Cognition 247 (2024) 105745

Contents lists available at ScienceDirect

Cognition

journal homepage: www.elsevier.com/locate/cognit

Perceived gaze dynamics in social interactions can alter (and even reverse) the perceived temporal order of events

Clara Colombatto[a,b,**], Yi-Chia Chen (陳鴨嘉)[c], Brian J. Scholl[b,*]

[a] Department of Psychology, University of Waterloo, Canada
[b] Department of Psychology, Yale University, United States of America
[c] Department of Psychology, University of California, Los Angeles, United States of America

ARTICLE INFO

Keywords:
Attention
Temporal order
Social perception
Gaze
Gaze deflection

ABSTRACT

Here's an all-too-familiar scenario: Person A is staring at person B, and then B turns toward A, and A immediately looks away (a phenomenon we call 'gaze deflection'). Beyond perceiving lower-level properties here — such as the timing of the eye/head turns — you can also readily perceive seemingly higher-level social dynamics: A got caught staring, and frantically looked away in embarrassment! It seems natural to assume that such social impressions are based on more fundamental representations of what happened when — but here we show that social gaze dynamics are unexpectedly powerful in that they can actually alter (and even reverse) the perceived temporal order of the underlying events. Across eight experiments, observers misperceived B as turning before A, when in fact they turned simultaneously — and even when B was turning after A. Additional controls confirmed that this illusion depends on visual processing (vs. being driven solely by higher-level interpretations), and that it is specific to the perception of social agents (vs. non-social objects). This demonstrates how social perception is tightly integrated into our perceptual experience of the world, and can have powerful consequences for one of the most basic properties that we can perceive: what happens when.

1. Introduction

What we pay attention to in our environments is determined not only by our goals and by intrinsic stimulus properties (such as visual salience), but also by a type of peer pressure. That is, the objects of our attention are often in part a function of what *other* people are attending to. Perhaps the best example of this is the common phenomenon of gaze following: when we observe another person turn to look in a specific direction, we often turn in that same direction (e.g. Milgram, Bickman, & Berkowitz, 1969). And even when we don't respond so overtly, seeing someone gaze in a particular direction will lead to enhanced detection of targets appearing in the gazed-at direction (e.g. Driver et al., 1999; Friesen & Kingstone, 1998) — an attentional benefit that occurs even when such cues are antipredictive, and we know that the gazed-at location is *less* likely to contain a target (e.g. Bayliss & Tipper, 2006). (For reviews, see Emery, 2000; Frischen, Bayliss, & Tipper, 2007.)

Recent work has demonstrated that such effects are surprisingly sophisticated, insofar as they are driven not by the brute presence of others' eye and head movements, but rather by the perception of another person's changing direction of attention (and perhaps intentions). In particular, this sophistication can be revealed in cases wherein someone turns their eyes and/or head in a specific direction *without* intending to look at something in that new direction. This sort of "eyes without minds" phenomenon may sound unusual (or even nonsensical), but it actually occurs in at least one familiar (if almost never studied) situation. Suppose you see one person ('A') staring intently at another person ('B'), and then when B turns toward A, A immediately looks away. In this scenario, one can readily perceive the lower-level properties of the eye and head movements, such as the direction of the various turns, and the order in which they unfold. But one can also readily apprehend the underlying social dynamics of such events: A got caught staring, and then averted their gaze to avoid embarrassment! As a result, A turned not to look *at* something, but rather to look *away* from someone. Recent work has shown that visual processing is sensitive to such social impressions — which have been called 'gaze deflection' — such that these types of eye/head turns elicit weaker gaze cueing than do normal gaze shifts, even while controlling for the lower-level spatiotemporal properties of the animations

* Correspondence to: B. J. Scholl, Department of Psychology, Yale University, Box 208047, New Haven, CT 06520-8047.
** Correspondence to: C. Colombatto, Department of Psychology, University of Waterloo, 200 University Avenue West, Waterloo, ON N2L 3G1, Canada.
E-mail addresses: clara.colombatto@uwaterloo.ca (C. Colombatto), brian.scholl@yale.edu (B.J. Scholl).

https://doi.org/10.1016/j.cognition.2024.105745
Received 15 February 2022; Received in revised form 9 February 2024; Accepted 12 February 2024
Available online 2 April 2024
0010-0277/

(Colombatto, Chen, & Scholl, 2020).

1.1. The current study: What happened when?

It seems natural (or even logically required) for such sophisticated social percepts to be constructed from more primary perceptual properties. First we see the brute facts of "what happens when" (A looks at B; then B looks at A; then A turns away), and then impressions of gaze deflection are essentially the (later, higher-level) perceptual *explanation* for why those specific events unfolded in that specific order. Here, in contrast, we explore the possibility that these social dynamics are extracted early enough in visual processing for such influences to also apply in the other direction — with perceived gaze deflection actually altering our percepts of what happened when. This may sound impossible or even paradoxical, but in fact a related phenomenon has been observed in the context of physical events: in 'causal reordering', impressions of physical causality (e.g. when one block impacts another, 'launching' it and causing it to move) can actually change the perceived temporal order of the block motions themselves (Bechlivanidis & Lagnado, 2013, 2016; Bechlivanidis et al., 2022; Tecwyn et al., 2020; for a general review of surprising interactions between time and physical causality, see Desantis & Buehner, 2019).

