**Perspective taking as virtual navigation? Perceptual simulation of how others see the
world reflects their location in space but not their gaze.**

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Word count: 7464

Abstract

Other peoples' (imagined) visual perspectives are represented perceptually in a similar way to our own, and can drive bottom-up processes in the same way as own perceptual input (Ward, Ganis & Bach, 2019). Here we test directly whether visual perspective taking is driven by where another person is looking, or whether these perceptual simulations represent their position in space more generally. Across two experiments, we asked participants to identify whether alphanumeric characters, presented at one of eight possible orientations away from upright, were presented normally, or in their mirror-inverted form (e.g. "R" vs. "Я"). In some scenes, a person would appear sitting to the left or the right of the participant. We manipulated either between-trials (Experiment 1) or between-subjects (Experiment 2), the gaze-direction of the inserted person, such that they either (1) looked towards the to-be-judged item, (2) averted their gaze away from the participant, or (3) gazed out towards the participant (Exp. 2 only). In the absence of another person, we replicated the well-established mental rotation effect, where recognition of items becomes slower the more items are oriented away from upright (e.g. Shepard and Meltzer, 1971). Crucially, in both experiments and in all conditions, this response pattern changed when another person was inserted into the scene. People spontaneously took the perspective of the other person and made faster judgements about the presented items in their presence if the characters were oriented towards upright to them. The gaze direction of this other person did not influence these effects. We propose that visual perspective taking is therefore a general spatial-navigational ability, allowing us to calculate more easily how a scene would (in principle) look from another position in space, and that such calculations reflect the spatial location of another person, but not their gaze.

Keywords: *visual perspective taking; perceptual simulation; gaze cuing; navigation; mental rotation; mental imagery*

Perspective taking as virtual navigation: perceptual simulation of how others see the world reflects their location in space but not their gaze.

1. Introduction

Visual perspective taking (VPT) allows people not only to derive what others can see, but also how they see it (Flavell, Everett, Croft, & Flavell, 1981). Doing so helps us navigate our social environment (Kozhevnikov, Motes, Rasch & Blajenkova, 2006), engage in joint action (Freundlieb, Kovács, & Sebanz, 2016) and work out what others will do next (Bach, Fenton-Adams, & Tipper, 2014; Creem-Regehr, Gagnon, Geuss, & Stefanucci, 2013; Kovacs, Teglas, & Endress, 2010). Deriving how the world appears to other people may also form a foundation for more sophisticated abilities to reason about others mental states, such as their beliefs, emotions, and goals (Batson, Early, & Salvarani, 1997; Erle & Topolinski, 2015; Tomasello, Carpenter, Call, Behne, & Moll, 2005; Mattan, Rotshtein & Quinn, 2016). Yet, the mechanisms underlying the ability to perspective take, and the stimulus features that trigger shifts to another's perspective are largely unclear.

Recent research has started to conceptualize perspective taking as a form of perceptual simulation, which “paints” or “inserts” another's view of the world onto one's own perceptual processes, as if it were one's own perceptual input (Kampis, Parise, Csibra, & Kovács, 2015; Surtees, Apperly, & Samson, 2013; Ward, Ganis, & Bach, 2019). As soon as another's perspective is represented in such a (quasi-)perceptual manner, it could drive one's own action and decision making processes just like own input, explaining the developmental link between VPT and higher level mentalizing abilities (Hamilton, Brindley, & Frith, 2009) and its link to joint action (Freundlieb, Kovács & Sebanz, 2016; Tversky & Hard, 2009).

Direct evidence for such a proposal had been lacking however. Consistent with a similar representational format of one's own and others' perspectives, it has been shown that own

judgments of a stimulus are harder if another person around us would make the same judgments differently. People find it harder, for example, to judge how many objects they can see from their own perspective when another actor sees a different number (Samson, Apperly, Braithwaite, Andrews, & Bodley Scott, 2010). Similarly, it is harder to identify a character as a “6” if it looks like a “9” to another person (Surtees, Samson, & Apperly, 2016), or to judge whether an object is to the left or the right to oneself when this object is in another location for another person (Tversky and Hard, 2009; Zwickel, 2009; Zwickel and Müller, 2010). Yet, these studies leave open whether the interference happens on the perceptual, conceptual, response or even metacognitive level, perhaps indexing simply the uncertainty when a person becomes aware that others would judge – or respond to – the same stimulus differently from another perspective, without representing how specifically they see it.

A recent series of studies from our lab (Ward et al., 2019) provided the first direct evidence that another’s visual perspective is perceptually represented. We reasoned that if people have (quasi-)perceptual access to the content of another’s’ perspective, then this perspective should not only interfere with one’s perceptual judgements (Sampson et al., 2010; Surtees et al., 2016), but should also *facilitate* them, precisely if this other perspective would offer a better view on an object than one has oneself. To test this, we let participants take part in a variant of the classic mental rotation task (Shepard & Melzer, 1971) in which they simply judged whether alphanumeric characters presented at varying orientations were ‘normal’, or mirror-inverted (e.g. “R” v. “Я”). The classic finding is that these judgements become progressively slower with increasing angular disparity away from upright (Cooper, 1975; Shepard & Melzer, 1971) because people must mentally rotate each item back into its canonical orientation before judging it. We find that this classic pattern can be dramatically altered simply by inserting another person into the scenes that views the items from another perspective. Items oriented away from participants were identified more quickly if they

appear upright to the other person, as if people could simply identify it from their alternative perspective. Conversely, they judged it more slowly if the item was even further rotated away from the other person. Regression analyses showed that recognition times across letter orientations can be predicted from the angular disparity of the item not only to the participant, but also to the other person, suggesting that participants mentally rotated the items from both their own and the other's perspective.

