Received: 18 October 2022 | Revised: 15 April 2024 | Accepted: 16 April 2024

DOI: 10.1002/wcs.1681

ADVANCED REVIEW

WIREs COGNITIVE SCIENCE WILEY

Co-perceiving: Bringing the social into perception

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Funding information
Volkswagen Foundation (Co-Sense); EMERGE EIC, Grant/Award Number: 101070918; BIDT; European Research Council (ERC), Grant/Award Number: 819040; Templeton Religion Trust

Edited by: Mohamad El Haj, Editor

Abstract

Humans and other animals possess the remarkable ability to effectively navigate a shared perceptual environment by discerning which objects and spaces are perceived by others and which remain private to themselves. Traditionally, this capacity has been encapsulated under the umbrella of joint attention or joint action. In this comprehensive review, we advocate for a broader and more mechanistic understanding of this phenomenon, termed co-perception. Co-perception encompasses the sensitivity to the perceptual engagement of others and the capability to differentiate between objects perceived privately and those perceived commonly with others. It represents a distinct concept from mere simultaneous individual perception. Moreover, discerning between private and common objects doesn't necessitate intricate mind-reading abilities or mutual coordination. The act of perceiving objects as either private or common provides a comprehensive account for social scenarios where individuals simply share the same context or may even engage in competition. This conceptual framework encourages a re-examination of classical paradigms that demonstrate social influences on perception. Furthermore, it suggests that the impacts of shared experiences extend beyond affective responses, also influencing perceptual processes.

This article is categorized under:

Psychology > Attention
Philosophy > Foundations of Cognitive Science
Philosophy > Psychological Capacities

KEYWORDS

collective mind, joint attention, perception, shared experiences, social cognition, social influence on perception

1 | INTRODUCTION

Imagine passengers seated on a bus, each engrossed in their smartphones or newspapers. What they look at and see is private to them. However, they all perceive something in common—the ambient sounds of traffic, cars passing by, people boarding, and disembarking. Now, let us say the bus' fire alarm suddenly blares. Instantly, most passengers would raise their heads, casting surprised glances at their neighbors. In contrast, if one passenger's screen displays a local flood

warning message, they would not immediately seek social confirmation that everyone else also saw it. Unlike the fire alarm, the warning message is not a perceptually common experience.

As we move through the same physical environment alongside others, we inevitably share certain perceptual encounters involving objects, events, and spaces. The bus scenario illustrates that sharing these experiences fundamentally involves perceiving the objects behind the experiences as common. On the flip side, other aspects of our experiences, occurring simultaneously, are perceived as private. The capacity to distinguish between commonly and privately perceived objects while we are surrounded by others is central, but has been missed from the study of perception. How and where is the distinction drawn between a sound that is heard just by us and one that is heard by all of us?

Here, we review evidence suggesting that the distinction between common and private objects is part of perception itself (Section 2). We also explain why this deceptively simple capacity to make such a distinction represents a ground for social cognition (Section 3) and expands our understanding of social perception (Section 4), which is usually reserved to talk about the perception of, rather than with, social agents (Section 5).

Before proceeding further, we need to clarify what we mean by perception—as this is a topic of debate. The general concept we adopt here is that perception involves gathering information about the environment or one's body through sensory channels and subsequently forming or updating one's sensory representation of this environment or bodily states. In many of the examples we examine, this updating process is typically accompanied by a conscious experience. However, it is important to note that consciousness is not a mandatory criterion for discussing something being perceived; demonstrating that perceptual decisions are influenced suffices. Furthermore, as we will delve into later, perception is not inherently synonymous with attention, particularly if attention is construed as the focal point for behavioral or cognitive selection (for instance, as proposed by Lindsay, 2020; Wu, 2023). This later distinction is part of why the capacity for co-perception is different from the ability to jointly coordinate attention or action on the same object.

2 | PERCEIVING WITH OTHERS DIFFERS FROM PERCEIVING ALONE

2.1 | Co-perception: Perceiving things as common or private

Perception can be private in two different ways. First, perception is private in the sense that perceptual experiences are exclusive to the perceiver. No one else can have direct access to your mental states. Your experience of pain, for instance, is inherently your own and cannot be directly shared. Second, perception can be private in the sense that the object of perception, that is, what you are perceiving, is exclusive to you. For example, listening to a song through your headphones is private in this sense, as the song is only audibly accessible to you. However, if the volume increases, the song can become perceptible to others, shifting it from a private experience to one that can also be common to others. If you become aware that it is perceived as common, it is more accurate to say that the sounds are perceived not just *in* common but *as* common. While perceptual access is necessarily private in the first sense, what is perceived can be private or common in the second.

Most experimental and theoretical studies on perception typically concentrate on a solitary individual, thereby conflating the two meanings of "private." In a classic visual experiment, for instance, a participant sits alone before a screen. She has a private experience of the visual stimuli on the screen in the first but also the second sense because no one else is simultaneously perceiving the stimuli. This is perfectly fine, but an individualist assumption follows: when another individual looks at the same picture at the same time, nothing fundamentally changes for perception. It is presumed that, as long as there is no discussion or coordinated action, the presence of another perceiver merely constitutes a parallel instance of individual perception. The presence of another perceiver does not significantly alter the perception of the first participant. At most, realizing the presence of someone else might induce a slight increase in stress or arousal in the first participant, which can impact their performance in a perceptual task—this is known as the "social motivation" or "social presence" effect (see Bond & Titus, 1983; Chevallier et al., 2014; Geen, 2019; Morgan et al., 2022; Oh et al., 2018; Zajonc, 1965).

Our perspective differs in the following way: When a viewer becomes aware of the presence of another observer, she still undergoes an experience that is private to her in the first sense (meaning the other person has no direct access to the viewer's experience). Nevertheless, she may also become aware that the second perceiver now commonly perceives the stimuli. This co-perception does not necessitate coordination between the two (as detailed in Section 4). It may be acknowledged by one or both.

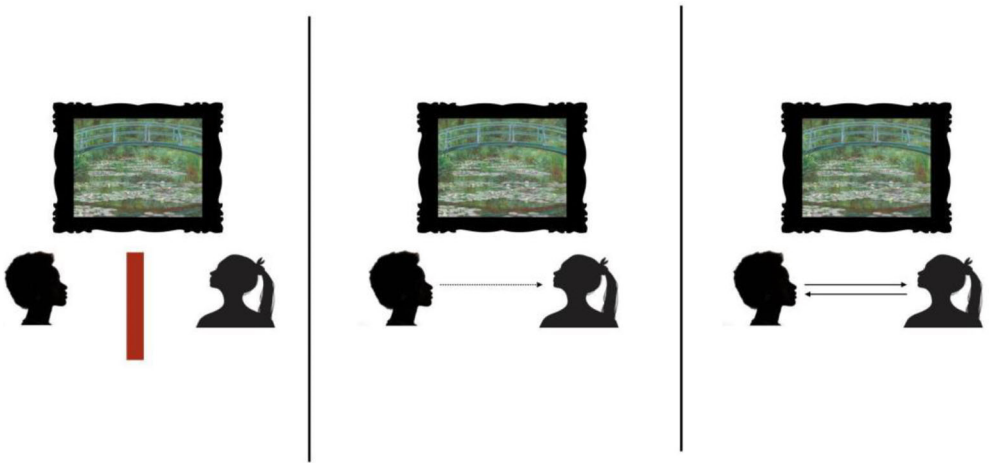

FIGURE 1 Individual, co-, and joint perception. *Left*: When two museum visitors perceive the same painting simultaneously without access to the fact that someone else is also seeing the same painting, the situation consists of only two parallel *individual perceptions*: Nothing would change for either perceiver if the other one was removed. *Middle*: If one visitor has access to the fact that the other is perceiving the painting as well, they become aware that the painting is perceived in common. This is sufficient to speak of *co-perception*, in this case from the left viewer perspective. *Right*: If both visitors are aware that they both see the same painting and are aware of this mutual awareness, the situation falls into a case of *joint perception*.