The possibility of causal reordering may seem understandable, insofar as launching impressions are well understood to be extracted during visual processing itself. This has been suggested ever since the initial introduction of this phenomenon (Michotte, 1963), and in recent years the lower-level nature of such impressions has been demonstrated in a particularly direct way by showing that such displays give rise to retinotopically-specific visual adaptation for causal impressions (Kominsky & Scholl, 2020; Rolfs, Dambacher, & Cavanagh, 2013). But no such effects are known to occur for a social phenomenon such as gaze deflection — and so it might seem even more striking to discover that sophisticated social dynamics can also cause us to misperceive "what happens when" in simple events.

We explored this in a series of eight experiments. In Experiments 1a, 1b, 2a, and 2b, we demonstrated that gaze deflection can indeed yield impressions of particular event orders in displays with movements that are actually simultaneous (e.g. when persons A and B turn at the same time). In Experiment 3, we showed that such effects depend on visual processing itself (and are not merely driven by higher-order judgments about what was most likely to have happened when). In Experiment 4, we demonstrated that this illusion is specific to social perception, and does not occur when the identical movements are performed by non-social objects. And in Experiments 5a and 5b we showed that gaze deflection can even *reverse* the perceived temporal order of events (causing us to see B turn before A, even when B was turning after A).

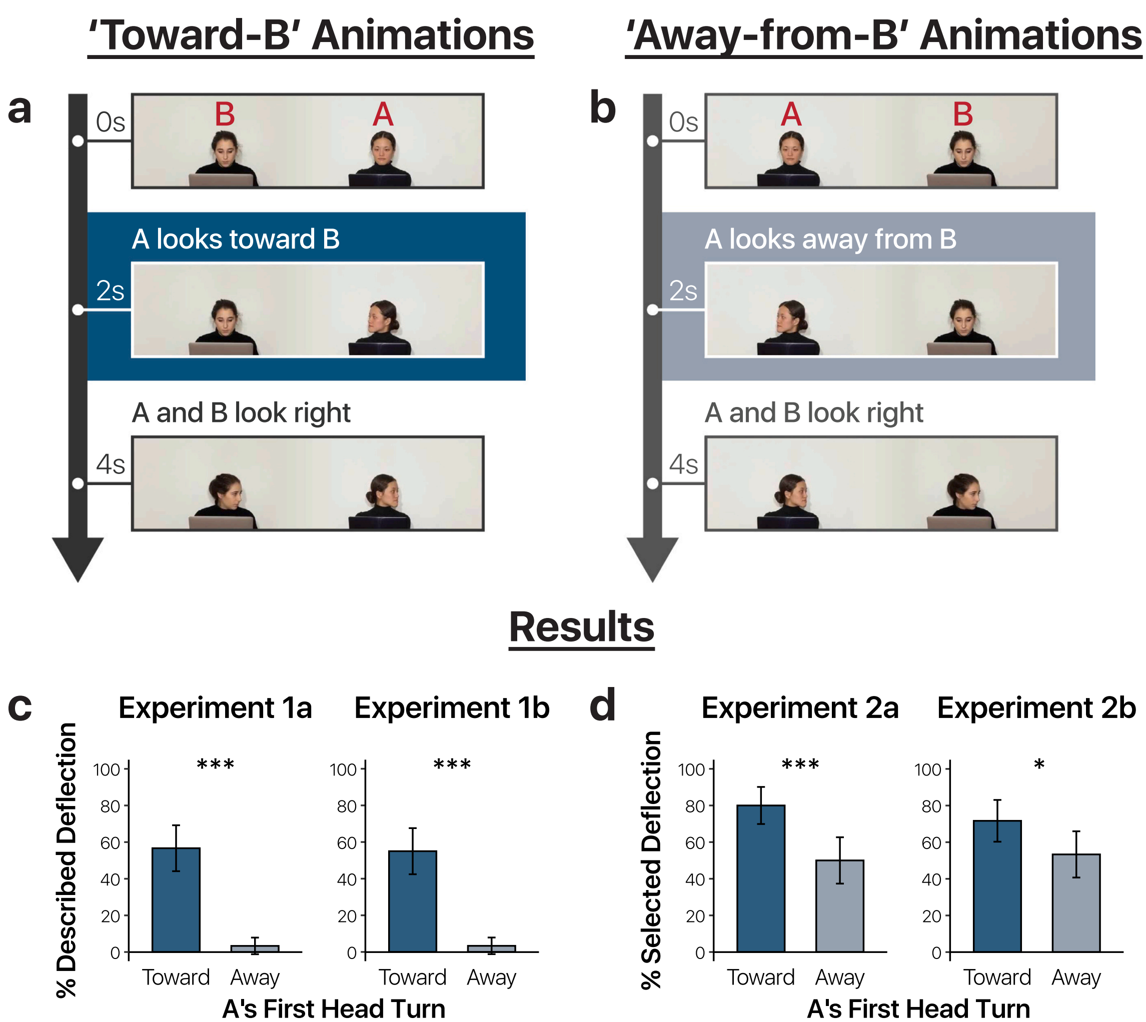

Fig. 1. Misperceptions of temporal order in synchronous animations. (a and b) Schematic depictions of the animations used in Experiments 1a, 1b, 2a, 2b, and 3 — including the Toward-B animations (a) and Away-from-B animations (b). (c) Percentage of observers who described B as turning earlier than A for Toward-B vs. Away-from-B animations in Experiment 1a (left panel) and 1b (right panel). (d) Percentage of observers who selected the option where B was turning earlier than A for Toward-B vs. Away-from-B animations in Experiment 2a (left panel) and 2b (right panel). Error bars indicate 95% confidence intervals (CIs).

