Visual perspective taking is not automatic in a simplified Dot task: Evidence from newly sighted children, primary school children and adults

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Abstract

In the Dot task, children and adults involuntarily compute an avatar's visual perspective, which has been interpreted as *automatic Theory of Mind*. We conducted three experiments in India, testing newly sighted children (N=5; all girls), neurotypical children (ages 5-10; N=90; 38 girls) and adults (N=30; 18 women) in a highly simplified version of the Dot task. No evidence of automatic perspective-taking was observed, although all groups revealed perspective-taking costs. A newly sighted child and the youngest children in our sample also showed an egocentric bias, which disappeared by age 10. Responding to recent work on what Theory of Mind tasks actually measure, we conclude that the standard Dot task relies so heavily on Executive Control that the alleged evidence of automatic Theory of Mind might simply reveal perspective switching costs.

Keywords: visual perspective taking; Theory of Mind; automaticity; interference; Executive Control.

Introduction

Visual perspective taking is a cornerstone of Theory of Mind development (Wellman, 2014). In Piaget and Inhelder's (1956) landmark study, 4-year-olds failed to adopt the visual perspective of a doll who was facing a model of three mountains from a different angle, selecting the view that matched their own, egocentric perspective. After decades of intense research, the most recent visual perspective-taking task was designed by Samson and colleagues (2010), who presented adults with an avatar in profile, which was facing one of two opposite walls. Participants had to indicate how many dots were on the walls, either from their own perspective or from the avatar's. In congruent trials, the participant and the avatar saw the same number of dots (i.e. all dots were on the wall that the avatar was facing), whereas in incongruent trials, the participant could see more dots than the avatar (i.e. some of the dots were on the wall behind the avatar). For an illustration from the present study, see Figure 1.

Figure 1: Sample pictures from the simplified Dot task that was administered longitudinally to five newly sighted children (ages 9-18) and cross-sectionally to neurotypical children (ages 5-10; N=90) and adults (ages 21-30; N=30). The picture on the left is from an incongruent

trial (i.e. the number of dots is different from the man's vs. the participant's perspective), whereas the picture on the right is from a congruent trial (i.e. both the man and the participant see the same number of dots).

Like the 4-year-olds in Piaget and Inhelder's study, the adults in Samson et al. (2010) also revealed an *egocentric bias*, showing lower accuracy rates and slower responses in incongruent trials than in congruent trials when asked to adopt the avatar's visual perspective. That is, their own view of the scene interfered with their calculation of the avatar's perspective. More interesting for the Theory of Mind community, these participants also revealed an *altercentric bias*: when asked to perform the task from their own visual perspective, participants also showed poorer accuracy and slower response times (RTs) when the avatar had a different perspective from their own. That is, even when the avatar's view was immaterial to their task, participants seemed to automatically calculate the avatar's perspective.

Analogous to the much debated false-belief task (Apperly & Butterfill, 2009; Wellman, 2014), Theory of Mind researchers have proposed both rich and lean interpretations of the altercentric interference observed with the Dot task. Samson et al. (2010) interpreted the original findings in line with Apperly and Butterfill's (2009) two-system account of Theory of Mind: humans can quickly and efficiently determine what another person sees, guided by direct cues such as their line of gaze. However, more complex forms of perspective taking (e.g., determining how a mountain range looks from some else's perspective; Piaget & Inhelder, 1956) require more Executive Control and do not appear to be automatic (see Flavell et al., 1981). Samson and colleagues 'avoided referring to these simple perspective-taking processes as "automatic" because automaticity is difficult to establish

without a more exhaustive investigation of the range of circumstances in which such phenomena are observed' (2010:1264).

More recently, a number of studies replicated and extended the results of Samson et al. (2010), which led to the conclusion that visual perspective taking is indeed an automatic process in humans (see Qureshi et al., 2010; Nielsen et al., 2015; Ferguson et al., 2017, 2018; Furlanetto et al., 2016; Simpson et al., 2017). The altercentric interference observed in these studies has been interpreted as evidence that the mere presence of an avatar automatically triggers perspective taking (Surtees et al., 2016). However, the results of these studies, as well as the rich interpretation of their findings, have not gone unchallenged. Santiesteban et al. (2014) observed similar interference when replacing the avatar with another directional cue, such as an arrow. In addition, Cole et al. (2016) and Conway et al. (2017) observed altercentric interference when the avatar's view had been blocked, challenging the conclusion that participants were calculating the avatar's visual perspective. The results of these studies have been interpreted as evidence that the altercentric interference observed with the Dot task results from domain-general processes that mediate automatic attentional orienting, rather than automatic Theory of Mind processes.