We propose to refer to the state when a perceiver is aware that her environment, or a portion of it, is simultaneously being perceived by someone else as *co-perception*.

We choose this specialized term to prevent potential misunderstandings with existing terms or everyday language. First, co-perception offers a more accurate description than "collective perception" because it does not presume that all members of the collective are all equally aware of the same thing. Only one viewer may be conscious of the presence of the other, therefore perceiving the painting as common to both (as depicted in Figure 1, middle panel), while the other is unaware that someone else is perceiving the painting and represents it as perceptually private. In such a scenario, asserting that the visitors "collectively" perceive the painting would be misleading. The term co-perception is the most fitting descriptor and applies when one or several individuals view the object as commonly perceived.

Second, co-perception is more than perception in a social context. It encapsulates something distinct from what has been studied for decades as "social perception." It usually involves how we perceive social agents as animate, sentient beings, or as occupying specific social roles. Effects of perceiving with others, as we will explore, have been investigated under various terms like "social influence on perception," "social presence," or "social facilitation," and co-perception variously connects with these effects, and in some cases unifies them.

What matters most here to us is that someone can be in a state of co-perception regarding some sensory contents while in a state of classic private perception regarding other sensory contents. Trivially, not everything that one perceives when someone else is present can be a target for a private/common distinction. Things like one's heartbeat or the slight acidic taste in one's mouth may never enter into co-perception because the other person cannot access these objects. More significantly, when one is engaged in co-perception, certain elements of their perception can either be considered common (as in the case of the bus sounds) or private (such as the screens), and this categorization can dynamically shift as perceivers move through space.

As we will continue to explain, establishing what is commonly perceived between two or more perceivers can work without relying necessarily on visual perspective only (as when we follow someone's gaze) or mental states (such as visual interest) but on coarse-grained perceptual engagement.

2.2 | How co-perception works

2.2.1 | Co-perception beyond gaze

Gaze cues are the primary social signal used in studies on how different individuals perceptually engaged with the same objects can influence each other.

The behavior around gaze is rich and well-studied and it gives an opportunity to understand what co-perception entails. Gaze following can be divided into two levels: low-level gaze following, which is a basic co-orienting response, and high-level gaze following, which involves a representation of others' visual perspectives (see, e.g., Povinelli & Eddy, 1996; Triesch et al., 2006). The distinction between these levels is based on whether the behavior requires mental state attributions. Low-level gaze following acts more like extending others' gaze by an invisible line and updating when this line does not go through certain occluders. It is considered more reflexive and does not involve attributing mental states to others. In tasks like the spatial cueing task (as described, for instance, by Milliken et al., 2003), participants are notably quicker at finding objects when the object's position matches the direction of someone else's gaze, compared to when it doesn't match. Such social effects are highly automatic: they are fast but occur with little control. Observers continue to follow the gaze even when the gaze cue is entirely non-predictive of where the target will appear and thus is detrimental to performance (Friesen & Kingstone, 1998). Both high and low-level gaze-tracking can be, in turn, distinguished from an even higher form of monitoring of other people's attention. Like high-level gaze following, attention monitoring is mentalistic. However, it also comes with additional mentalistic inferences beyond visual perspective: What is the other person interested in? What are they thinking that is different from me? Are they trying to communicate something?

In the visual domain, low-level gaze following is sufficient to establish co-perception. High-level gaze following and attention-monitoring can bring an additional sensitivity to where people are attending but are not required for animals to exhibit sensitivity to commonly versus privately perceived objects (see Figure 2). On the other hand, low-level gaze monitoring is not necessary to establish co-perception.

Three main arguments establish how and why co-perception goes beyond gaze-following. First, gaze-following is too demanding to be the only means to establish what is commonly or privately perceived. Gaze following remains a challenging skill, even for humans. Employing a new paradigm, Prein et al. (2023) have demonstrated that children between the ages of 3 and 5.5 exhibit greater imprecision in tracking the target object of others' gaze. Furthermore, individual differences in this skill persist into adulthood. It is worth noting that this imprecision does not hinder younger children or less precise adults from monitoring a coarse-grained perceptual common engagement of others with a range of objects or broader areas.

A second argument comes from evidence that gaze direction is not the only cue used to monitor what others see: body postures are also sufficient (Azarian et al., 2017). Body posture exerts a similar influence on perceptual decisions as gaze cueing does in experiments solely focused on gaze direction. When the body posture aligns with the identifiable target, participants are quicker to detect the target than when the agent's body posture is incongruent with the identifiable target.

A third argument, however, comes from moving beyond the vision-centric perspective in the research on shared perception. Tracking gaze or body *orientation* works well for monitoring what others see, but what about what they hear or smell? For audition, it is possible to draw a difference between what is heard in common (or privately) based

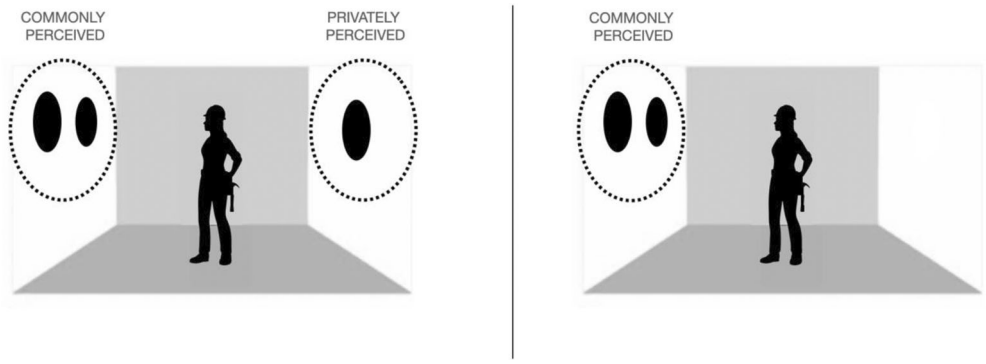

FIGURE 2 Commonly versus privately perceived objects. The presence of an avatar in the participant's field of view (represented here by the full 3D area) is sufficient to elicit a distinction between commonly and privately seen areas. When asked to report the number of dots they can see, the participants answer (3) requires counting both the common and privately seen objects (left panel) or only commonly seen objects (right panel). Participants are faster in the second case. Proper controls were performed to ensure that wider spatial dispersion cannot account for the difference in reaction times between the left and right panel illustrated here.

on context, distances, and sound properties, irrespective of the head or body orientation of the others. Trivially, we treat tinnitus or the sounds in our headphones as heard privately, and a loud sound in the street as heard in common with those around us, but probably not by those two blocks away. Behaviorally, depending on whether we want to be heard by others or not, we show sensitivity to how the sounds we produce will be heard by them and us by speaking louder or softer, adjusting our motion, and moving closer or farther away from people and making ever so subtle movements.