2. Experiment 1a: Perceptual reports

We first asked whether the perception of gaze deflection would cause people to see a particular sequential order of events even when there was none — i.e. when the two events actually occurred simultaneously. Observers viewed animations depicting two actresses ('A' and 'B') in which (1) A turned to look toward B, and then (2) A and B simultaneously turned to look in the opposite direction (as depicted in Fig. 1a and in the first online animation). And to ensure that the result could not simply reflect lower-level (and perhaps non-social) stimulus properties, we also tested a control condition (depicted in Fig. 1b and in the second online animation) in which the two actresses made the same gaze shifts, but their positions were swapped to eliminate impressions of gaze deflection: (1) A turned to look away from B, and then (2) A and B simultaneously turned to look in the opposite direction. In this initial exploration, we simply showed each observer a single animation, and asked them to describe what they had seen in 2–3 sentences. As such, these free responses provide participants' impressions with no prior prompts or demands regarding temporal order. Animations from this experiment and all subsequent ones are available online at https://perception.yale.edu/gaze-temporal-order/.

2.1. Method

2.1.1. Observers

A total of 120 observers (67 females; $M_{age} = 28.25$) were recruited through Prolific Academic (prolific.com), and each completed a single trial in a 3-min session in exchange for monetary compensation. (All observers were from the U.S., and had normal or corrected-to-normal visual acuity.) This preregistered sample size was chosen before data collection began based on pilot data, and was fixed to be identical across all experiments reported here (except for Experiment 3). All experimental methods and procedures were approved by the Yale University Institutional Review Board, and all observers provided informed consent. The preregistered methods and analyses for this and all subsequent experiments can be viewed at https://osf.io/b7jdp/, and the raw data for this and all subsequent experiments can be viewed in the Supplemental Material available online.

2.1.2. Apparatus

Observers were redirected to a website where stimulus presentation and data collection were controlled by custom software written in HTML, JavaScript, CSS, and PHP. (Since the experiment was rendered on observers' own web browsers, viewing distance, screen size, and display resolutions could vary dramatically, and so we report stimulus dimensions using pixel [px] values.)

2.1.3. Stimuli and design

Observers viewed a silent animation (1000 × 266px) centered in their browser window and surrounded by a gray (HEX code #5F5D5B) 6px frame on a dark gray (#404040) background. As depicted in the sample screenshots in Fig. 1a and b, two people were sitting in front of laptops and were viewed from the front, on a background wall (approximately #DFDFD7). The people initially looked straight ahead, with the timings of the movements described below reported with respect to the beginning of the animation.

In the 'Toward-B' animation (Fig. 1a), the right person ('A') turned her head (at 2.0 s) to the left, such that at the end of her head turn (at 2.8 s) she seemed to stare at the left person ('B'). At 4.0 s, both people turned their heads in the other direction, such that at the end of their head turns (at 4.5 s) they were both looking to the right. The final tableau was then visible for an additional 1.5 s (i.e. until 6.0 s), at which point it disappeared. In the 'Away-from-B' animation (Fig. 1b), the left person (A) turned her head (at 2.0 s) toward the left, such that at the end of her head turn (at 2.8 s) she was looking away from the right person (B). At 4.0 s, both people turned their heads in the other direction, such that at the end of their head turns (at 4.5 s) they were both looking to the right. The final tableau was then visible for an additional 1.5 s (i.e. until 6.0 s), at which point it disappeared.

There were thus 2 animations corresponding to 2 directions of A's first head turn (Toward-B/Away-from-B). In addition, for half of the observers (counterbalanced across conditions), the videos were horizontally flipped, resulting in 2 possible head turn directions (Left/Right), for a total of 4 animations — each viewed by 30 unique observers.

2.1.4. Procedure

Each observer was instructed to watch a single animation as closely as possible, as it would be short and it would be displayed only once. Upon a keypress, they viewed the animation, and immediately after it ended (and disappeared), they were instructed: "In about 2-3 sentences, please describe the animation you just watched." In particular, they were asked to "[t]ry to make your description detailed enough so that someone else who has never watched the animation would be able to reproduce it just by reading your description", and they were required to write for at least 30s. Observers then answered a series of questions that allowed us to exclude those (per the preregistered criteria) who guessed the purpose of the experiment (e.g. mentioning order of events; $n = 1$); who reported having interrupted the survey ($n = 4$); who reported past participation in a similar study ($n = 2$); whose viewport size was smaller than the dimensions of the animation ($n = 3$); who encountered problems (e.g. writing that "I had some wifi connectivity issues and could not watch some of the video", $n = 5$); who reported not paying attention (by answering less than 50 on a 1–100 scale, from "I was very distracted" to "I was very focused"; $n = 3$), or who failed to answer our questions sensibly (e.g. responding "Puppies" to a question asking what they thought the experiment was testing, $n = 7$). In addition, we excluded observers whose descriptions omitted information about (or were ambiguous with respect to) the order of events (e.g., writing that "Two women with their hair pulled back turn their heads while looking at laptops. They both wear long sleeved black shirts.", $n = 18$). These observers ($n = 37$, some of whom triggered multiple criteria) were excluded and replaced without ever analyzing their data.