The main aim of the present study was to use a highly simplified version of the Dot task with a group of participants with a unique visual profile, which has provided a way to address questions of nativism vs empiricism (Held et al., 2011; Sinha et al., 2020). As part of Project Prakash (Sinha & Held, 2012; Sinha, 2013), we tested five girls in India ranging in age from 9 to 18 years (mean: 12.4 years), who had been treated for blindness due to dense bilateral congenital cataracts (for details of the factors used to determine congenitality, see Ganesh et al., 2014). Each child underwent cataract removal surgery in recent years and received intraocular lens implants. These children are currently receiving tailored education at a specialized boarding school in Delhi.

The debate around the automaticity of perspective taking has often considered two theoretical possibilities: adults may come to automatically adopt other people's visual perspective through extensive social interaction; alternatively, basic visual perspective taking may be an innate Theory of Mind capacity that can already be observed in infancy (Qureshi et al., 2010; Surtees et al., 2012, 2016; Furlanetto et al., 2016). The Prakash children investigated in this study offer an important test-case of these hypotheses, having gained vision later in childhood. If these children reveal altercentric interference in a simplified version of the Dot task, their performance would suggest 'original automaticity' (i.e. an automatic response that is present from birth; Surtees et al., 2012), since their experience with visual perspective taking was limited during development. It must be noted, however, that while the visual acuity of the Prakash children normally improves significantly after surgery, their vision is often compromised – which could also affect performance in the Dot task, above and beyond their Theory of Mind abilities. The present investigation was therefore conceived as an exploratory study, looking at the development of perspective taking in Prakash children and neurotypical school children. The simplified version of the Dot task employed in our study also offers a basic test of the richest interpretation of the altercentric interference observed with this paradigm; namely, the view that the altercentric bias results from an automatic process that is triggered by the mere presence of another person (Surtees et al., 2012, 2016).

Developmental evidence

Surtees et al. (2012) adapted the Dot task to investigate perspective taking in children aged 6-10 years and adult controls. They argued that developmental work was important to determine whether perspective taking changes as children gain practice and cognitive

resources. Surtees and colleagues predicted that, if the results of Samson et al. (2010) revealed original automaticity, children should also reveal altercentric interference when performing the Dot task from their own perspective. Alternatively, if the automatization of perspective taking requires social experience, children should differ from adults in their perspective-taking skills.

Surtees et al. observed evidence of both egocentric and altercentric interference at all ages. Interestingly, egocentrism did not decline during development, suggesting that improvements in visual perspective-taking in adulthood are not brought about by a reduction in one's egocentric bias. As Surtees et al. argue, "egocentrism in adults does not merely resemble egocentric phenomena observed in children but, for simple perspective taking at least, reflects the same underlying cognitive processes: We cannot help having our own perspective and this interferes with judgments about the perspective of others" (2012:458). In addition, altercentric interference was only observed in their first experiment with an avatar: when Surtees and colleagues changed the avatar for a non-social directional cue in their second experiment, participants performed comparably in congruent and incongruent trials. This difference led the authors to conclude that perspective taking is automatically triggered by the presence of an agent – and not by non-social directional stimuli.

Surtees et al. (2012) used a mixed-trial design, in which children had to change perspectives across trials. Before the avatar and the dot(s) appeared on the screen, children were told how many dots they themselves or the avatar could see (depending on the type of trial), and they had to respond Yes or No according to what they saw in the next slide. A critical challenge to the conclusions of Surtees et al. (2012) is that the children in their study may have had problems ignoring the avatar's perspective in those trials when they had to perform the task from their own perspective, because in other trials, the avatar's perspective was critical. In other words, children may have experienced *perspective-switching costs* that

would not have affected their performance in a different task design. Surtees et al. (2012) ruled out the possibility that their results could be due to a carryover effect across different types of trials because they did not observe the same type of interference when they employed a non-social directional cue in their second experiment. Since both experiments used a mixed-trial design, carryover effects should have been observed in both versions of the task (social and non-social). However, more recent studies with adults have shown that using a block design (where participants do not change perspectives from one trial to the next) reduces the degree of altercentric interference observed.

Ferguson et al. (2017; see also see Surtees et al., 2016) observed that altercentric interference could be reduced, or even eliminated when participants performed the task from their own perspective in consecutive trials. These results seem to contradict the automaticity claims made in other studies with the Dot task (e.g., Surtees et al., 2012, 2016; Furlanetto et al., 2016). However, the authors interpret their results as consistent with the rich interpretation of previous studies because their eye-tracking data revealed different fixation patterns when participants were performing the task from their own perspective and from the avatar's.