These data showed that people can represent the *content* of another's (imagined) viewing perspective in a form that can drive perceptual judgements in the same bottom-up manner as our own perception (e.g. Roelfsema & de Lange, 2016), allowing us to make judgments from others' perspectives that would be more difficult from our own. Importantly, these shifts to the others' perspective occurred spontaneously, even when the persons in the scene were completely task-irrelevant. They were enhanced when participants were explicitly instructed to take the others' perspective, but were eliminated when the other person was replaced by an inanimate object (Ward et al., 2019), suggesting that these perceptual shifts capture another's ability to see (or at least mentally represent) the world.

This paradigm provides us with a unique window into the process that underlie visual perspective taking. Here, we use this task to test which cues are used to drive spontaneous shifts into another's visual perspective. One important candidate is another person's gaze. Gaze has long been associated with mentalizing and perspective taking, exemplified perhaps by the folk-psychological interpretation of perspective taking as "seeing through another's eyes". People are highly sensitive to others' gaze, to the extent that one's own spatial attention is involuntarily directed to the object another person is looking at, creating shared attention (for a review, see Frischen, Bayliss and Tipper, 2007). Importantly, this effect is at least partially driven by mental state attributions to the gazing person (Morgan, Freeth &

Smith, 2019), and seeing others gaze at an object transfer their emotional state (e.g. a smile or frown) to it, rendering it more/less appealing (e.g., Bayliss, Paul, Cannon & Tipper, 2006; for review, Becchio, Bertone & Castiello, 2008). In addition, a person's gaze direction signals how they intend to act upon an object (Ambrosini, Costantini & Sinigaglia, 2011), promotes later (automatic) imitation of these actions (Wang & Hamilton, 2012), and increases activity in brain regions related to Theory of Mind and mentalizing (e.g., Mosconi, Mack, McCarthy & Pelphrey, 2005; Williams, Waiter, Perra, Perret & Whiten, 2005). If the associated processes rely on embodying the content of another's visual perspective, then visual perspective taking, too, should be highly sensitive to where another is looking.

Another possibility is however that spontaneous visual perspective taking is separate to these mentalizing processes and primarily driven by the presence – and spatial location – of another person in the scene. In other words, people might be putting themselves generally into the shoes of others, without truly looking through their eyes. It is well supported that people embody another's location in space. Several studies have shown, for example, that it takes longer to explicitly judge where an object is from another's perspective the more this person is oriented away from us, as we mentally rotate our own bodies into the other's perspectives, with this transformation taking longer the more we are oriented away from them (Kessler & Thompson, 2010; Kessler & Rutherford, 2010; Kozhevnikov et al., 2006; Surtees et al., 2013). Other studies link perspective taking not to Theory of Mind and mentalizing, but to more fundamental navigational abilities (Allen, Kirasic, Dobson, Long & Beck, 1996; Hegarty & Waller, 2004; Kozhevnikov et al., 2006) and the ability to decide from which other locations one can interact with the environment (Gunalp, Moossaian & Hegarty, 2019; Kessler & Thompson, 2010).

Strikingly, there is very little evidence about whether another's eye gaze is an important cue for taking another's visual perspective. Most studies have demonstrated only that another

person's eyes contribute to working out *what* this person can or cannot see (Level 1 perspective taking), not *how* they see it (Level 2 perspective taking). These studies have shown that this form of Level 1 perspective taking relies on a process that “mentally scans” (Kosslyn, Ball, & Reiser, 1978) the line of sight between another's eyes and the object they can potentially see (e.g., Michelon & Zacks, 2006) and that, based on this information, people work out whether their own judgment and others differs (e.g., Surtees et al., 2013). To our knowledge only two studies have investigated how others' eye gaze contributes to Level 2 perspective taking, people's ability to work out *how* objects look to the other person, with both providing non-conclusive results. Mazzarella, Hamilton, Troiano, Mastromauro and Conson (2012) found that seeing another person reach for an object induces spatial interference effects from the others' perspective, so that participants were less likely to judge object location from their own perspective. However, merely seeing the other person shift their eyes towards the object (and not reaching for it) did not induce a detectable shift to their perspective. Similarly, Furlanetto, Cavallo, Manera, Tversky and Becchio (2013) showed that while viewing someone gaze at an object numerically increased shifts to their spatial perspective, this did not seem to be statistically robust, and even removing gaze cues altogether (by blurring the eye region) did not affect whether people judged objects from another's or their own perspective.

Our paradigm provides an ideal means to disentangle these two possibilities. By measuring how much faster items are identified the more they are oriented towards other people in the scenes (and slower the more they are oriented away from them), our paradigm provides a quantitative measure of participants' tendency to spontaneously take another's visual perspective. If another's gaze is critical to trigger these VPT processes, then these recognition biases should only be seen for an actors that gazes at the items but be eliminated if the actor is not looking directly at them, but gazes elsewhere. If, on the other hand, VPT represents a

mental transformation from one's own position in space into that of another, then the gaze direction of this other person will not influence recognition times, and *all* conditions will show shifts towards the incidentally presented people in the scenes, even if they gaze away from the relevant items. Here, we test these predictions in two experiments.