2.2. Results and discussion

The first author coded observers' descriptions based on whether they mentioned B turning earlier than A in the critical (i.e. second) head turn. (A representative example of a description that was coded in this way: "[T]he girl being looked at raised her head and looked at the girl on the right, who proceeded to look to the other side". A representative example of a description that was *not* coded in this way: "[B]oth women glanced to their right simultaneously".) The proportions of descriptions mentioning this particular event order are depicted separately for Toward-B and Away-from-B animations in the left panel of Fig. 1c. The results were clear: observers who watched Toward-B animations were almost 20 times more likely to report B turning earlier than A, compared to observers who watched Away-from-B animations (56.7% vs. 3.3%; $z = 6.37, p < .001, h = 1.34$) — a tendency to see an order of events that is consistent with gaze deflection. When these descriptions were also coded by a naïve rater (who had not previously seen the animations, and who was blind to the experimental hypotheses and conditions), interrater agreement was high (Cohen's kappa = 0.89), and the difference between Toward-B and Away-from-B animations was even greater (63.3% vs. 6.7%).

3. Experiment 1b: Direct replication

Given the importance of direct replications, we reran the experiment on another group of 120 observers (65 females; $M_{age} = 30.98$), again excluding observers (per the preregistered criteria) who guessed the purpose of the experiment ($n = 1$); who reported having interrupted the survey ($n = 2$); whose viewport size was smaller than the dimensions of the animation ($n = 4$); who encountered problems ($n = 5$); who failed to answer our questions sensibly ($n = 1$); or whose descriptions omitted information about (or were ambiguous with respect to) the order of events ($n = 19$). These excluded observers ($n = 28$, some of whom triggered multiple criteria) were replaced without ever analyzing their data.

As depicted in the right panel of Fig. 1c, observers who watched Toward-B animations were again almost 20 times more likely to report B turning earlier than A, compared to observers who watched Away-from-B animations (55.0% vs. 3.3%; $z = 6.23$, $p < .001$, $h = 1.30$), replicating Experiment 1a. Again, agreement with a second naïve rater was high (Cohen's kappa = 0.88; 53.3% vs. 5.0%).

4. Experiment 2a: Forced selections

The results of Experiments 1a and 1b suggest that social impressions can alter perceived temporal order, but the data depended on what observers chose to highlight in their free responses. So we also assessed their experiences using a more direct forced-choice question: after viewing the same experimental or control animations, observers overtly selected which of two descriptions (differing in the order of head turns) best matched the animation they had just seen.

4.1. Method

This experiment was identical to Experiments 1a and 1b, except as noted here. Instead of soliciting open-ended descriptions of the animations, we told observers that "[p]articipants in this experiment watched one of two videos. We will now describe these two versions, and ask you to identify which one you watched. The two videos differed in the order of the head turns made by the characters". They then saw a still frame from the animation, with A and B labeled, along with two descriptions (displayed in a randomized order): (1) "First, A turned her head to the side. Second, A turned to the other side. Lastly, B turned"; (2) "First, A turned her head to the side. Second, B turned. Lastly, A turned to the other side". They were then asked to select which video they watched, along with a third "I don't know/I am not sure" option, without time constraint. There were again 2 animations corresponding to 2 directions of A's first head turn (Toward-B/Away-from-B), as well as 2 possible head turning directions (Left/Right), and 2 possible orders of response options in the forced choice question, for a total of 8 conditions — each completed by 15 unique observers.

We recruited a new set of 120 observers (69 females; $M_{age} = 29.85$; with this preregistered sample size chosen to match that of Experiments 1a and 1b), again excluding observers (per the preregistered criteria) who reported having interrupted the survey ($n = 4$); whose viewport size was smaller than the dimensions of the animation ($n = 2$); who encountered problems ($n = 9$); or who reported not paying attention ($n = 3$). These excluded observers ($n = 14$, some of whom triggered multiple criteria) were replaced without ever analyzing their data.

4.2. Results

As depicted in the left panel of Fig. 1d, observers who watched Toward-B animations were considerably more likely to select the option where B turned earlier than A, compared to observers who watched Away-from-B animations (80.0% vs. 50.0%; $z = 3.45$, $p = .001$, $h = 0.64$), again showing an illusory temporal order consistent with gaze deflection. (And of the observers who didn't select the option where B turned earlier than A, most selected the option where A turned earlier than B [16.7% vs. 46.7%], while few selected "I am not sure" [3.3% vs. 3.3%].)

5. Experiment 2b: Direct replication

Given the importance of direct replications, we reran the experiment on another group of 120 observers (57 females; $M_{age} = 30.39$), again excluding observers (per the preregistered criteria) who reported having interrupted the survey ($n = 1$); whose viewport size was smaller than the dimensions of the animation ($n = 10$); who encountered problems ($n = 4$); who failed to answer our questions sensibly ($n = 1$); or who reported not paying attention ($n = 2$). These excluded observers ($n = 17$, some of whom triggered multiple criteria) were replaced without ever analyzing their data.

As depicted in the right panel of Fig. 1d, observers who watched Toward-B animations were more likely to select the option where B turned earlier than A, compared to observers who watched Away-from-B animations (71.7% vs. 53.3%; $z = 2.07$, $p = .038$, $h = 0.38$) — thus replicating Experiment 2a. (And of the observers who didn't select the option where B turned earlier than A, most selected the option where A turned earlier than B [23.3% vs. 41.7%], while few selected "I am not sure" [5.0% vs. 5.0%].)