Besides vision and audition, smell and touch also allow for co-perception without monitoring the close directionality of gaze or full body orientation. The two offer interesting complexities: environmental smells, like sounds, can be perceived as common. Haptic touch, say when two people are touching the same vase or tool, can mean that the object is commonly touched, but very few studies have investigated this case. At least during social touch, say a handshake, the two perceivers feel the skin contact area in common.

Our perspective on co-perception suggests that we both use heuristics and actively monitor how individuals engage with the multisensory environment in a detailed, adaptable, and nuanced manner. This encompasses more than just tracking their gaze or body orientation to identify their specific area of visual focus or broader visual field. Additionally, co-perception is not a given. It is conceivable for an animal to be sensitive to the presence of a fellow member or a potential threat without necessarily perceiving which parts of the environment are private or shared between them.

2.2.2 | Monitoring social perceptual engagement

Moving beyond directional cues for thinking about common perception has other theoretical implications. The main one concerns the "social" specificity of the processes involved in perceptual monitoring.

Many studies have questioned whether directional effects induced by gaze or body orientation are necessarily social and, hence, specific to social presence. For example, symbolic cues such as arrows and directional words also reliably orient attention (Hommel et al., 2001; Ristic et al., 2002; Taylor & Klein, 2000; Tipples, 2002, 2008). The mechanisms underpinning the effects of gaze and arrows have so far been shown to proceed differently: eye gaze cueing triggers focused activation related to enhanced visual processing, while arrows activate much broader brain regions, including those related explicitly to volitional orienting (Hietanen et al., 2006; Ristic et al., 2002). The influence of directional symbolic cues is smaller than cues from a human-like agent (Becchio et al., 2013; Nielsen et al., 2015). Similarly, the degree of social influence depends on how active the agent's role is (Zhao et al., 2015) and whether they have perceptual access to the object or at least are presented as having this access (see, e.g., Furlanetto et al., 2016). Explanations in terms of a perhaps especially sensitive attentional cueing, where we use people as directional cues, differ from explanations in terms of a spatial and visual perspective-taking involving a special "decentering" from one's own experience and states, eventually seen as a basic form of mentalizing. However, the two explanations can also be combined (see Capozzi & Ristic, 2020, for discussion).

Returning to our core topic, the current state of research suggests that extracting directional information rests on social-specific and domain-general attentional mechanisms. By contrast, it is possible to hypothesize that the non-directional cues allowing one to monitor perceptual engagement are socially specific and do not take off the ground with purely symbolic or poorly animated virtual agents. Evidence still remains to be gathered.

Mechanistically, it is important to investigate further the sensitivity to others' perceptual engagement. Several EEG studies on perception have provided evidence for a so-called "Social N400," that is, a modulation in the negative-going event-related brain potential (ERP) peaking around 400 ms after the perceiver sees meaningful stimuli, such as words, faces, objects, and scenes either alone or in the presence of another co-perceiver (see Sinha et al., 2023). One higher-level interpretation asks whether such a process necessarily involves a form of "perceptual simulation" of the other person's perception (see Samuel et al., 2021)—which would make it more mentalistic than what is proposed here. Another question is how this sensitivity to object or property engagement relates to sensitivity to spatial engagement. Developmental evidence here suggests that the capacity to take another's spatial perspective is learned and different from the sensitivity to how exactly the objects are seen (e.g., their color, see Woo & Spelke, 2021).

While much remains to be done to understand precisely *how* co-perception differs from isolated perception, both computationally and neurally and across the senses, converging evidence already shows that perceiving together significantly influences perceptual decisions and processing.

3 | BEYOND SOCIAL INFLUENCE ON BELIEFS: HOW CO-PERCEIVING AFFECTS PERCEPTUAL DECISIONS

3.1 | Knowing what others perceive

3.1.1 | Social influence on perceptual judgments is well established

The influence of others on perception has been intensely debated following seminal experiments on social conformity (see, e.g., Asch, 1951, 1955; see also Hoffman et al., 2001; and for review, see Bond & Smith, 1996). Many such classic findings on social influence speak only indirectly to co-perception for at least two reasons.

i. They focus on verbal influences, where co-perceivers hear what others think about a commonly perceived object;
ii. They mostly measure post-perceptual reports and judgments.

Such studies illustrate the traditional assumption that, as far as perceptual experience or decisions are concerned, nothing changes (or should change) when the same person sees the same stimuli alone (therefore as a privately perceived object) or is surrounded by others (therefore as a commonly perceived object).

This evidence shows that many people adjust what they believe or report when others disagree, sometimes for the worse, but sometimes for the better (for review see Kampis & Southgate, 2020). In a marked divergence from the tradition showing the adverse effects of normative conformity, driven by a wish to belong, more recent studies highlight that informational conformity can benefit perceptual accuracy. Co-perceivers achieve higher sensitivity in a two-interval forced-choice visual discrimination task as long as they can discuss what each saw and have comparable individual sensitivities (see Bahrami et al., 2010). The latter clause is particularly interesting as the matching of perceptual sensitivity is not something that perceivers explicitly communicate or can independently ascertain but rather a fact about their perception.

What matters most to our current point is that the studies looking at social influence on perception *presuppose* that people have perceived the same thing in common. Social influence on reports or beliefs cannot get off the ground if people are aware that they perceive different objects, or have doubts that they perceive the same thing. However, as mentioned earlier, most of these studies give less emphasis to the initial stage, where objects are perceived in common, concentrating instead on aligning beliefs or reports. Emphasizing the distinct nature of co-perception—as centered on the commonality—should rectify this viewpoint.

3.1.2 | Methodological lessons from co-perception

The first lesson from the co-perception framework that we propose is to draw attention to the link between what happens at the perception stage (for common objects) and the effects on beliefs or reports. In Asch's seminal work, it is crucial not only that co-perceivers watch the same stimuli but also that they get the opportunity to agree most of the time on what they see in common. The critical (exceptional) trials, where the confederates unexpectedly disagree with the participant and eventually trigger a social conformity effect, only represent a small portion of the trials—and necessarily so.