2. Experiment 1 – manipulating gaze between trials

Experiment 1 tests how another's gaze affects perspective taking, using a within-subject design. Participants were shown a series of scenes depicting a table in front of them. In each trial, an alphanumeric character appeared on the table, presented either normally, or in its mirror-inverted form, at varying rotations away from upright. Participants had to simply judge, with a button press, whether the items were mirrored or normal ("R" vs. "Я"). In some trials, another person was seen sitting to the left or the right of the table. Our previous studies have shown that people spontaneously make use of another person's perspective when making these judgements. When letters are facing another person, it was easier to judge whether they are mirrored or normal than it would be if this other person was not there or sitting in the opposite direction, indicating that people judged the letters through this person's eyes. Here we manipulated – between trials – the direction in which the person was looking, in order to test whether people's tendency to spontaneously represent how an object looks to another person is affected by whether this person is actually looking at the object. In different trials, the person on the screen could either (1) look at the item on the table, as in our prior work, or (2) look away from it to the wall in the room. If perspective taking takes the others' gaze into account, then the ability to recognize an object from another's perspective should be enhanced – or only found – when the person is actually looking at the to-be-judged item, but less so if looking at the participant or the room's back wall. If, however, perspective

taking emerges from a general rotation of one's own body into the spatial location of another then it should happen irrespective of where the actor is looking.

2.1. Method

2.1.1. Participants

Thirty-seven (31 females) naive participants were initially recruited via the University of Plymouth participation pool. All participants were adults (age range 18-35) and gave written informed consent according to the declaration of Helsinki. Approval was obtained from the University of Plymouth Ethics Committee. Participants received course credit as compensation. As in Ward et al., (2019), participants with more than 20% error rates across all conditions were not considered for analysis ($n=5$). The remaining thirty-two participants (27 females; mean age: 20.1 years, range: 18-35) provide enough power to detect effects in the range of $d = .45$. Prior work on this paradigm (Ward et al., 2019) has revealed that effect sizes are substantially larger ($.747 < d < 1.08$ for the main perspective taking effect).

2.1.2. Apparatus, stimuli and procedure

The study was conducted in behavioural testing lab space of the Action Prediction lab of the University of Plymouth. It was administered using Presentation® software (Version 18.0, Neurobehavioral Systems, Inc., Berkeley, CA, www.neurobs.com). Stimuli were presented on a 19" LED computer monitor (Resolution: 1900x1200; Refresh rate: 60Hz). Responses were made on a standard computer keyboard with UP, DOWN, and SPACE keys as active response keys. Red and green stickers were positioned on the DOWN and UP keys, respectively.

Participants sat upright facing the screen at a distance of approximately 60cm and were given written and verbal instructions. Before the experiment proper commenced, they were given examples of the rotated items that would appear on the screen and completed eight training trials that were identical to the main experiment. The experiment proper consisted of 520 trials. Each trial (Figure 1) started with a fixation cross displayed for 400ms, followed by 300ms blank screen. The subsequent stimulus sequence included three frames, each measuring 33.4 by 23.5 degrees of visual angle. The first frame was presented for 800 ms. In one third of the trials, it showed a view onto a corner of a square table in a grey room without a person being present (No-Person trials). The remaining trials showed a person (either male or female) sitting at the same square table, gazing outwards at the participant. The person sat either on the left side of the table (Person-left trials) or on its right side (Person-right trials), so that they were positioned at roughly 270 or 90 degree angle to the position at which the rotated items would appear, relative to the participant.

Figure 1. Example stimuli used in Experiment 1. Looking direction (Item-gaze or Averted-gaze) varied between trials.

The second frame in the sequence was identical to the first for the No-Person trials. In the other trials, the person looked down towards the middle of the table in half the trials, where the item would appear, and in the other half they looked away towards the corner of the room. Because this second frame was presented without inter-stimulus interval, it created the impression of apparent motion (Wertheimer, 1912), so that the person seemed to shift their gaze from the participant towards the table or towards the back of the room. Then, after a random interval between 700ms and 1400ms, the third frame was presented. This was identical to frame 2, but now one of 48 possible items appeared on the table, at the location on the table the on-screen person was gazing at. This item was one of three alphanumeric characters (4, P, or R), presented either in the canonical version or mirror-inverted about their vertical axis, in one of eight orientations (0° , 45° , 90° , 135° , 180° , 225° , 270° , 315° , with 0° denoting the upright canonical orientation and angles increasing in a counter-clockwise

fashion) relative to the participant. The characters always appeared in the same position on the table, half-way between the outward corner of the table and its centre, such that the persons to the left and right would gaze at the table from roughly 90° and 270°, respectively (perpendicular to the viewpoint of the participant). Character rotation occurred around the character's centre point.

Participants were asked to judge whether each character was presented in its canonical or mirror-inverted form (e.g. “R” vs “R”). Participants responded using their right hand by pressing the green key to indicate a canonical item and the red key to indicate a mirrored item. Response times were measured relative to item onset. The third frame remained on the screen until a response was made to a maximum duration of 3500ms.

2.2. Analysis

Data (pre-)processing and analysis was identical to Ward et al., (2019) and conducted in Microsoft Excel (2010) and JASP (2018). Violin plots were created using Raincloud Plots (Version 1; Allen, Podiaggi, Whitaker et al., 2019). Power analyses were conducted in G*Power (Version 3.1; Erdfelder, Faul, & Buchner, 1996).