6. Experiment 3: Perception vs. judgment

The previous four experiments collectively suggest that observers misapprehend the order of events in such animations to be consistent with the socially meaningful schema of gaze deflection. But might participants merely be reporting what they *think* is most likely to have happened, rather than what they actually *perceived* as having happened? This possibility seemed unlikely to us, as the animations employed in the previous experiments elicit a distinct phenomenology of temporal order in naïve observers: when viewing Toward-B animations, it really does *look* like person B (the 'catcher') turns their head before person A (who gets 'caught looking'), even when those turns are in fact synchronous — something that we hope readers will be able to appreciate for themselves in the online demonstrations. Nonetheless, we also sought to demonstrate the necessity of visual processing more directly in a new experiment. In particular, we reasoned that if the bias stemmed from observers thinking about the likelihood of the events (rather than from perceiving the animations), it could arise even in the absence of visual input (as per the 'blindfold test', van Buren & Scholl, 2018, van Buren and Scholl, 2024).

We thus ran a new "meta" experiment in which new participants were told about other previous observers having completed an experiment in which they encountered the sorts of animations used in our previous experiments, and we then asked the new participants to predict which option most previous observers would have reported having seen (in a forced-choice question like that used in Experiments 2a and 2b). In one condition, we again included the same animations from Experiments 1a, 1b, 2a, and 2b. But in another new critical condition, we simply replaced the animations with *descriptions* of the underlying events. If the tendency to see an order of events that is consistent with gaze deflection stems from higher-level inferences about the likelihood of these events unfolding with or without the involvement of visual processes, then we should see the illusory temporal order emerge for both the new participants who saw the animations and those who merely read the descriptions. But if these illusory temporal order impressions actually depend on visual experiences, then the same tendency should appear in this new "meta" experiment with the animations, but not with the descriptions.

6.1. Method

This experiment was identical to Experiments 2a and 2b, except as noted here. All participants were told that "[w]e recently ran a study where other Prolific participants watched a video and answered a question about it. Your job is to guess which answer the other group of participants selected in response to the question". Half of the participants were shown the animations (just as in Experiments 2a and 2b), being told: “First, we will show you the video that the other participants watched. Second, we will tell you about the question they were asked, and then you will guess what their responses were.” The other half simply read descriptions of the events: “First, we will describe the video that the other participants watched. Note that the other participants watched the videos, rather than reading the descriptions you will see. Second, we will tell you about the question they were asked, and then you will guess what their responses were.” These participants then read the following description of the animations (for at least 20s): “The video depicted two people (A and B) sitting next to each other. (1) At the beginning, both A and B were facing forward. (2) Next, A turned her head to the side, facing [towards/away from] B. (3) Then, A and B both turned their heads to the other side at the same time”. All participants were then told that: “After watching the video, the other participants were given two descriptions, and they were asked to identify which one corresponded to the video they watched; they also had a third option to select if they did not know or weren’t sure.” They were then shown the same options as in Experiments 2a and 2b, and were asked to choose the option they thought most observers would have reported having watched.

There were thus 2 types of stimuli (Animations/Descriptions), and 2 types of sequences corresponding to 2 directions of A’s first head turn (Toward-B/Away-from-B), as well as 2 possible orders of response options in the forced choice question, for a total of 8 conditions — each completed by 125 unique participants. We recruited a new set of 1000 participants (533 females; $M_{age} = 35.04$; with the total preregistered sample size estimated for an interaction effect), again excluding participants (per the preregistered criteria) who reported having interrupted the survey ($n = 19$); whose viewport size was smaller than the dimensions of the animation ($n = 18$); who reported past participation in a similar study ($n = 4$); who encountered problems (e.g., “I sneezed while watching”; $n = 21$); who failed to answer our questions sensibly ($n = 33$); or who reported not paying attention ($n = 13$). These excluded participants ($n = 102$, some of whom triggered multiple criteria) were replaced without ever analyzing their data.

6.2. *Results and discussion*

Participants’ choices in this forced selection task are depicted in

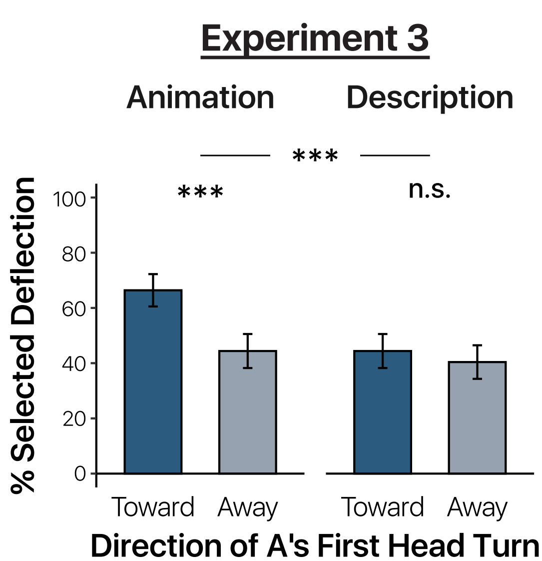

Fig. 2. An illusion driven by perceptual processing. Percentage of participants who selected the option where B was turning earlier than A for the Toward-B vs. Away-from-B conditions in Experiment 3, graphed separately for observers who watched animations vs. participants who read descriptions. Error bars indicate 95% CIs.