Second, insisting on this commonality at the stage of perception should send a warning against studies that introduce a delay or separation between individual perception and the social feedback or discussion. They then artificially divide the process of social influence on perception into two stages. The first involves perception, where observers are even sometimes isolated, and the second stage is social feedback, or real interaction, where people hear from people who are presented as having viewed the same object. Besides linguistic communication, the fact that people are removed from the actual co-perception situation deprives them of nonverbal access to others' perceptual interaction with the environment (facial expression, patterns of behavior).

3.1.3 | A strong hypothesis: The strength of co-perception affect the strength of social influence on judgments

Some experimental designs assume that for social influence to operate, it is enough to tell people they have perceived the same object as someone else, either at the same or even at a different time. This assumption makes the

commonality a question of testimony rather than direct perceptual evidence. Our point is not to deny that social influence on decisions or judgment can indeed operate under mere testimony conditions but to stress that such studies de facto miss the fact that social influence can also affect perception itself when studies let people directly experience things with others (see e.g., Molleman et al., 2019).

Social influence on judgment is, for instance, modulated by whether the perceiver can assume that the others had better access to the object perceived in common. Individual perceivers are more likely to adjust their beliefs or adjust them to a higher degree (i) when they face difficult perceptual situations (e.g. noisy, difficult, ambiguous; see El Zein et al., 2019, 2023) and (ii) when they have low confidence in the accuracy of their own perception and/or the other has higher confidence (Gradassi et al., 2022; Reyna et al., 2023).

3.1.4 | The core hypothesis: Co-perception affects more than judgments

Perceptual decisions and processing, and not just linguistic perceptual reports, may be affected by knowing how others see commonly perceived objects. Recent studies (Germar & Mojzisch, 2019; Germar et al., 2023) show that social feedback can affect not only response bias but perceptual experience. Participants were asked to adjust the proportion of orange and blue pixels of a square until they perceived the proportion of both colors as being equal (i.e., 50% blue, 50% orange); they then received feedback regarding what other participants had done and had to adjust the point of subjective equality. This second phase showed that perception (and not report) was affected by social information about others' perceptual decisions.

One EEG study went one step further and examined whether social influence at the level of reports or decisions was accompanied by any change in perceptual processing (Zanesco et al., 2019). They used the classical paradigm introduced by Moscovici et al. (1969), demonstrating that people who had judged an ambiguously green-blue stimuli to be, say, "blue" were ready to change their decision to "green" when informed that other perceivers had judged it to be green. Zanesco and colleagues measured their participants' EEG signals and added another step. After participants saw and named the color of a patch, they received confirming or disconfirming social feedback but then were crucially exposed to the same colored patch again. If social influence made a difference only to report, one would expect that the visual processing for the initial and second viewing of the same patch would be the same. If social influence affected processing, then after disconfirming feedback, one would expect that the visual processing of the same patch would be different. The event-related potentials in early visual brain areas were consistent with this latter hypothesis. Since the presented ambiguous stimuli were identical, the observed effect could not have been driven by the physical features of the object itself. However, it must stem from the social influence on perceptual processing. How this social influence could work is an open question: The positive reward associated with social agreement can explain such results, with rewards being shown to influence perceptual processing (Takagaki & Krug, 2020). Nevertheless, normative conformity is not, as we discussed, the only possible influence at play, and informational conformity could also operate and follow different routes (Mahmoodi et al., 2022).

Studies like Germar and Mojzisch (2019), Germar et al. (2023), or Zanesco et al. (2019) are important because they show that when people are informed about what and how others see, it does not just affect *what* they report but it actually changes *how* they perceive. Moving forward, the study of such social influences on perception should focus on situations where people see things with others naturally rather than being told "someone else has seen the same thing." Allowing the social influence to go both ways, instead of one person receiving feedback, also makes experiments more realistic and should eventually make social influence even stronger (see, e.g., Mahmoodi et al., 2018; Zonca et al., 2021).

With this distinction in mind, we turn to studies that have considered co-perception more directly, allowing people to appreciate how others perceptually engage with the same environment as theirs.

3.2 | The difference between common and private objects affects perceptual decisions

What happens when people are in the presence of others and have access not to verbal feedback but simply to how others engage with their perceived environment—that is, their gaze, overall movement, body orientation and posture, distance, and so on?

As already mentioned and in line with the vision-centric aspect of many such studies, many experiments have documented an involuntary integration of a co-perceiver's perspective (Azarian et al., 2017; Hietanen et al., 2006; Samson et al., 2010; Tipples, 2002) based on body orientation only. People are, for instance, presented with a series of dots on both the left and right sides of a room and can also see a virtual co-perceiver looking only to the left or the right. When people are asked to say how many objects they see, they are faster when all visible objects are co-perceived, rather than when some visible objects are co-perceived and others only privately perceived objects (Becchio et al., 2008; Nuku & Bekkering, 2008).

Similar effects can be shown with the orientation of visual objects (Ward et al., 2019). People may automatically integrate their co-perceiver's perspective even when the other perspective is irrelevant to successful task completion. When asked to judge the angle at which an object could tilt before falling over, participants misrepresented the angle so that the other's gaze was 'pushing' the object away from the participant (Guterstam et al., 2019).

These effects are not limited to spatial aspects. Electroencephalography (EEG) evidence on facial processing (Böckler & Zwickel, 2013) shows that when a participant perceives a target face in the presence of someone with a different spatial perspective, the participant's perceptual processing yielded higher amplitudes of the N170 and the N250 event-related potential (ERP). These activation patterns correspond to higher demands in structural encoding and face recognition. The higher demands in perceptual processing show that the brain automatically encodes the other perspective and maintains the two different perspectives.

Thinking of such effects in terms of co-perception can provide an umbrella for much of this evidence: when two co-perceivers perceive exactly the same objects, there is a congruence between objects that are privately and commonly seen; when two co-perceivers perceive different number or aspects of objects, for instance, because of a conflict in spatial perspectives, there is an incongruence between common and private objects of perception (see Figure 2).

Saccone et al. (2018) also examined the social influence on the perception of personal space. They demonstrated that the presence of others alters visuomotor processing, such that near-body space is perceived as different when someone else is present. In the presence of others, social space is divided, eliciting object affordances to preserve independent near-body space boundaries. In other words, the perceptual construction of the visuospatial environment changes once it becomes social. Similarly, the action properties of an object might be modified by another person's gaze, as shown by kinematic studies using motor interference (Castiello, 2003). Motor interferences occur when a target object is presented along with distractors, for instance, when an agent needs to grasp a large ball among smaller balls.

These experiments show that the presence of others changes not only how external objects are perceived but also the perceived environmental structure (Deroy & Longin, 2024; Seemann, 2019). The results hold even when objects are inaccessible from a self-centered perspective and can only be accessed from the perspective of another (Becchio et al., 2013). Patients with visual neglect were shown to better detect objects in their neglected field when incorporating another person's perspective. Patients could even report objects in a social setting that are inaccessible from an individual perspective. These findings further suggest that social presence alters the social perceptual space.