While the looking behavior reported by Ferguson and colleagues confirms that the Dot task taps into Theory of Mind processes (with participants distinguishing between their own and the avatar's perspective), the comparable accuracy rates and RTs observed in congruent and incongruent trials when participants could maintain their own perspective across trials strongly suggest that perspective-switching costs are partly responsible for the altercentric interference observed in other studies. This hypothesis was further investigated in the present study.

The question of whether the egocentric and altercentric biases observed with the Dot task result from the Executive Control demands of the task (rather than from automatic Theory of Mind processes) is relevant to a recent review by Quesque and Rossetti (2020), who investigated what Theory of Mind tasks actually measure. These authors argue that most classic tests, including the Dot task, do not require participants to represent another's mental states. Instead, standard tasks measure lower-level processes that do not directly test for Theory of Mind. Quesque and Rossetti (2020) conclude that more attention should be paid to the methods used in Theory of Mind research in order to improve our understanding of the underlying concepts.

The main methodological aim of this study was to simplify the Dot task to make it suitable for Prakash children, and that way be able to test the rich interpretation of previous findings. To that end, we used a block design in which participants were first asked to perform the task from their own perspective, and only in the second half were they asked to perform the task from the agent's perspective. The results of Ferguson et al. (2017) suggest that this block design may eliminate the altercentric interference observed in earlier studies (cf. Surtees et al., 2012). In addition, we wanted to avoid loading children's short-term memory by giving them a number of dots ahead of each display (e.g., 'You see three' or 'He sees three') and asking them to verify that information. Instead, we asked children to directly indicate whether there were one or two dots on the scene (Block 1), or whether the man in the picture could see one or two dots (Block 2). This is an important modification that greatly reduces the working memory demands of the Dot task. Finally, we administered the task four times in order to see whether Prakash children would develop strategies to improve their perspective taking over time.

For a more thorough investigation, the simplified Dot task was administered to five Prakash girls in Experiment 1, and to neurotypical school children (ages 5-10) in Experiment

2 and adult controls in Experiment 3. Sample size in the first experiment was determined by the number of Prakash girls attending the boarding school at the time of testing (N=5), while in the second and third experiments, sample size was established a priori according to previous studies (N=30 per age group). All experiments were conducted in India. All measures, manipulations, and exclusions in the study are disclosed in the experimental report.

Experiment 1

Methods

Participants

Five Prakash girls (ages: 9, 10, 12, 18, 13; M=12.4) were recruited from a boarding school in Delhi (India). They were tested four times, at 4-day intervals during a period of 2 weeks in October 2020. The study was approved by MIT's IRB under protocol "Development of Visual Perception" (\#:0403000050R016). See Table 1 for demographic and clinical information.

Table 1: Demographic and clinical information for the Prakash girls in the study

Participant	Age at surgery	Date of surgery	Type of cataract	Age at testing	PreOp Acuity (in logMAR)	PostOp Acuity (in logMAR)
A	8	Jan-19	Total anterior capsular	9	2.67	6mo: 2.16
B	8	Jan-18	Nuclear	10	1.87	12mo: 1.42
C	11	Jan-19	B/L	12	2.67	6mo: 2.67
D	11	Dec-12	B/L Membranous	18	FC@30cm	Not available
E	12	Jan-19	B/L Membranous	13	1.53	6mo: 1.04

Note: FC = finger counting; B/L = bilateral

Materials, task design and procedure

A series of 6 pictures were taken, showing a man in profile standing between two close walls (see Fig.1 for sample pictures). One or two large red dots were shown on the walls, aligned with the man's head. To facilitate visual perception of the scene, the space depicted in the pictures was considerably narrower than the 3D spaces that were computer-generated in avatar versions of this task. Thus, only the head and shoulders of the man were shown in the pictures (rather than a full body silhouette seen from a distance). The pictures fully counterbalanced the wall that the man was facing (right-left), with two pictures showing one dot in front of the man, two pictures showing two dots in front of the man, and two pictures showing one dot in front and one dot behind the man. In this simplified design, when dots were shown on both walls, the agent's and the participant's perspectives were incongruent; otherwise, they were congruent.

The task was built using jsPsych (de Leeuw, 2015), a JavaScript library. Prior to the start of the task, a series of 20 practice trials were delivered in a random order showing only one or two dots on the walls (i.e. without the man standing in between the walls). Children were asked to press the P and Q keys on their keyboard to indicate one or two dots, respectively. The actual task employed a two-block design, with each block including 40 trials and a pause built in between the two blocks. In the first half of the task, children were asked to indicate how many dots they saw in the picture, as fast and accurately as they could. Then, during the break, they were told that they were going to change perspective: now they had to indicate how many dots the man could see from where he was standing.