Fig. 2, separately for observers who watched Animations vs. participants who read Descriptions of the animations. Inspection of this figure suggests two clear patterns of results: (a) The results with observers who watched the animations replicated the effect from Experiments 2a and 2b; but (b) this bias vanished for participants who simply read the descriptions. These impressions were confirmed by the following analyses. There was a significant difference between Toward-B and Away-from-B conditions for observers who watched the animations (66.4% vs. 44.4%; $z = 4.95$, $p < .001$, $h = 0.45$), but there was no such difference for participants who only read the descriptions (44.4% vs. 40.4%; $z = 0.90$, $p = .365$, $h = 0.08$). And the difference between these differences (i.e., the interaction effect) was also highly reliable ($z = 2.87$, $p = .004$). (And of the participants who didn’t select the option where B turned earlier than A, most selected the option where A turned earlier than B [Animations: 30.8% vs. 48.0%; Descriptions: 45.2% vs. 48.0%], while few selected “I am not sure” [Animations: 2.8% vs. 7.6%; Descriptions: 10.4% vs. 11.6%].)

This suggests that the reported temporal order in these experiments is in fact dependent on visual processing, and that higher-level reasoning itself is not sufficient to give rise to the illusion. Of course, we can’t rule out the possibility that visual processing and higher-level reasoning are both necessary for experiencing the illusory temporal order. For example, the visual inputs may lead to necessary representations for higher-level inferences to operate on, which then produce a temporal order *judgment* consistent with gaze deflection. This type of explanation, however, cannot explain the illusory *perception* of the temporal order (which we hope that readers may experience first-hand by viewing the online animations).

7. Experiment 4: People vs. objects

The current experiments aim to demonstrate an illusion of temporal ordering driven by social factors, but the precise manipulations employed in the previous experiments involve motions that are not necessarily social in nature — since even non-social objects can rotate. To test more directly whether social factors are intrinsic to these effects, we thus ran a new experiment with the identical motions as in the animations employed in Experiment 1–3, but now performed by turning cubes (instead of turning heads) — as depicted in the third and fourth online animations. Critically, this allowed us to control for lower-level properties of the displays such as spatial distance and movement speed, and to isolate the role of social factors. (We thank an anonymous reviewer for prompting us to run this additional experiment.)

7.1. *Method*

This experiment was identical to Experiments 2a and 2b, except as noted here. Instead of being asked about “head turns made by the characters”, all participants were asked about “rotations made by the blocks”. The response options were thus “First, A rotated to the side. Second, A rotated to the other side. Lastly, B rotated.” and “First, A rotated to the side. Second, B rotated. Lastly, A rotated to the other side”. There were again 2 animations corresponding to 2 directions of A’s first rotation (Toward-B/Away-from-B), as well as 2 possible rotation directions (Left/Right), and 2 possible orders of response options in the forced choice question, for a total of 8 conditions — each completed by 15 unique observers.

We recruited a new set of 120 participants (66 females; $M_{age} = 33.82$; with this preregistered sample size chosen to match that of Experiments 1 and 2), again excluding participants (per the preregistered criteria) who reported having interrupted the survey ($n = 2$); whose viewport size was smaller than the dimensions of the animation ($n = 2$); who failed to answer our questions sensibly ($n = 1$); or who reported not paying attention ($n = 3$). These excluded participants ($n = 8$) were replaced without ever analyzing their data.

7.2. Results and discussion

Observers who watched Toward-B animations were just as likely as observers who watched Away-from-B animations to select the option where B rotated earlier than A (65.0% vs. 66.7%; $z = 0.19$, $p = .847$, $h = 0.04$). (And of the observers who didn't select the option where B turned earlier than A, most selected the option where A turned earlier than B [25.0% vs. 26.7%], while few selected "I am not sure" [10.0% vs. 6.7%].) Additional comparisons revealed that this null result was also significantly different than the highly reliable results that were obtained in Experiment 2a ($z = 2.58$, $p = .010$), Experiment 2b ($z = 2.26$, $p = .024$), and the Animation condition in Experiment 3 ($z = 5.32$, $p < .001$).

This suggests that the effects reported here are truly *social*, since the illusion vanished when the identical movements in the identical positions were performed by turning geometric objects, rather than turning heads. For example, the illusion of temporal order reported in the previous experiments may in part be due to observers allocating their