Dependent measures were the recognition times (measured from item onset) for each character orientation (0°, 45°, 90°, 135°, 180°, 225°, 270°, 315), depending on Person location (No-Person, Person-left, Person-right) and Gaze direction (Item-gaze, Averted-gaze). As in our original study (Ward et al., 2019), the recognition times for each angle and condition were mapped onto two orthogonal and statistically independent summary measures, so that they can be compared across conditions, without accruing alpha inflation due to multiple testing, which would result if each of the eight angles were compared separately.

These two summary measures are derived by treating each participant's recognition time for this character orientation as a vector in a polar coordinate system, with the recognition time providing the distance from the origin and the rotation angle the polar angle.

The first summary measure (Toward/Away-bias) quantifies the mental rotation effect (Shepard & Meltzer, 1971) and indexes to what extent characters are recognized faster the more they are facing towards the participants (0°) rather than away from them (180°), separately for each participant and condition (No-Person, Person-left Item-gaze, Person-left Averted-gaze, Person-right Item-gaze, and Person-right Averted-gaze). A character orientation's contribution to the Toward/Away-bias is derived simply from the recognition times multiplied with the negative of the cosine of the orientation angle. As a result, characters contribute negatively the more they face the participants (315° , 0° , 45°) and positively the more they are oriented away from them (225° , 180° , 135°). Positive values on this score therefore indicate faster recognition of letters oriented towards rather than away from the participant.

The second summary measure (Left/Right-bias) indexes how much faster characters were recognized when oriented towards the left (270°) rather than right (90°), and therefore allows us to quantify whether people present in these location induce shifts in how quickly these letters can be identified. It was derived analogously to the Towards/Away-bias. The contribution of a character's orientation to the Left/Right-bias was calculated as the recognition time multiplied with the sine of the orientation angle. Character orientations contribute negatively the more they face to the right (45° , 90° , 135°) and positively the more they face to the left (225° , 270° , 315°). A zero value on the Left/Right-bias therefore indicates that items oriented left and right are identified equally quickly, while positive

numbers indicate faster identification for left- compared to right-oriented letters, and vice versa for right-oriented letters.

By averaging these values, separately for each summary measure, participant and condition (No-Person, Person-left-item, Person-left-averted, Person-right-item, Person-right-averted), we can calculate, first, whether characters are recognized faster the more they appear in the canonical orientation to the participant compared to when they are oriented away (positive values on the Toward/Away-bias), reflecting the expected mental rotation effect. Similarly, they allow us to calculate to what extent characters are recognized faster the more they are oriented leftwards and would appear in their canonical orientation to a person sitting to the left (positive values on the Left/Right-bias) rather than rightwards, appearing in their canonical orientation to a person sitting on the right (negative values). We were then able to determine if this difference in left/right biases changed depending on whether the other person was looking at the object or not. Note that the direct comparison of the Person-left and Person-right conditions is statistically identical to the comparison of how much the presence of person shifts mental rotation performance in the Person-left and Person-right conditions relative to the No-Person baseline (i.e. how much person presence shifts recognition times away from 0 towards either 90^0 or 270^0), as this would involve subtracting the same baseline value from each of the two conditions for each participant, and would therefore not affect the absolute difference between them.

2.2.1. Across-participant regression analyses

In prior work, the mental rotation effect is typically also characterised in terms of a linear regressions of an items' recognition time to its angular disparity relative to the participant, for each participant separately (Shepard & Meltzer, 1971). The results reveal linear increases

with increasing angular disparity for the large majority of participants. Here, we used this analysis model to test whether an item's recognition times can be described, on a single participant basis, as a linear increase of the character's angular disparity *both* to the participant and to the other person. To this end, we entered each participant's item mean recognition times for each character orientation in each condition (No-Person, Person-item, Person-averted) as dependent variable in a multiple regression analysis, with the item's angular disparity to the participant and to the other person as two statistically independent predictors. This analysis provides regression coefficients for both predictors – angular disparity to participant and other person – for each participant and condition separately. We report mean across-participant regression coefficients for each of these two predictors and compare them with t-tests against zero, and against each other.

3. Results

Erroneous responses (7% on average) were excluded from the analysis of recognition times (RTs), as well as trials with RTs longer than 2000ms, or shorter than 150ms.

Figure 2. (A) Mean recognition times (RTs) for mirror-inverted/canonical judgements for Item-gaze trials when the actor is inserted on the right and the left showing faster recognition times for items oriented upright to the actor. (B) Left/right bias when the inserted person is looking at the table showing faster recognition times for items appearing upright to the actor. (C) Mean recognition times (RTs) for mirror-inverted/canonical judgements for Averted-gaze trials (D) Left/right bias when then inserted person appears to look away from the table (towards to wall).

3.1. Mental rotation

We first determined whether our data replicated the classical mental rotation effect (Shepard & Metzler, 1971). To this end, we first compared the overall (across conditions) towards/away bias, indexing, in milliseconds, how much more slowly items are identified the more they are oriented away from the participant compared to towards them, with a simple t-test against zero. The towards/away bias across all conditions was positive, $M=56.34$;

$SD=28.05$, $t(31)=11.36$, $p<.001$, $d=2.01$, $BF_{10}=5.797e+09$, showing – unsurprisingly – that items are identified more quickly the more they are oriented towards rather than away from participants. This mental rotation effect was also confirmed by regressing each item's recognition time to the expected linear increase with angular disparity, as in prior research, (Shepard & Melzer, 1971; Ward et al., 2019), revealing positive slopes in all participants, mean $\beta = 1.4$; $t(31)=14.60$, $p<.001$, $d=2.6$, $BF_{10}=3.181e+12$.