Children used their right hand to indicate one dot (letter P on their keyboard) and their left hand to indicate two dots (letter Q on their keyboard). In Block 1, trials showing one dot corresponded with the Congruent condition (i.e. the dot appeared in front of the man), while trials showing two dots corresponded with the Incongruent condition (i.e. one of the dots appeared behind the man). A possible right-hand bias would therefore augment any allocentric interference observed in Block 1 (i.e. slower responses in the Incongruent condition). In Block 2, the correct response in the Congruent condition was 2 (i.e. two dots appeared in front of the man), while the Incongruent condition required responding 1 (i.e. one dot was in front of the man, while a second dot appeared behind). A possible right-hand bias would therefore reduce any egocentric interference observed in Block 2 (i.e. faster responses in the Incongruent condition). The division of keys and responses for each condition therefore favored 'Theory of Mind performance', potentially increasing allocentric interference and reducing egocentric interference in each block. Failing to see such patterns can therefore not be due to a potential right-hand bias.

The task was hosted on Cognition.run (<https://www.cognition.run/>) and administered remotely with the help of an assistant at the boarding school where the Prakash girls are studying. The experimenter contacted the assistant and the participant via Zoom. They were provided a link to the task and were asked to share their screen. Before the practice session started, the assistant ensured that the participant placed their fingers on the correct keys. Audio feedback was given for each practice trial (ringing applause or slightly downbeat sound). Once they completed the 20 practice trials, participants were told that they still had to indicate how many dots were on the screen, but now a man would be standing in between the two walls. In the second block of trials, children were asked to indicate how many dots the man could see using the same two keys. No feedback was given during the two trial blocks.

Results

Run 3 / Block 1 data from Participant E had to be discarded because she was pressing the wrong keys. With the exception of those data, accuracy rates were almost at ceiling in the four runs of the task (Mean percentage of correct responses across participants: 97% (Run 1), 97% (Run 2), 95% (Run 3) and 97% (Run 4)). Accuracy data were therefore not analysed. We interpret the high accuracy rates as evidence that the visual materials and the task were suitable for the Prakash girls in the study.

Group RT analysis

Using linear mixed effects regression, we modelled the outcome variable of RTs (for accurate responses) with Condition (Congruent, Incongruent), Block (Block 1, Block 2), Run (Run 1, Run 2, Run 3, Run 4) and their interactions as predictor variables. Run was entered as a scaled continuous predictor and deviation coding was used for Condition (Congruent=-0.5, Incongruent=0.5) and Block (Block 1=-0.5, Block 2=0.5). The model was fit with the maximal random effect structure for participants and items (Barr et al., 2013).

Descriptive statistics for RTs (in milliseconds) on congruent and incongruent trials split by block and run are shown in Figure 2. The results revealed a marginal main effect of Run ($p=.0602$), with RTs becoming faster across runs (for the full model output, see Table 2).

Figure 2. Average RTs (in milliseconds) on congruent and incongruent trials from Experiment 1, split by block and run.

Table 2 Model output for RTs (collapsed across participants) in Experiment 1

Fixed effect	Coefficient	SE	P-value
Block	-21.2250	100.0340	.8397
Condition	16.6630	151.9270	.9172
Run	-255.4880	99.8520	.0602
Block x Condition	376.7670	228.4650	.1583
Block x Run	51.1470	87.3790	.5832
Condition x Run	-48.2270	100.2010	.6515
Block x Condition x Run	-19.8210	169.5050	.9107

Note: Significant and marginal main effects and interactions are shaded.

Individual RT analyses

The same RT model that was used to analyse the group data was used to analyse each participant's individual data across runs.

Participant A

There was a significant main effect of Run for Participant A ($p=.0025$), who exhibited faster RTs as the runs progressed (for the full model output, see Table 3).

Table 3. Model output for Participant A's RTs in Experiment 1

Fixed effect	Coefficient	SE	P-value
Block	-76.5150	136.0930	.7144
Condition	-224.4290	200.6330	.4785
Run	-488.4900	272.1860	.0025
Block x Condition	550.6390	88.6370	.2130
Block x Run	92.7460	401.2670	.5691
Condition x Run	-66.9670	161.0640	.7208
Block x Condition x Run	-17.5850	322.1280	.9568

Note: Significant and marginal main effects and interactions are shaded.