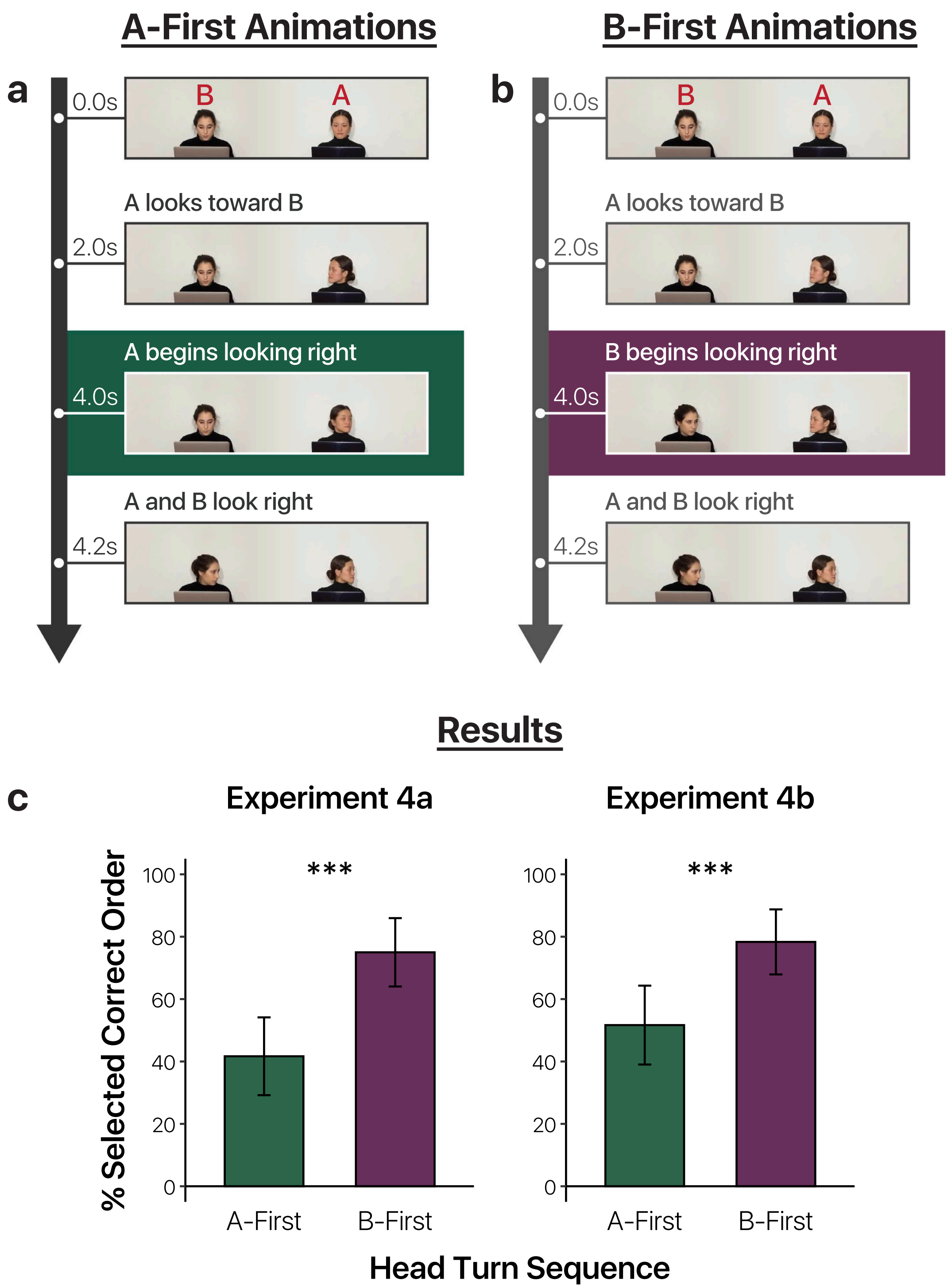

Fig. 3. Reversal of perceived temporal order in asynchronous animations. (a and b) Schematic depictions of the animations observers viewed in Experiments 5a and 5b, including the A-First animations (a) and B-First animations (b). (c) Average accuracy for observers who watched A-First vs. B-First animations in Experiment 5a (left panel) and 5b (right panel). Error bars indicate 95% CIs.

attention differently in the various conditions — e.g., they might fixate on B as A turns toward her in Toward-B animations, but not as A turns away from her in Away-from-B animations. Such differential fixation patterns could of course contribute to participants' impressions of temporal order — but these would still be specific to the natural experience of viewing gaze deflection, since they vanished in displays with the identical spatial extents and distances between relevant motions.

8. Experiment 5a: Reversing time

Beyond changing *synchronous* head turns to *asynchronous* percepts consistent with gaze deflection (as in the previous experiments), the power and consistency of these results led us to wonder whether this illusion is also powerful enough to *reverse* the perceived temporal order of events. To find out, we showed observers animations in which the head turns occurred in the reversed order, with a delay previously shown to be sufficient for accurate performance on temporal order judgments of moving objects (Craig & Busey, 2003, Experiment 4). Again, observers selected which of two options ('B first' or 'A first') best described the animation they had just watched.

8.1. Method

This experiment was identical to Experiments 2a and 2b, except as noted here. The Toward-B animations were altered such that instead of turning synchronously, at 4.0 s either A or B started turning (resulting in 'A-First' [as depicted in Fig. 3a and in the fifth online animation] or 'B-First' [as depicted in Fig. 3b and in the sixth online animation] animations, respectively), and the other person started turning 210 ms later, at 4.2 s. The person who turned first again ended her head turn at 4.5 s, while the other ended at 4.7 s. The final tableau was then visible for an additional 1.3 s (i.e. until 6.0 s), at which point it disappeared. There were thus 2 animations corresponding to 2 orders of head turns (A-First/B-First), as well as 2 possible head turning directions (Left/Right), and 2 possible orders of response options in the forced choice question, for a total of 8 conditions — each completed by 15 unique observers.

We recruited a new set of 120 observers (61 females; $M_{age} = 32.36$; with this preregistered sample size chosen to match that of Experiments 1 and 2), again excluding observers (per the preregistered criteria) who reported having interrupted the survey ($n = 5$); whose viewport size was smaller than the dimensions of the animation ($n = 4$); who reported past participation in a similar study ($n = 2$); who encountered problems ($n = 2$); or who failed to answer our questions sensibly ($n = 2$). These excluded observers ($n = 12$, some of whom triggered multiple criteria) were replaced without ever analyzing their data.