An issue with some of these experiments is that they cannot easily tell whether the congruence effect occurs at the level of perceptual processing or at the level of responses, that is, decision or action. One problem is that tasks that show more rapid responses to visual targets congruent with a co-perceiver's gaze or body orientation cannot show a gain in decision accuracy as performance reaches a ceiling (see, e.g., Furlanetto et al., 2016). An important question is whether, besides introducing a possible congruence effect, co-perceiving the same objects with others genuinely impacts perceptual processing. This is what we review in the next section.

3.3 | Are commonly perceived objects always prioritized? A nuanced approach

Besides the evidence of an effect of congruence (or incongruence) between co-perceivers objects of perception, is the perception of common objects facilitated? The question is as impactful as intriguing, given that the literature provides initial findings on prioritizing or enhancing the resulting co-perceived objects.

Commonly perceived objects are shown to lead to an "amplification of experience," meaning that objects knowingly experienced in common are privileged when it comes to social learning, memory, pleasure or pain, as well as other cooperative or affiliative behavior (see Boothby et al., 2014, 2017; Haj-Mohamadi et al., 2018; Nahleen et al., 2019; Sarasso et al., 2022; Shteynberg et al., 2014). Great apes who have watched a video together with a human or a conspecific subsequently approach that individual faster or spend more time in their proximity than when they had viewed

something different (Wolf & Tomasello, 2019; see also Wolf & Tomasello, 2020; and below for more discussions on this effect). The effects, however, are not evidenced across the board, and other studies show that co-perceived objects do not lead to any experiential or downstream preferential treatment (Jolly et al., 2019; Mairon et al., 2020).

Our co-perception approach is compatible with both the positive and negative findings. It posits only that co-perception distinguishes between private and common objects but leaves it open to context to determine which should be enhanced. Once a distinction is made for the perceiver between objects perceived in common and those only perceived privately, either can be enhanced or preferentially processed later—explaining or predicting where a "social amplification" effect occurs. This leads to three situations: common objects are prioritized; private objects are prioritized; neither are prioritized but a distinction is made.

According to this co-perception framing, it makes sense to prioritize co-perceived objects, which can be targets of immediate or future coordination: commonly perceived objects will be prioritized in cooperative or affiliative settings, when the co-perceiver is a possible or actual ally. Similarly, these common objects will be prioritized in cultural contexts, which build cognitive common ground or explain why we seek shared experiences for the intrinsic affiliative value they offer (Fernández Castro & Pacherie, 2021).

By contrast, in other settings, such as deception or competition, our account predicts that the perception of private objects may be prioritized. This does not apply to competitive settings when all objects are commonly perceived. For example, only one food item is present and seen by both individuals) but to those where some remain privately perceived (one food item is seen by both individuals; one is seen only by one.

In neutral settings (e.g., in the presence of a neutral co-observer, with whom no coordination or competition needs to occur) the difference should still be made in perception before competitive or coordinative goals have been set—in what Yavuz et al. call "social perceptual vigilance." Social perceptual vigilance is the minimal manifestation of how the difference between common and private objects is processed.

Yavuz et al. could only observe a neural difference without any behavioral effects in terms of perceptual or metacognitive performance. Other evidence of a perceptual difference occurring in such neutral settings nonetheless exists, though it also calls for interpretation.

For instance, Seow and Fleming's (2019) study examined whether people would perceive common objects differently. They asked: Would perceptual sensitivity change when two perceivers see the same things? To address this question, Seow and Fleming conducted a variant of the spatial gaze-following studies, using this time as a detection task rather than a counting or identification task. A perceiver was shown barely visible, low-contrast Gabor patterns either to the left or the right side of a room, while the orientation and state (blindfolded or not) of another virtual perceiver determined whether they could also co-see the patterns. The participant sensitivity improved: they committed fewer false alarms and misses when the avatar co-perceived the same target presentation area. This effect was only obtained when the avatar demonstratively saw the stimulus (i.e., was facing the stimulus and was not blindfolded), ruling out that purely low-level cueing effects were sufficient to create this facilitation.

Besides being better, could people be faster when they perceive the same targets, with accuracy being equal compared to isolated conditions? This question is examined by Battich et al. (2021), who compared participants' responses to a classic audiovisual illusion (Shams et al., 2000) in isolated and social contexts. In this sound-flash illusion experiment, 1 or 2 flashes were presented and accompanied by 1 or 2 sounds. Participants were instructed to count the number of flashes either when the flashes were only seen privately by them or when someone else was also looking at the same flashes with them. Seeing and hearing a congruent number of flashes and sounds is straightforward and leads to almost no error. However, seeing one flash while hearing two sounds sometimes makes people erroneously see two flashes (a 'fission' illusion), while seeing two flashes while hearing one sound can make people erroneously see one flash ('a fusion illusion'). The error rate depends on how often the participant reported seeing one flash instead of two—or two instead of one. As in the spatial perspective experiments reported above, participants responded faster when the stimuli were co-perceived. However, given the well-documented speed/accuracy trade-off in individual perception, the prediction is that their error rate should also increase when perception is faster (Bertucco et al., 2015; Donkin et al., 2014; Sanders & Rath, 1991). Contrary to this prediction, people were faster but not more erroneous when they co-perceived the targets, by comparison with how they did alone when the stimuli were only perceived as private. Here, the confound of social presence was excluded by a third condition, where one person was seeing the screen but still in the presence of someone else who was not seeing the screen and looking elsewhere.

Such effects need to be consolidated but open an important question: according to the mere "social perceptual vigilance" hypothesis, in neutral settings, when the other perceiver is neither an ally nor a competitor, the difference between common and private objects can be neurally marked without affecting perceptual performance. According to

another hypothesis which we coin the "coordinated readiness" hypothesis, neutral settings show a "default" facilitation of commonly perceived objects. As in Seow and Fleming (2019) or Battich et al. (2021), co-perceived objects are processed not only faster but also more efficiently—with congruence or incongruence in perspective or representation, further modulating the effect in a task-dependent way.

3.4 | Interim summary

The information discussed above contributes to our understanding of co-perception and its connection to a wide range of social influence observed in the realm of perception. Co-perception is defined as a sensitivity between objects, events, or places that are commonly perceived and those perceived privately. It forms the basis for many well-established and recent findings on how social factors influence our perception: individuals are attuned to differences in how they and others perceive space, or they are affected by the perspectives of others when it comes to shared objects.