Participant B

Results revealed no significant main effects or interactions for Participant B (for the full model output, see Table 4).

Table 4. Model output for Participant B's RTs in Experiment 1

Fixed effect	Coefficient	SE	P-value
Block	218.5480	140.0510	.1733
Condition	-43.4200	198.7780	.8435
Run	-142.9430	100.4740	.2667
Block x Condition	12.0690	280.1020	.9671
Block x Run	-192.5690	141.1510	.2259
Condition x Run	124.5690	200.948	.5871
Block x Condition x Run	132.1140	282.302	.6578

Note: Significant and marginal main effects and interactions are shaded.

Participant C

Results revealed a significant main effect of Run for Participant C ($p=.0210$), who exhibited faster RTs as the runs progressed (for the full model output, see Table 5). There was also a significant main effect of Condition ($p=.0155$), with faster RTs in congruent than incongruent trials. Finally, there was a significant Block x Condition interaction ($p=.0196$), driven by a significant difference between congruent and incongruent trials in Block 2 ($p<.001$), but not in Block 1 ($p=.962$) (see Fig. 3).

Table 5. Model output for Participant C's RTs in Experiment 1

Fixed effect	Coefficient	SE	P-value
Block	-201.0520	208.7040	.3363
Condition	508.4300	208.7040	.0155

Run	-487.3840	128.5070	.0210
Block x Condition	980.2960	417.4080	.0196
Block x Run	154.7560	226.1450	.5017
Condition x Run	-323.6130	257.0150	.2796
Block x Condition x Run	-457.3440	452.2910	.3241

Note: Significant and marginal main effects and interactions are shaded.

Figure 3. Average RTs (in milliseconds) on congruent and incongruent trials split by block for Participant C in Experiment 1.

Participant D

Results revealed a trending effect of Block for Participant D ($p=.0970$), who exhibited faster RTs in Block 1 (for the full model output, see Table 6).

Table 6. Model output for Participant D's RTs in Experiment 1

Fixed effect	Coefficient	SE	P-value
Block	106.2870	60.7960	.0970
Condition	-138.1200	63.1320	.1362
Run	-6.1840	29.9520	.8366
Block x Condition	89.8170	121.5920	.4694
Block x Run	-46.3480	59.8900	.4397
Condition x Run	-17.0090	59.9030	.7767
Block x Condition x Run	65.3070	119.7810	.5860

Participant E

Results revealed a significant main effect of Run for Participant E ($p=.0159$), who exhibited faster RTs as the runs progressed (for the full model output, see Table 7). There was also a marginal Block x Run interaction ($p=.0664$), in which the difference between blocks decreased as runs progressed (see Fig. 4).

Table 7. Model output for Participant E's RTs in Experiment 1

Fixed effect	Coefficient	SE	P-value
Block	-153.0600	129.8300	.2395
Condition	-19.7600	129.8300	.8791
Run	-152.8600	62.9800	.0159
Block x Condition	226.2500	259.6600	.3844
Block x Run	232.2200	125.9600	.0644

Condition x Run	4.5900	125.9600	.9710
Block x Condition x Run	181.2500	251.9100	.4725

Note: Significant and marginal main effects and interactions are shaded.

Figure 4. Average RTs (in milliseconds) split by block and run for Participant E in Experiment 1.

Discussion

The high accuracy rates and increasingly faster RTs observed across runs in the group analyses suggest that the visual materials and task design were suitable for the Prakash children in Experiment 1. However, the RT analyses only revealed significant interactions for Participant C, whose performance was comparable in congruent and incongruent trials in Block 1, revealing no altercentric interference when performing the task from her own

perspective. By contrast, Participant C's RTs were significantly slower in incongruent trials than in congruent trials in Block 2, revealing egocentric interference when having to adopt the agent's visual perspective.

Treating these results as case studies, Participant C's performance challenges the view that perspective taking is an innate human ability that operates automatically from infancy (Surtees et al., 2012, 2016). Alternatively, there might be a critical period when infants must be able to visually perceive their social interactions in order to trigger automatic visual perspective taking. Experiment 2 aimed to investigate that possibility by testing neurotypical children between the ages of 5 and 10 years on the same simplified version of the Dot task.

Experiment 2

Methods

Participants

Ninety children were recruited from a primary school in Delhi (India). The school serves middle-class families and teaches Kindergarten to Grade 12 (ages 4-17). Arrangements were made with the School Principal so that the experimenters would contact the teachers in the participating grades, who would in turn contact the parents of the children and set up a 3-way Zoom call. Thirty children were recruited from Grade 1 (5-6 years), thirty from Grade 3 (7-8 years) and thirty from Grade 5 (age 9-10 years).