8.2. Results and discussion

As depicted in the left panel of Fig. 3c, observers who watched B-First animations were more accurate — selecting the 'B first' option more than observers who watched A-First animations selected the 'A first' option (75.0% vs. 41.7%; $z = 3.70$, $p < .001$, $h = 0.69$). (And of the observers who didn't select the accurate order of events, most selected the inaccurate order of events [B-First animations: 21.7%; A-First animations: 56.7%], while few selected "I am not sure" [3.3% vs. 1.7%].) This demonstrates how gaze deflection can not only alter, but also effectively *reverse* the perceived order of events.

9. Experiment 5b: Direct replication

Given the importance of direct replications, we reran the experiment on another group of 120 observers (68 females; $M_{age} = 31.06$), again excluding observers (per the preregistered criteria) who reported having interrupted the survey ($n = 3$); whose viewport size was smaller than the dimensions of the animation ($n = 6$); who reported past participation in a similar study ($n = 2$); who encountered problems ($n = 2$); who failed to answer our questions sensibly ($n = 1$); or who reported not paying attention ($n = 1$). These excluded observers ($n = 13$, some of whom triggered multiple criteria) were replaced without ever analyzing their data.

As depicted in the right panel of Fig. 3c, observers who watched B-First animations were more accurate — selecting the 'B first' option more than observers who watched A-First animations selected the 'A first' option (78.3% vs. 51.7%; $z = 3.06$, $p = .002$, $h = 0.57$) — thus replicating Experiment 5a. (And of the observers who didn't select the accurate order of events, most selected the inaccurate order of events [B-First animations: 20.0%; A-First animations: 45.0%], while few selected "I am not sure" [1.7% vs. 3.3%].)

10. General discussion

The eight experiments reported here collectively demonstrate that impressions of gaze deflection can alter the perceived temporal order of events in social interactions. This illusion seemed especially robust and reliable in at least 7 ways: *First*, the magnitudes of these effects were enormous — e.g. with observers' free reports being 20 times more likely to describe the illusion than the actual state of affairs (in Experiments 1a and 1b). *Second*, these effects readily replicated in six independent samples, each producing the same qualitative pattern of results. *Third*, this illusion was apparent when assessed in multiple ways — including both spontaneous descriptions (as in Experiments 1a and 1b) and forced-choice responses (as in Experiments 2a, 2b, 3, 5a, and 5b). *Fourth*, it vanished (as predicted) when the very same head turns were played in different spatial locations (simply by swapping the positions of actresses, as in Experiments 1, 2, and 3) while retaining all lower-level properties (e.g., differential head turn speed). And the effect also vanished when the same types of motions (in the same positions) occurred in (non-social) geometric objects (as in Experiment 4). *Fifth*, it was powerful enough not just to *introduce* a temporal order where there was none (as in Experiments 1, 2, and 3) but also to *reverse* an existing temporal order (as in Experiments 5a and 5b). *Sixth*, this illusion depended on visual experience, and could not be explained merely by appealing to expectations about what was most likely to have happened (as demonstrated in Experiment 3). And *seventh*, we note informally that beyond the statistical tests reported here, this illusion seems to work well as a demonstration in naive observers (as can be appreciated in the online animations).

Ultimately, while gaze deflection is but one of the many social dynamics that we may experience in everyday life, this illusion may be seen as a testament to the power of social perception. Seeing, despite its apparent instantaneity, takes time to unfold. In particular, some steps in visual processing must take place before some other steps — and it seems especially intuitive to think that seemingly higher-level processing (such as social interpretations) must occur after some lower-level foundations (such as what movements happened when) have already been encoded. But the present experiments demonstrate that this is not always so: inspired by studies of causal judgments (Bechlivanidis & Lagnado, 2013), the present experiments show how the perceptual schema of gaze deflection can disambiguate (and even reverse) the order in which we see the underlying physical motions in the first place — revealing a complex interplay between social perception and basic representations of what happens when.

CRediT authorship contribution statement

Clara Colombatto: Conceptualization, Methodology, Software, Formal analysis, Investigation, Validation, Data curation, Visualization, Writing – original draft, Writing – review & editing. **Yi-Chia Chen (陳鴨嘉):** Conceptualization, Methodology, Software, Visualization, Writing – original draft, Writing – review & editing. **Brian J. Scholl:** Conceptualization, Methodology, Visualization, Writing – original draft, Writing – review & editing, Supervision, Project administration, Funding acquisition.

Declaration of competing interest

None.

Data availability

The data can be found online at https://doi.org/10.1016/j.cognition.2024.105745.

Acknowledgments

For helpful conversation and/or comments on previous drafts, we thank members of the Yale Perception & Cognition Laboratory and the Turk-Browne Laboratory, and three anonymous reviewers. For assistance with coding the descriptions in Experiments 1a and 1b, we thank Joanna Zukin. This project was funded by ONR MURI #N00014-16-1-2007 awarded to BJS. The authors declare no competing interests.

Appendix A. Supplementary data

The raw data for these experiments can be viewed in the Supplemental Material available online, and the preregistered methods and analyses for each experiment can be viewed at https://osf.io/b7jdp/. Supplementary data to this article can be found online at https://doi.org/10.1016/j.cognition.2024.105745.

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