The studies mentioned earlier employed diverse methods to incorporate social context and control for it. Consequently, it remains challenging to pinpoint the minimal or essential conditions needed for a person to display sensitivity to another person's presence or perspective. A question here is what kind of "awareness" of the social situation is necessary for a perceiver to monitor the difference between private and common objects. The evidence, so far, is not conclusive on the necessary conditions but provides different evidence on what is sufficient:

i. Some studies suggest that being perceptually aware of the other's presence and perceptual engagment is not necessary: simply assuming that an unseen person is also perceiving the same thing is enough to trigger a co-perception context (e.g., Atmaca et al., 2011). Cognitive awareness here would seem sufficient for co-perception.
ii. Other studies, including, for instance, Seow and Fleming (2019), use virtual agents that are designed to signal "perception" and awareness without actually perceiving or being aware. These cues are sufficient to elicit co-perception at a psychological level, though, from a more metaphysical perspective, this is a mere "illusion" of co-perception. Here, a form of perceptual awareness of "perceiver-like" cues, even without the corresponding explicit endorsement of their perceiver status, would seem sufficient for co-perception.
iii. In contrast, other studies indicate the importance of the other person being physically present, visible, genuine and/or somewhat communicative about their interaction with the object (see Sinha et al., 2023; Wolf & Tomasello, 2020). However, it is important to note that even under these circumstances, it becomes evident that co-perception does not necessarily rely on joint attention or other types of mental coordination. While it is true that joint attention or action can take place, they transform co-perception into a special case of joint perception. It is this distinction which we clarify in the following sections.

4 | JOINT PERCEPTION AS A SPECIAL CASE OF CO-PERCEPTION

4.1 | Co-perception does not require coordination

Let us consider a scenario where two individuals are together in a museum, enjoying the artwork on display. In this situation, three different social dynamics can unfold:

i. Both viewers are unable to perceive or access each other's interaction with the museum environment, possibly due to a physical barrier like a wall. Consequently, they also lack awareness or access to the fact that they are both looking at the same paintings. Even though they observe the same paintings on the wall, they do not distinguish between shared and private objects. This does not fall under co-perception, even though they are not alone.

The situation can resemble cases where multiple participants participate in a visual experiment, each in a separate booth. Although they may be engaging with the same stimuli, at least the same kind of stimuli, they may not be aware that others also view the same objects. Some experiments enrich these settings by instructing participants that they are presented with similar kinds of stimuli, though the specific instances are different (e.g., Bahrami et al., 2010; but see also Deschamps et al., 2016). However, they can still coordinate their later judgment on what kind of stimuli they are. Such experiments share some features with co-perception but do not constitute strictly speaking cases of co-perception.

i. Both viewers are aware of the other's perceptual engagement and that they both see the same paintings in common. They both de facto see the same painting and are perceptually sensitive to the fact that it is common. These cases count as co-perception and relate to cases of joint attention broadly construed (more on this below).
ii. The first viewer is aware of the perceptual engagement of the other and that they are both seeing the same paintings, but the second is unaware or has no such access. There is a discrepancy here: only the first viewer can distinguish between common and private perceived objects. The first viewer is in a situation of co-perception, but the other is not. This asymmetry already shows that some cases of co-perception can occur without mutual coordination.

Notably, it shows that co-perception does not require mutual or reciprocal awareness or "openness"—as in cases of joint attention. Instead, joint perception resulting from joint attention is a special and more demanding case of co-perception.

4.2 | Joint perception is narrower than co-perception

Case (ii) described above, when the two viewers see the same paintings and are aware that they see the same paintings cannot but evoke the topic of joint and shared attention, a topic that has been under investigation for over four decades (Bruner, 1974; Lewis, 1969; Scaife & Bruner, 1975; see Mundy et al., 2009; Sebanz & Knoblich, 2009; Tomasello, 1995, for seminal papers).

While there are ongoing debates about the precise definition of joint attention (see Siposova & Carpenter, 2019), it is unquestionably linked to the concept of people perceiving things collectively. For instance, if both you and I focus our attention on a specific painting together, we both perceive it as co-perceived. Additionally, co-perception is also associated with another shared state, namely joint action. When two individuals engage in activities like chasing a deer or carrying a piano together, the success of their joint action hinges on them pursuing the same deer and lifting the same piano. The intricate synchronization of their actions necessitates their sensitivity to what they both co-perceive and, conversely, what is perceived solely by one of them.

When it comes to activities that demand synchronization or alignment on a tangible object in the present moment, both joint attention and joint action necessitate that the object is perceived collectively. However, it is crucial to note that perceiving an object as common does not automatically entail the involvement of joint attention or joint action. To clarify, recognizing objects as common does not call for mental coordination or mutual awareness. This is evident in the example provided earlier (in case (iii)), where only one person is aware that they are viewing the same painting as another visitor.

To provide a more precise distinction, we propose separating the category of objects commonly perceived from the special instance of objects jointly perceived. When the perceived object meets the criteria for joint attention or joint action, it is not only commonly perceived but also jointly perceived (see Figure 2). A different dynamic arises when the two visitors not only view the painting as common (at the first level) but also become attuned to the fact that they are both cognizant of the shared object of perception being genuinely common (at a higher order or mutual awareness, as illustrated in Figure 1, right panel).

This mutual awareness operates within a triadic relationship involving both agents and the object of perception, and it necessitates three types of information (Battich & Geurts, 2020): (i) awareness of one's own attentional or perceptual state, (ii) awareness of the other's attentional or perceptual state, and (iii) awareness of the target of joint attention and perception.

Consider also the classical, though again still debated, condition that joint action requires a commitment to act on a common goal. When two hunters are coordinating to chase a deer, they are committed to running after the same deer and do their best to chase and shoot that animal with their arrows. The commitment requires that each does their best to keep the deer in sight. In this case, it also seems that there is a mutual commitment to extend and maintain the joint perception of the deer. Regardless of the limits or benefits of the mutual knowledge or commitment views of joint attention and joint action, the conditions put on jointness holds for attention and action can also define a notion of jointly perceived objects.

The key point here is that joint attention or joint action delineate a specific and narrower domain within co-perception. First, they give precedence to objects that are commonly perceived (in contrast to co-perception, which may also be neutral or prioritize private objects). Second, they necessitate a level of coordination and mutual awareness.

Returning to the example of the bus, the passengers do not synchronize their attention to the traffic sounds. Their presence and actions on the bus do not arise from a shared plan or coordinated efforts. Despite this, they still perceive the sounds as communal, while also regarding their phone screens as private.

4.3 | Joint perception versus joint attention

We should continue to distinguish between joint perception and joint attention, especially in a narrow sense. When two perceivers are aware of their mutual engagement with the same surroundings and objects, the objects they would categorize as jointly perceived (as opposed to privately perceived) are much more inclusive and encompassing than those they would categorize as jointly attended to. This distinction seems evident if we consider that perception encompasses a broader scope than attention (see, e.g., Cheng, 2017). Concrete examples can also assist us in sidestepping the ongoing debate regarding the relationship between consciousness and attention (see e.g., Wu, 2017, for an overview).

Imagine we are in a museum, and we both recognize that we are both looking at the same painting. In this scenario, we jointly perceive the painting, even if we are not focusing on the same parts simultaneously. It is entirely possible that we might be paying attention to different details and even overlooking certain parts of the painting, yet we still consider the entire painting as jointly perceived. Since attention is a temporary and often changing state, closely tied to moment-to-moment actions like eye movements or selecting points of interest, the jointly attended objects represent just a portion of the objects that are jointly perceived. In reality, we might frequently think we are jointly attending to something spatially when, in fact, we are simply jointly perceiving it. In this situation, the jointly perceived object encompasses more than what both participants are attending to (see Figure 3 for a visual representation).