Materials, task design and procedure

The same materials, task design and procedure used in Experiment 1 were used again in Experiment 2. The task was conducted via Zoom, on a three-way call connecting a schoolteacher, the participating child (with a parent) and the experimenter.

Results

Accuracy analysis

Using logistic mixed effects regression, we modelled the binary outcome variable of Response Accuracy (Correct=1, Incorrect=0) with Condition (Congruent, Incongruent), Block (Block 1, Block 2), Age, and their interactions as predictor variables. Age was entered as a scaled continuous predictor and deviation coding was used for Condition (Congruent=-0.5, Incongruent=0.5) and Block (Block 1=-0.5, Block 2=0.5). The model was fit with the maximal random effect structure for participants and items (Barr et al., 2013).

Descriptive statistics for each age group's accuracy on congruent and incongruent trials split by block are shown in Figure 5.

Figure 5. Mean proportion of accurate responses on congruent and incongruent trials from Experiment 2, split by block and age.

Our results revealed a significant main effect of Age ($p < .001$), in which accuracy improved as age increased (for the full model output, see Table 8). There was also a marginal main effect of Condition ($p = .0501$), in which participants were more accurate on congruent than incongruent trials. Finally, there was a significant interaction of Block x Condition ($p < .001$), driven by a significant difference in congruent and incongruent trials in Block 2 ($p < .001$), but not in Block 1 ($p = .327$) (see Fig. 6).

Table 8. Model output for response accuracy in Experiment 2

Fixed effect	Coefficient	SE	P-value
Block	.0096	.3014	.9747

Condition	-.7419	.3787	.0501
Age	.4115	.1220	.0007
Block x Condition	-2.2037	.5860	.0002
Block x Age	-.0419	.1746	.8102
Condition x Age	.0846	.1608	.5987
Block x Condition x Age	-.0652	.3184	.8376

Note: Significant and marginal main effects and interactions are shaded.

Figure 6. Mean proportion of accurate responses on congruent and incongruent trials from Experiment 2, split by block.

RT analysis

Using linear mixed effects regression, we modelled the outcome variable of RTs (for accurate

responses) with Condition (Congruent, Incongruent), Block (Block 1, Block 2), Age, and their interactions as predictor variables. Age was entered as a scaled continuous predictor and deviation coding was used for Condition (Congruent=-0.5, Incongruent=0.5) and Block (Block 1=-0.5, Block 2=0.5). The model was fit with the maximal random effect structure for participants and items (Barr et al., 2013).

Descriptive statistics for each age group's RTs (in milliseconds) on congruent and incongruent trials split by block are shown in Figure 7.

Figure 7. Average RTs (in milliseconds) on congruent and incongruent trials from Experiment 2, split by block and age.

Our results revealed a significant main effect of Age ($p < .001$), whereby RTs were faster as age increased (for the full model output, see Table 9). There was also a significant main effect of Block ($p < .001$), in which RTs were faster in Block 1. A significant Block x Age interaction ($p = .0181$) revealed that younger children's RTs slowed down considerably in

Block 2, whereas older children's RTs were comparable across blocks (see Fig. 8). We also found a significant Block x Condition interaction ($p=.0261$), which revealed a difference in incongruent trials across blocks ($p<.001$), with slower RTs for incongruent trials in Block 2, but no difference across blocks for congruent trials ($p=.189$) (see Fig. 9). Finally, there was a significant Block x Condition x Age interaction ($p=.0261$), in which younger children's RTs were slightly faster in incongruent than congruent trials in Block 1, but their RTs were faster for congruent trials in Block 2 (see Fig. 10).

Table 9. Model output for RTs in Experiment 2

Fixed effect	Coefficient	SE	P-value
Block	334.8890	73.1140	<.001
Condition	23.2270	75.1690	.7868
Age	-428.2430	79.691	<.001
Block x Condition	310.9750	62.972	.0261
Block x Age	-182.5120	118.693	.0181
Condition x Age	-53.4320	71.619	.5250
Block x Condition x Age	-296.0150	114.671	.0261

Note: Significant and marginal main effects and interactions are shaded.

Figure 8. Block x Age interaction for RTs (in milliseconds) in Experiment 2. Regression lines reflect the best fit of data. The shaded bands around the regression lines represent a 95% confidence region for the regression fit.

Figure 9. Average RTs (in milliseconds) on congruent and incongruent trials from Experiment 2, split by Block.