We then verified that this overall mental rotation effect was not affected by person presence. As the actors would sit at 90 and 270 degree angle to the participant, and their location was therefore orthogonal to the towards/away axis, we did not expect that the presence/location of the other person would affect the overall mental rotation effect. Indeed, a 2x3 ANOVA on the towards/away-biases across conditions with the factors Gaze (item, averted) and Location (person left, person right, no person) did not reveal any main effects or interactions, $F<2.68$, $p>.08$, for all. When the six conditions were analysed separately, slower recognition of turned away items was present in all conditions, $t(31) > 8.29$, $p <.001$, $d > 1.5$ for all.

3.2.Perspective taking

The main question was whether people would spontaneously take the perspective of the other person in the scenes, such that items were recognized faster when oriented towards compared to away from them, and whether this effect, in turn, was determined by where this person was looking. We therefore calculated, for each participant and condition separately, the left/right-bias (for details, see analysis-section), indexing, in ms., how much faster items were identified the more they were oriented to the left than to the right. The resulting left/right-bias summary scores were then entered into a 2 x 2 repeated measures ANOVA with within-subjects factors of Location (Person-left, Person-right) and Gaze (Averted-gaze, Item-gaze). This analysis revealed decisive evidence for a main effect of Location, $F(1,31)=27.921$, p

$<.001$, $\eta p^2=.474$, $BF_{10}=4379.04$. As in our prior work (Ward et al., 2019), left/right-biases were more negative (indexing faster recognition of rightwards- than leftwards oriented letters) when someone was sitting on the right, and more positive (indexing faster recognition of leftwards- than rightwards oriented letters) when someone was sitting on the left. Strikingly, this analysis provided moderate evidence against a main effect of Gaze, $F(1,31)=.545$, $p=.466$, $\eta p^2=.017$, $BF_{10}=.203$, and against an interaction of Location and Gaze, $F(1,31)=.291$, $p=.593$, $\eta p^2=.009$, $BF_{10}=.216$, showing that the position of the actor, and not where they were looking, was the critical cue to induce perspective taking. Indeed, when the difference in left/right-bias between Person-left and Person-right conditions was compared separately for each gaze condition, the predicted differences were apparent for both Item-gaze trials $t(31)=-3.287$, $p=.003$, $d=.58$, $BF_{10}=14.55$, and Averted-gaze trials $t(31)=5.044$, $p<.001$, $d=1.01$, $BF_{10}=1145.37$, with effect sizes, if anything, being larger in the away trials.

Table 1. Means (M) and Standard Deviations (SD) for the Left/Right- and Towards/Away-biases in Error rates in Experiment 1 and Experiment 2. Relates to Figure 2 and Figure 4. Forward/Away and Left/Right-biases were calculated analogously as for the recognition times. * $p<.05$. ** $p<.01$, *** $p<.005$.

Exp.	Looking direction	Toward/away bias			Left/right bias		
		Person-left M (SD)	Person-right M (SD)	No-Person M (SD)	Person-left M (SD)	Person-right M (SD)	No-Person M (SD)
1.	Item	.021 (.027)***	.022 (.027)***	.021 (.024)***	-.0001 (.024)	-.005 (.02)	.0004 (.02)
	Averted	.024 (.028)***	.025 (.026)***	.021 (.024)***	.003 (.021)	-.006 (.022)	.0004 (.02)
2.	Item	.028 (.026)***	.024 (.026)***	.022 (.03)***	.004 (.011)	-.001 (.017)	.004 (.015)
	Averted	.028 (.027)***	.031 (.032)***	.022 (.025)***	-.0019 (.014)	-.0023 (.015)	-.003 (.016)
	Participant	.034 (.029)***	.025 (.024)***	.033 (.022)***	-.007 (.02)	-.01 (.021)	-.005 (.019)

3.3. Regression analyses

As in our previous studies, we tested whether recognition times could be described as independent linear increases depending on an item's angular disparity to the participant as

well as the other person, by using both disparities as orthogonal predictors in a simple regression model, for each participant and condition separately (and then comparing them against zero). Overall, these revealed very strong evidence for independent contributions of both the angular disparity to the participant, mean $\beta = 1.39$, $t(31)=11.09$, $p<.001$, $d=1.96$, $BF_{10}=3.278e+09$, and to the other person, mean $\beta = .27$, $t(31)=4.95$, $p<.001$, $d=.87$, $BF_{10}=919.8$, showing that recognition times can be described by independent mental rotation functions from one's own and the other person's perspective.

