns of brain activity. This issue was particularly evident for the competence meta-analysis,

which included 22 experiments spanning diverse competence subtypes including intelligence, socio-economic status, and dominance. Accordingly, the absence of convergent findings for competence should be interpreted in the light of this heterogeneity, which may have precluded the detection of a single consistent neural signature for this aspect of social impressions.

Conclusions and future directions

We identified an extensive network associated with the formation of social impressions, including common and specific structures for the processing of their distinct underlying dimensions.

The general process of “forming social impressions” of others' stable attributes engages cortical areas associated with person perception, semantic control, and mentalizing, alongside subcortical structures in charge of emotional processing, overall providing a multifaceted representation of others. At a deeper level, “implicit judgments” engage the fusiform gyrus and middle occipital areas underlying perceptual analyses of social stimuli, while “explicit judgments” engage key structures of the mentalizing and semantic control networks such as the mPFC and IFG as well as pre-SMA, respectively. While “competence judgments” did not yield consistent patterns of brain activity, evaluating “warmth” recruits the pars orbitalis of the right IFG, likely translating inferences about others' warmth into consistent social choices and behavior. “Attractive” faces activate cortical and subcortical sectors of the reward system (such as the caudate). While both attribution types engaged the right insula—likely reflecting the affective core of category-based evaluation linked to prejudice—“psychological attributions” preferentially recruited mentalizing regions (precuneus and posterior cingulate), whereas “physical attributions” engaged regions associated with social categorization and face processing (such as the right IFG and intraparietal sulcus as well as the fusiform gyrus). Finally, the person perception recruited brain structures implicated not only in perceiving other individuals (fusiform gyrus), but also in observing their actions to extract their meaning (pre-SMAs and intraparietal sulcus), and in the emotional processing of their significance (insula and cerebellum).

Our perspective suggests that social impressions of stable traits rely on cognitive and neural processes distinct from those supporting the attribution of transient mental states. Although both types of social inference likely share person perception (ie the ability to distinguish inanimate objects from humans; Arioli et al. 2018) as a prerequisite, they may subsequently diverge into partially different mechanisms. Mental state attribution requires selective attention to contextual information, likely engaging the pSTS and TPJ. Conversely, impressions of stable traits involve relatively invariant cues (eg physical characteristics, personality), likely involving the mPFC. Since the present study focused exclusively on stable attributes, future studies should directly compare these neural representations with those underlying transient mental states and empirically test the proposed divergence.

While advancing knowledge of social cognition in the healthy brain, these findings provide a benchmark for studying the neural bases of social difficulties across different clinical populations. Indeed, an atypical formation of social impressions has been observed both in psychiatric (Bleich-Cohen et al. 2009; Fertuck et al. 2019; Haker et al. 2014; Nicol et al. 2013; Xie et al. 2021; Pinkham et al. 2008; Taylor et al. 2011) and neurological (Adolphs et al. 1998; De Renzi et al. 1989; Heberlein et al. 2004) disorders. The present results may thus

guide the design of neuromodulation-based treatments selectively targeting well-defined neural correlates in individuals with social deficits also affecting the formation of social impression (Penton et al. 2022). Social phobia and social anxiety, in particular, are characterized by impairments in forming and updating impressions of others (Tsuji and Shimada 2018) and this factor is thought to be central to the maintenance of these disorders (Haker et al. 2014). In combination with psychotherapy and cognitive rehabilitation, and consistent with our findings, prefrontal neurostimulation may enhance perceptions of trustworthiness and warmth while reducing attentional biases toward social threats (Heeren et al. 2017).

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Author contributions

E.M.W.K.: conceptualization, data curation, formal analysis, investigation, methodology, project administration, validation, visualization, writing-original draft; M.A.: conceptualization, data curation, investigation, methodology, project administration, supervision, validation, visualization, writing-original draft; F.C.: investigation, methodology, validation, visualization, writing-review and editing; N.C.: investigation, methodology, validation, visualization, writing-review and editing, and Z.C.: conceptualization, funding acquisition, project administration, resources, supervision, validation, visualization, writing-review and editing.

Supplementary material

Supplementary material is available at *Cerebral Cortex* online.

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Conflicts of interest

None of the authors have a conflict of interest to declare.

Data availability

All data can be found in the included articles.

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