Figure 10. Block x Age x Condition interaction for RTs (in milliseconds) in Experiment 2. Regression lines reflect the best fit of data. The shaded bands around the regression lines represent a 95% confidence region for the regression fit.

Discussion

Experiment 2 did not reveal evidence of altercentric interference in any of the age groups: children from 5 to 10 years were able to perform the Dot task from their own perspective, without suffering interference from the agent's view. This pattern of results may be explained by our task design, which did not require children to switch perspectives across trials (see also Ferguson et al., 2017; Surtees et al., 2016). It is therefore possible that, by not even mentioning it in the instructions, the agent's visual perspective may not have been salient enough to cause interference in the first half of the task.

While children performed comparably in congruent and incongruent trials in Block 1, RTs were faster in Block 1 than in Block 2, revealing a cost for adopting the agent's perspective in the second half of the task. However, the perspective-taking cost decreased with age, revealing more efficient visual perspective taking in older children. Likewise, the

difference between congruent and incongruent trials was greater in Block 2 than in Block 1, but this difference was also modulated by age: older children suffered less egocentric interference when performing the task from the agent's perspective.

Unlike Surtees et al. (2012), who did not observe a reduction of egocentric interference across ages, our simplified Dot task revealed two developmental patterns. First, by the age of 10, children were able to perform the task from the agent's perspective as efficiently as they had performed the task from their own perspective in the first half of the task. Second, between the ages of 5 and 10, children went from suffering strong egocentric interference in the second half of the task, to performing comparably in congruent and incongruent trials in the two blocks. These results show that a sufficiently simplified version of the Dot task (simpler, at any rate, than the task design used by Surtees et al. (2012) with children of the same age) can reveal development of visual perspective taking in school children.

The question remains, however, as to whether adults would suffer altercentric interference in this version of the Dot task – perhaps because they have automatized perspective taking over years of social interaction, whereas primary school children may not have done so yet. Alternatively, the block design used in this task may reveal that adults do not necessarily suffer altercentric interference in the Dot task, challenging the automaticity view. In addition, it would be interesting to see whether, in a very simple perspective-taking task, adults develop strategies during the course of the task to reduce both altercentric and egocentric biases.

Experiment 3

Methods

Participants

Students at Jawaharlal Nehru University and University of Delhi (India) were contacted via email to take part in an online task for payment. The first 30 volunteers (aged 21-30) were recruited through this method before the link for the task was disabled.

Materials, task design and procedure

The same materials, task design and procedure used in Experiments 1 and 2 were used again with adults in Experiment 3. The only difference was that the task was performed online individually, rather than on a Zoom call with an experimenter.

Results

Accuracy analysis

Using logistic mixed effects regression, we modelled the binary outcome variable of Response Accuracy (Correct=1, Incorrect=0) with Condition (Congruent, Incongruent), Block (Block 1, Block 2) and Trial (1-80), and their interactions as predictor variables. Trial was entered as a scaled continuous predictor and deviation coding was used for Condition (Congruent=-0.5, Incongruent=0.5) and Block (Block 1=-0.5, Block 2=0.5). The model was fit with the maximal random effect structure for participants and items (Barr et al., 2013).

Descriptive statistics are shown in Figure 11, revealing comparable accuracy rates in congruent and incongruent trials in Block 1, and a 12% decrease in incongruent trials, relative to congruent trials, in Block 2.

Figure 11. Mean proportion of accurate responses on congruent and incongruent trials from Experiment 3, split by block.

Model results did not reveal any significant main effects or interactions (for the full model output, see Table 10). Only the Condition x Trial interaction revealed a trend ($p=.0849$), such that accuracy rates decreased in the course of the task for Incongruent trials, while they remained constant for congruent trials (see Fig. 12).

Table 10. Model output for response accuracy in Experiment 3

Fixed effect	Coefficient	SE	P-value
Block	-0.2334	1.6830	.8897
Condition	-0.7058	1.8107	.6967
Trial	2.2745	1.6816	.1762

Block x Condition	-3.6005	3.5621	.3121
Block x Trial	4.9256	3.3381	.1401
Condition x Trial	5.6429	3.2755	.0849
Block x Condition x Trial	9.0777	6.5890	.1683

Figure 12. Trending Condition x Trial interaction for response accuracy in Experiment 3. Regression lines reflect the best fit of data. The shaded bands around the regression lines represent a 95% confidence region for the regression fit.