To test how these relationships were affected by the other person's gaze, regression coefficients for each participant and condition were entered into a 2 x 2 repeated measures ANOVA with Gaze (Item, Averted) and Perspective (Self, Other) as within-subject factors. This analysis only revealed a main effect of Perspective, $F(1,31)=68.96$, $p<.001$, $\eta p^2=.69$, $BF_{10}=2.118e+18$ showing that, as expected, angular disparity towards the participants determined recognition times to a stronger extent than angular disparity to the other person. Replicating the main analysis, the analysis provided moderate *against* a contribution of gaze, neither revealing a main effect of Gaze, $F(1,31)=.267$, $p=.609$, $\eta p^2=.009$, $BF_{10}=.24$, nor an interaction of Gaze and Perspective, $F(1,31)=.044$, $p=.835$, $\eta p^2=.001$, $BF_{10}=.193$. In Item-gaze trials, both the angular disparity away from upright to the participant, mean $\beta=1.39$, $t(31)=9.55$, $p<.001$, $d=1.7$, $BF_{10}=1.044e+08$, and to the actor, mean $\beta=.25$, $t(31)=3.273$, $p=.003$, $d=.58$, $BF_{10}=13.98$ contributed to recognition times. This pattern was the same in the Averted-gaze trials, with the stronger contribution again coming from the angular disparity to the participants, mean $\beta=1.42$, $t(31)=10.81$, $p<.001$, $d=1.9$, $BF_{10}=1.799e+09$, and the smaller contribution coming from the angular disparity to the other person in the scene, mean $\beta=.30$, $t(31)=5.25$, $p<.001$, $d=.91$, $BF_{10}=2002.84$.

4. Experiment 2 – manipulating gaze between participants

Experiment 1 confirmed that the mere presence of a person is sufficient to induce a shift into their perspective. As in our prior research (Ward et al., 2019), we found that oriented items were recognized more rapidly if they appeared closer to their canonical orientation to another person in the scenes. Moreover, recognition times could be well-described by mental rotation functions centred on both one's own and the other person's perspective. Strikingly, however, these shifts into the others' perspective were independent of the other person's gaze and occurred irrespective of where they are looking at the to-be-recognized item or away from it. This suggests that taking another's visual perspective is based on their location in space, but not their gaze at (or away) from the relevant items.

One reason for this lack of a difference might be that within-participant experiments such as ours suffer from influential companion (e.g., Poulton, 1992) and carry-over effects (MacFie, Bratchell, & Greenhoff, 1989), for example when a participant's memory of the actor's gaze (e.g. at the item) in a previous trial influenced their processing in the current trial (e.g. at the wall). In Experiment 2, we therefore varied gaze *between* participants to rule out such an explanation. In addition, we added a third condition, in which the on-screen actors looked outwards at the participant. Prior work suggests that such gaze at the participant plays a special role in social cognition. It serves as an alerting signal, captures attention, and eliminates gaze cuing altogether (e.g. Mazzarella et al. 2012; for a review, see Hamilton, 2016). It may therefore provide the perhaps strongest manipulation of gaze. If visual perspective taking takes into account what another actually sees through their ideas – rather than what they *could* see from their position in space – then it should now be disrupted.

4.1. Method

4.1.1. Participants

Ninety-one (61 females) naive participants were initially recruited via the University of Plymouth participation pool. All participants were adults (age range 18-35) and gave written informed consent according to the declaration of Helsinki. Approval was obtained from the University of Plymouth Ethics Committee. Participants received course credit as compensation. After exclusion ($>20\%$ error), 80 participants (51 females; mean age: 19.9 years, range: 18-30) were considered for analysis, with at least 26 participants for each condition. This provides enough power to detect effects in the range of $d = .5$ for our critical comparison of left/right-bias across person locations. Results of the previous study (Ward et al., 2019) and as well as Experiment 1 show that effects are likely larger.

4.1.2.. Apparatus, stimuli and procedure

Participants completed 584 trials following the same apparatus and procedure as in Experiment 1. Between participants, we varied whether the actor always looked out towards the participant (participant-gaze), looked directly at the item on the table (item-gaze), or looked away from the item towards the corner of the room (averted-gaze). In each group, an equal number ($1/3^{\text{rd}}$) of trials showed a person on the left, a person on the right, or no person. The starting frame in each trial showed the table, with either the person present or absent. Depending on the participant's group allocation, the person present in the scenes either looked directly at the future item location, at the corner of the room or outwards towards participant. This frame was displayed for a randomized time between 1500 and 2220ms. It

was directly followed by the appearance of the item on the centre of the table for 3500ms (while the person remained present), or until a response was made (Figure 3).

Figure 3. Example stimuli used in Experiment 2. Participants viewed only one of the three possible looking directions in a between-subjects design.

5. Results

As in Experiment 1, erroneous responses (10% on average) were excluded from the analysis of recognition times (RTs), as well as trials with RTs longer than 2000ms, or shorter than 150ms.

5.1. Mental rotation

We again first verified that our data would replicate the mental rotation effect (Shepard & Metzler, 1971). As in Experiment 1, a simple t-test comparing toward/away bias across all conditions against zero confirmed that recognition times were generally slower the more

items were rotated away from participants, $t(79)=20.69$, $p<.001$, $d=2.31$, $BF_{10}=2.223e+30$.

This mental rotation effect was also confirmed by regressing each item's recognition time to the expected linear increase with angular disparity, revealing positive slopes in all but one participant, mean $\beta = .85$; $t(79)=54.96$, $p<.001$, $d=6.15$, $BF_{10}=9.342e+60$.

To confirm that this overall mental rotation effect was not affected by person presence, we ran a 3x3 ANOVA on the towards/away-biases across conditions with the factors Gaze (item, averted, participant) and Location (person left, person right, no person) as in Experiment 1. As before, this did not reveal any main effects or interactions, $F(2/4,154/77)<2.47$, $p>.088$, $BF<.404$ for all. The mental rotation effect was present in all conditions, $t(25/26) > 9.17$, $p <.001$, $d > 1.8$, for all.