Moreover, the object of joint perception can function independently of joint attention. In certain multisensory situations, documented as instances of "division of attentional labor," two participants jointly perceive the same audio-visual movie. However, they are instructed to focus on different stimuli: one on the visual stimuli and the other on the sounds. The participants respond only to the stimuli in their designated sensory mode (Sellaro et al., 2020; Wahn et al., 2018). In this scenario, the attentional focus of the two perceivers may differ, and they may not be jointly attending. Nonetheless, they are still jointly perceiving the entire audio-visual clip.

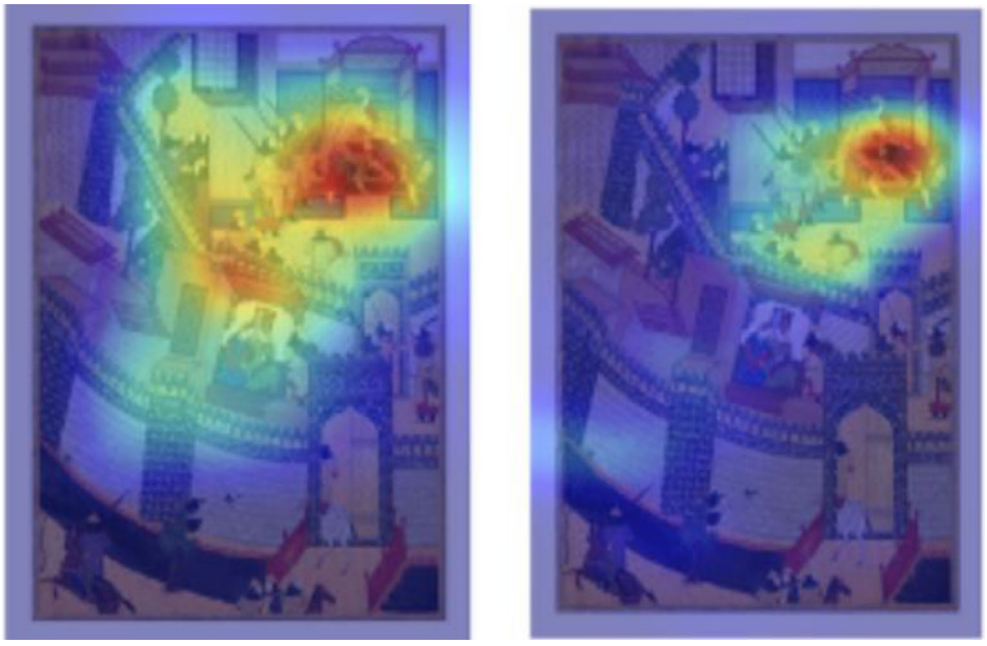

FIGURE 3 Eye-tracking heat maps. Eye-tracking heat maps for two different individuals (left and right) acquired during an episode of coordinated joint attention. The two individuals actually did not attend to exactly the same part of the painting. Their discussion shows that they both take the whole painting to be perceived in common (Image courtesy of @BahadorBahrami).

5 | THE CENTRALITY OF THE PRIVATE VERSUS COMMON DISTINCTION IN PERCEPTION

5.1 | Philosophical implications: collective subjects versus common contents

Co-perception in a broad sense, when excluding joint perception, does not necessitate the coordination of mental states as observed in joint attention and action. Some concepts proposed in the literature regarding joint phenomena can be applied to elucidate co-perception. Specifically, co-perception can be understood as a distinction between an individual and a collective experience or a singular versus plural "mode" of experiencing (e.g., Gallotti & Frith, 2013; Rescorla, 2018; Tuomela, 2006).

For example, in the bus scenario, it can be framed as:

I see my screen; we hear the traffic noise.
Or
I see my screen (in an "I-mode"); I hear the traffic noise (in a "we-mode").

However, there are common challenges with theories that emphasize either the agent or mode: What kind of ontological or psychological entity constitutes a collective agent? What psychological processes and mechanisms correspond to these "modes," especially in singular or plural forms? Some difficulties, though, are more specific to co-perception: the posited individual and collective agents or modes must coexist simultaneously during the same experience. At any given moment, I perceive my screen as private and the traffic sound as shared. Does this imply that I am a single subject for the visual scene and a collective subject for the auditory scene simultaneously? Can I perceive one thing in an "I-mode" and another in a "we-mode" at the same time?

If one were to accept the possibility of two subjects or modes across two senses, consider another example: within my visual field, the small painting on the left might be perceived as private, while the large painting on the right is seen as shared. In this case, the observer who perceives both paintings would need to be viewed as divided into two agents or modes. This perspective appears to introduce a fragmentation in the perceptual experience of the observer, which raises some challenges.

Furthermore, there is a complication when adopting the notion of a "subjective upgrade" from individual to collective to explain co-perception. Collective agents or modes typically pertain to cooperative or affiliative situations: scenarios where the individual subject either belongs to or desires to be part of a collective entity (see Fernández Castro & Pacherie, 2021). While co-perception may occasionally foster a sense of bonding (see Wolf & Tomasello, 2019) and can be motivating, it doesn't necessarily have to. Some instances of co-perception occur outside of cooperative or affiliative contexts, such as for epistemic reasons. For instance, if two sports coaches watch their soccer teams play and have been long-time rivals, they both collectively perceive the ball being passed, yet neither of them desires to be part of a "we" with the opposing team.

An alternative perspective on co-perception suggests that it relies on our ability to categorize certain perceived objects or spatial areas as shared while designating others as personal or private. This leads to the emergence of what we can term a "perceptual common," which can be treated differently from objects perceived as private. This capacity does not demand a conceptual understanding of commonality or privacy, nor does it necessitate the higher-order awareness typically associated with establishing common ground (as discussed by Stalnaker, 2002). However, it may require a capacity for distinguishing between oneself and others, which raises the question of who possesses this capability.

5.2 | Who can co-perceive, when and with whom? Infants, nonhuman animals, and virtual worlds

Young infants or nonhuman animals lacking a strong self-other distinction do not meet the minimal conditions for being sensitive to another perceptual engagement (Steinbeis, 2016). The co-perception framework that we have outlined here stresses that in order to perceive something to be common, one also needs the capacity to perceive

something to be private. What makes the private/common distinction part of represented content is that the perceiver can eventually *misperceive* something as common while it is actually private (or vice-versa). It follows from here that organisms lacking a capacity for co-perception lack the capacity to perceive that what they have seen is private. Failing the classic Sally and Ann false belief task is a prime example of when some event is perceived by the infant alone and not treated differently than when the infant is in the room with another confederate (see Helming et al., 2016, for discussion).

However, it is incorrect to assume that these organisms inherently possess the capacity or inclination to perceive the world through a default "common" assumption, as it is sometimes asserted. It is more accurate to say that they perceive the world in an undifferentiated mode where there is no distinction between self and other perceptual access. They lack the ability to differentiate between what they perceive and what others perceive.