5.2.Perspective taking

We then tested whether the task would replicate the shift to the other person's perspective and whether this shift was modulated by their gaze. Left/right-biases from all participants were entered into a 2 x 3 repeat measures ANOVA with within-subjects factors of Location (Person-left, Person-right) and between-subject factors of Gaze (Averted-gaze, Item-gaze, Participant-gaze). It again revealed a main effect of Location, $F(1,77)=29.472$, $p<.001$, $\eta p^2=.277$, $BF_{10}=15474.14$. As can be seen in Figure 3, left/right-biases were more negative when someone was sitting on the right and more positive when someone was sitting on the left. Thus, letters were identified more quickly when pointing leftwards when someone was also sitting on the right, but identified more quickly when oriented rightwards when someone was sitting on the left. However, as in Experiment 1, there was neither a main effect of Gaze, $F(2,77)=1.189$, $p=.310$, $\eta p^2=.030$, $BF_{10}=.230$, nor an interaction of Location and Gaze, $F(2,77)=2.11$, $p=.128$, $\eta p^2=.052$. $BF_{10}=.554$. Pairwise comparisons of the critical Left/Right actor locations for all conditions confirmed that regardless of where the actor was looking,

recognition times were faster when items that would usually be difficult to recognise were easier when appearing upright from this person's position, $t(26)=2.347$, $p=.027$, $d=.5$, $BF_{10}=2.055$, $t(26)=2.730$, $p=.011$, $d=.54$, $BF_{10}=4.239$, and $t(25)=4.173$, $p<.001$, $d=.89$, $BF_{10}=94.93$ for Item, Participant, and Averted-gaze, respectively.

Figure 4. (Left) Mean recognition times (RTs) for mirror-inverted/canonical judgements and (Right) Left/right bias when the inserted person is looking at the table showing faster recognition times for items appearing upright to the actor for (A) Item-gaze, (B) Participant-gaze, and (C) Averted-gaze.

5.3. Regression analyses

As in Experiment 1, we tested whether recognition times can be described as independent linear increases depending on an item's angular disparity to the participant as well as the other person. Mean beta coefficients for all gaze conditions were entered into a simple regression model, with the angular disparity of the character relative to the actor and the participant as independent predictors of recognition times. To test for differences between gaze conditions, mean Beta for all participants were entered into a 3x2 ANOVA with the between-subjects factor, Gaze (item, participant, averted), and within-subjects factor, Perspective (own, other). As in Experiment 1, a 2 x 3 ANOVA revealed only a main effect of Perspective, $F(1,77)=285.99, p<.001, \eta^2=.788, BF_{10}=1.587e+34$, showing that the angular disparity of an item to one's own perspective determined recognition times to a stronger extent than to the other's perspective. There was no main effect of Gaze, $F(2,79)=.231, p=.794, BF_{10}=.099$, and no interaction of Perspective and Gaze, $F(2,77)=.23, p=.795, \eta^2=.006, BF_{10}=.130$. Step-down analyses confirmed that, in each condition, recognition times could be described by a linear combination of an item's angular disparity to the participant (Item-gaze, $\beta=1.45, t(26)=10.207, p<.001, d=1.95, BF_{10}=7.276e+7$; Averted-gaze, $\beta=1.57, t(26)=13.697, p<.001, d=2.64, BF_{10}=6.344e+7$; Participant-gaze, mean $\beta=1.63, t(25)=10.352, p<.001, d=2.03, BF_{10}=3.399e+10$) and to a lesser extent to the other person (Item-gaze, mean $\beta=.13, t(26)=2.234, p=.034, d=.429, BF_{10}=1.684$; Averted-gaze, $\beta=.13, t(26)=2.699, p=.012, d=.52, BF_{10}=68.782$; participant-gaze, $\beta=.28, t(25)=4.032, p<.001, d=.79, BF_{10}=3.982$).

6. General Discussion

Using our recently developed task (Ward et al., 2019), we tested whether spontaneous shifts into another's visual perspective depend on the other person looking at the to-be-judged item.

We replicated the finding that people spontaneously represent – perceptually simulate – the content of another’s viewing perspective and use it to recognize items that would be more difficult to recognize from their own perspective. Thus, participants identified leftwards oriented items oriented more quickly when another person was sitting to the right than on the left, and vice versa for rightwards oriented items. Moreover, as in our original study (Ward et al., 2019), recognition times were well described by mental rotation functions based on the item’s orientation away from the participant and the other person. Our results therefore confirm that participants spontaneously shift their perspective into the location of another person and represent how an item would look from this position. Once represented in such a quasi-perceptual manner, the content of another’s viewing perspective can therefore drive perceptual decision making in a similar manner as one’s own perceptual input, and drive mental rotation processes.

Here we asked whether these spontaneous acts of visual perspective taking only reflect the other person’s location in space or whether they are also driven by the person’s gaze at the task-relevant objects (or away from them). We therefore manipulated, in two experiments, whether the other person was directly looking at the item, towards the wall, or towards the participant (Experiment 2 only). Neither experiment revealed an influence of gaze on visual perspective taking. The signature perspective taking effect – that items are identified more quickly when appearing upright to another person – was robustly present irrespective of whether this person was looking at the item, towards the wall, or directly at the participant, and irrespective of whether looking direction was manipulated between-trials in Experiment 1 and between participants in Experiment 2, preventing any obscuring influence of carry over or influential companion effects (MacFie et al., 1989; Poulton, 1982).

These data show that spontaneous visual perspective taking is primarily driven by the presence of another person and their location in space, but does not take into account where they are looking. This insensitivity to another's gaze is surprising under the (folk-psychological) assumptions that visual perspective taking is based on a sophisticated mechanism that allows us to "see" through another's eyes (e.g., Furlanetto, Becchio, Samson, & Apperly, 2016). It may also be surprising given the crucial role others' gaze is assumed to play in social perception generally. Viewing another's gaze provides immediate information about *whether* another person can see an item (e.g., Gardner et al., 2018), shifts one's own spatial attention towards the gazed at object (Frischen et al., 2007), and transfers the actor's emotional evaluation (e.g., when smiling, frowning) to the object so that one's own and others judgments align (Becchio et al., 2008). Our data suggest that these effects, insofar as they imply any sort of mental state attribution, are separate from the perceptual shifts into the eyes of the other person, and therefore reflect different mechanisms (see Cole, Atkinson, Le, & Smith, 2016, for a similar argument for gaze cuing).

Instead, the reliance on another's position in space suggests that spontaneous visual perspective taking relies on a more general mechanism that calculates how an item would, in principle, look from another's vantage point, irrespective of whether this person is currently looking at the item. It is consistent with the observation that visual perspective taking, when explicitly instructed, relies on mentally rotating one's own body into the position of the other person (e.g., Kessler & Rutherford, 2010; Surtees et al., 2013). In such views, rather than gaze, the ability to mentally transform one's own position in space into that of another is integral for deriving how the world looks to this other person.

These findings align visual perspective taking with fundamental navigational abilities, particularly the ability to navigate an imagined environment, rather than with more

sophisticated Theory of Mind and mentalizing abilities. Several authors have made such a case, reporting for example a correlational link between perspective taking and navigational skills, or that people are just as ready to judge items from the perspective of another person or from the perspective of a location they could, potentially, occupy (Gunalp et al., 2019; Hegarty & Waller, 2004; Kessler & Thompson, 2010; Kozhevnikov et al., 2006). Similarly, it is well-established that a key node of the theory of mind network, the Temporoparietal junction (TPJ) is also involved in visual perspective taking (e.g., Zacks, Rypma, Gabrieli, Tversky and Glover, 1999; for meta-analysis, see Schurz, Aichhorn, Martin & Perner, 2013) and self-other distinction (David et al., 2006; Lamm, Bukowski, & Silani, 2016) perhaps on the basis of the spatial difference vector between self and other (e.g., Jeannerod, 2007). However, the TPJ, and posterior parietal regions in general, are also implicated in imagined navigation (Committeri, Piccardi, Galati & Guariglia, 2015), specifically the translation of allocentric hippocampal place representations into representation of a location into egocentric space (Boccia, Sulpizio, Palermo, Piccardi, Guariglia, & Galati, 2017). The perhaps most dramatic example for this relationship is the link between the TPJ and out-of-body-experiences, in which patients subjectively “see” the world (and themselves) from outside their own body. The TPJ is the one region typically impaired in patients that report these experiences and stimulation of the TPJ in healthy individuals, via transcranial magnetic stimulation (TMS), can induce them (Blanke et al., 2005). We therefore speculate that the ability to visually perspective-take might emerge from an evolutionary ancient mechanism that allows us to calculate what we can see – and what/how we can interact with – from different positions in space, therefore serving both epistemic and action functions. More sophisticated abilities for mentalizing and Theory of Mind can then capitalise on the emerging insights that other perspectives might provide one with very different knowledge of the same scenes (Frith & Frith, 2007; Kessler & Thompson, 2010; Mundy & Newell, 2007),

giving rise to a common neuronal network for Theory of Mind, visual perspective taking, self-other distinction and (imagined) navigation.

A question for future research is how complete this simulation of different locations is. In our experiments, the other person's posture remained consistent across conditions, and their head was averted to the corner of the room, or outwards towards the participant. What, however, would happen if not only the actor's head, but their whole body was turned to face away from the table in our task? Such studies would allow one to disentangle if visual perspective taking is primarily based on locations in space, or whether it is embodied, in the sense that it is derived from a mental model of oneself in a target posture (Amorim, Isableu, & Jarraya, 2006). If so, this would predict that one's own ability to embody another's posture through our own behaviour might influence these effects. Aligning one's posture with that of another person has been shown to make judgements from their perspective easier (Kessler & Thompson, 2010; Kessler & Rutherford, 2010). In our own task, could participants' inadvertent imitation of their virtual partner's posture then explain why mental rotation can be performed with such ease from their perspective, even without any instruction to do so?

6.1. Conclusion

This study provides the first evidence that perceptual shifts into another person's perspective are unaffected by where this person is looking. It therefore confirms that people perceptually represent the content of another's perspective in a (quasi)perceptual manner, but that these perceptual simulations are based on their location in space, but do not take into account whether this person can actually 'see' target items. These data link perspective taking to more fundamental navigational skills and the ability what one could, in principle, see from another's vantage point, irrespective of what this person is currently looking at.

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Acknowledgements

We thank the members of the Action Prediction Lab, Plymouth University, (www.actionprediction.org) for discussion and comment on an earlier version of this article. Eleanor Ward was funded by a PhD student grant from the University of Plymouth.

Author contributions

EW and PB designed the experiment with GG. EW programmed the study, prepared the stimuli and collected all data. EW and PB and GG analysed the data. EW, PB, GG wrote the manuscript.

KM provided critical feedback throughout.

Declaration of interests

The authors declare no competing interests.

Data available at <https://osf.io/2cxpr/>