Animals, particularly chimpanzees, have evolved some form of perceptual sensitivity to what others see. Chimpanzees organize their cooperative hunting behavior by assigning specific roles to each individual—ranging from chasers to ambushers and blockers. Each role must be performed successfully in coordination with the others for the hunt to succeed, making a perceptual common essential for the emergence of cooperative hunting behavior (Boesch, 1994, 2002). Similarly, studies like Hopkins and Taglialatela (2013) and Shepherd and Cappuccio (2011) found that chimpanzees, similar to humans, are sensitive to the gaze direction of others (for evidence on dogs, see Catala et al., 2017). An intriguing study on ravens shows that directional cues are not necessary, as these birds are also shown to be sensitive to their food being seen in common between them and conspecifics they only hear (Bugnyar et al., 2016). Further discussion is needed to see whether co-perception differs in some respects between different animals.

In addition to developmental and comparative cases, co-perception sheds light on our interactions with artificial agents or avatars. It is important to note that, similar to joint attention, joint perception necessitates that each perceiver attributes complex mental states to the other. Therefore, genuine joint perception cannot occur when the other agent lacks mental states and social awareness. While we may "believe" or pretend to jointly perceive with a mere avatar, we are not truly doing so. Avatars, much like mere pairs of eyes, cannot engage in mutual knowledge. The case is no less stringent in the case of co-perception when minimal social cues, such as an avatar on the screen orienting their body toward different targets (as discussed in Seow & Fleming, 2019), are enough to trigger an automatic representation that the object is commonly perceived. Even such situations still do not constitute authentic cases of co-perception because no genuine perceiver is involved. Nevertheless, they could still activate its mechanisms and differentiate between common and private. It is anticipated that co-perception in these cases will not be as effective in eliciting further effects, such as feelings of affiliation or enhanced experiences, as is typically observed when we jointly perceive things with real individuals.

Can co-perception occur with artificial agents equipped with perceptual-like capabilities that allow them to sense and represent their environment? This perspective allows us to reframe research involving interactive robotic agents (as explored, e.g., by Wykowska et al., 2015) not only as an investigation into the mechanisms of social influence in human participants but also as an exploration of co-perception within a hybrid human-AI context (for a comprehensive overview, see Chevalier et al., 2020, and for other instances of perceptual connections between humans and AI systems, see Longin & Deroy, 2022).

In virtual environments like the meta-verse (as discussed by Mystakidis, 2022), individuals, through their avatars, can be aware of what others are perceptually engaged with. However, this operates under various assumptions, such as the assumption that the avatar is linked to a "perceiving" agent.

What poses a more intricate and intriguing challenge is how virtual objects blur the distinction between "kind" and "instance." For example, if two visitors are logged on to explore the same virtual art gallery in the meta-verse, they are not technically viewing the same "instance" of virtual objects, as each perceives the object through their own virtual reality glasses. Nevertheless, what they can co-perceive is still the same category or type of object. This connection appears adequate in generating a semblance of co-perception and some of its subsequent effects (as exemplified in Tarr et al., 2018). A noteworthy consideration in virtual reality and meta-verse settings is that such environments are explicitly hosted somewhere (e.g., a server, a computer processor, etc.) digitally. This explicit digital representation encompasses what each agent (human or avatar) perceives. Consequently, one might argue that a strictly private perceptual experience in VR is never entirely attainable.

In all these cases, the study of co-perception emerges as a crucial component in the advancement of virtual environments in the future.

6 | CONCLUSIONS: BRINGING TOGETHER SENSORY AND SOCIAL PERCEPTION

Co-perception, the ability to discern whether objects are perceived commonly or privately, underpins many of our social interactions without necessitating explicit coordination. It is important to acknowledge the significance of co-perception for both humans and nonhuman animals. The representation of "perceptual commons" enables real-time interactions, strategic behaviors, and some offline ones. It accounts for actions like competitive or collective hunting, concealment, and everyday social exchanges with unfamiliar individuals. This highlights that the collective context in which perception inherently unfolds introduces a fundamentally "social" aspect to our perception. Once we gain access to the perceptual engagements of other perceivers with the same objects or areas of space, our perception allows us to distinguish between what is common and private in our perception, enabling downstream systems to prioritize one type of object over the other.

The concept of co-perception offers a framework that we hope will stimulate further discussions and experiments, with implications for philosophical theories of social cognition, common ground, and comparative cases. Many theoretical and experimental questions still await investigation, including understanding when and how co-perception manifests in the brain, elucidating computational disparities between isolated and co-perception of the same objects, and identifying the circumstances under which the common/private distinction can be inaccurate or modulated by social affiliation or affective contexts (e.g., Beaurenaut et al., 2021; Shafaei et al., 2020). Besides the bonding effects of collective experiences, our account highlights the cognitive role of co-perception in ensuring that the information is not only shared but also perceived as public. The practical ramifications are numerous and recommend harnessing not only social influences (e.g., Boon-Falleur, 2022) but also social perception in collective problems. It is useful for instance to ensure that individuals not only receive information about topics like climate change or socially beneficial behaviors through private channels but also instantly perceive this information as public and shared with co-perceivers.

At this juncture, it is crucial to underscore how this concept bridges the realms of sensory and social perception. Typically, "social perception" is reserved for discerning other entities as "minded" or "social agents" (see Schultz & Frith, 2022; and Geiselmann et al., 2023, for an in-depth discussion). When certain stimuli exhibit specific movements, face-like shapes, eyes, human-like forms, or voices, we perceive and categorize them as "agents" and interact with them differently. In a co-perception context, we engage with these agentive stimuli, but this time, we also represent what they are perceptually engaged in within our environment. In such instances, our perceived environment takes on a "socialized" aspect, as we differentially perceive objects or spaces as commonly or privately perceived.

Before we interact and coordinate with other minds, we share parts of what we perceive with others in a way that is fundamental to our social and individual lives.

AUTHOR CONTRIBUTIONS

Ophelia Deroy: Conceptualization (equal); supervision (lead); writing – original draft (equal); writing – review and editing (equal). **Louis Longin:** Conceptualization (equal); writing – original draft (equal); writing – review and editing (equal). **Bahador Bahrami:** Resources (supporting); visualization (lead); writing – review and editing (equal).

ACKNOWLEDGMENT

Open Access funding enabled and organized by Projekt DEAL.

FUNDING INFORMATION

Ophelia Deroy was funded by the Volkswagen Foundation (Co-Sense), EMERGE EIC project (Project 101070918), and the BIDT (Co-Learn grant). Bahador Bahrami is supported by the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation program (819040—acronym: rid-O). Bahador Bahrami is also supported by the EMERGE EIC (Project 101070918) and Templeton Religion Trust.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

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How to cite this article: Deroy, O., Longin, L., & Bahrami, B. (2024). Co-perceiving: Bringing the social into perception. *WIREs Cognitive Science*, e1681. https://doi.org/10.1002/wcs.1681