RT analysis

Using linear mixed effects regression, we modelled the outcome variable of RTs (for accurate responses) with Condition (Congruent, Incongruent), Block (Block 1, Block 2), Trial (1-80), and their interactions as predictor variables. Trial was entered as a scaled continuous predictor and deviation coding was used for Condition (Congruent=-0.5, Incongruent=0.5)

and Block (Block 1=-0.5, Block 2=0.5). The model was fit with the maximal random effect structure for participants and items (Barr et al., 2013).

Descriptive statistics for adults' RTs (in milliseconds) on congruent and incongruent trials are plotted by block in Figure 13.

Figure 13. Average RTs (in milliseconds) on congruent and incongruent trials from Experiment 3, split by block.

Our results revealed a significant main effect of Block ($p < .001$), whereby RTs were faster in Block 1 than in Block 2 (for the full model output, see Table 11). There was also a significant main effect of Trial ($p < .001$), such that RTs became faster as the task progressed. Finally, the Block x Condition x Trial interaction revealed a trend ($p = .0962$), such that RTs in congruent trials became comparably faster across Block 1 and Block 2, whereas a difference was observed in incongruent trials across the two blocks. More specifically, RTs in incongruent trials were initially slower in Block 2 than in Block 1 but became comparably

faster by the end of the second block (see Fig. 14).

Table 11. Model output for RTs in Experiment 3

Fixed effect	Coefficient	SE	P-value
Block	876.02	96.59	<.001
Condition	56.44	47.35	.2519
Trial	-432.21	50.80	<.001
Block x Condition	109.55	84.70	.2003
Block x Trial	-78.81	59.08	.1922
Condition x Trial	-40.55	39.32	.3034
Block x Condition x Trial	-136.06	81.17	.0962

Note: Significant and marginal main effects and interactions are shaded.

Figure 14. Trending Block x Condition x Trial interaction for RTs (in milliseconds) in Experiment 3. Regression lines reflect the best fit of data. The shaded bands around the regression lines represent a 95% confidence region for the regression fit.

Discussion

Adults in this highly simplified version of the Dot task did not reveal either altercentric interference (Block 1) or egocentric interference (Block 2). However, RTs were slower in Block 2 than in Block 1, suggesting that performing the task from the agent's perspective was cognitively costly. There was also a potential trade-off effect between accuracy and speed of response in incongruent trials, such that accuracy decreased during the task in incongruent trials, while RTs became faster. As for evidence of adults developing strategies during the task, a trending 3-way interaction showed that, in incongruent trials, RTs were initially slower at the start of Block 2 than Block 1, but participants became comparably efficient by the end of the task. This pattern of results tentatively suggests that adult participants were able to overcome any egocentric interference they might have suffered at the start of the second block.

Overall, the results of Experiment 3 suggest that, while performing the Dot task from the agent's perspective may come at a cost, when the task design is sufficiently simplified (with the two conditions administered in separate blocks and no working memory load), adults do not show evidence of either altercentric or egocentric interference.

General discussion

Previous studies with the Dot task have revealed both altercentric and egocentric biases: participants suffered interference from the avatar's view when performing the task from their

own perspective, while their own view compromised their visual perspective taking when attempting the task from the avatar's view. Here we used a highly simplified version of the Dot task that employed a block design (where participants first performed the task from their own perspective, and only had to adopt the agent's perspective in the second half) with only two direct responses (1 or 2 dots) in order to adapt the task for newly sighted children. Unlike previous studies, we did not observe evidence of altercentric interference in any of the groups: Prakash children (Experiment 1), neurotypical children between the ages of 5 and 10 years (Experiment 2) and adults (Experiment 3) all performed the task from their own perspective without suffering interference from the agent's view. These findings suggest that previous evidence of altercentric interference may have resulted from employing a mixed-trial design, in which participants had to switch perspectives from one trial to the next. While altercentric interference has been observed with other designs (see Samson et al., 2010; Surtees et al., 2016), most Dot tasks required participants to switch perspectives across trials. Our results are in line with a recent study by Ferguson et al. (2017), who observed that altercentric interference was reduced or even disappeared when participants could maintain their own perspective across trials.

While participants in our study did not suffer altercentric interference in the first block of trials, they revealed longer RTs in the second block (Experiments 2 and 3), suggesting that visual perspective taking is cognitively costly, even in a highly simplified task. In addition, one of the Prakash girls in Experiment 1 revealed an egocentric bias in the second block, with longer RTs in incongruent than congruent trials. This pattern of results is consistent with the developmental findings from Experiment 2: children ages 5-10 showed both lower accuracy rates and longer RTs in incongruent than in congruent trials in the second half of the task. In addition, 5-year-olds showed evidence of egocentric interference, revealing longer RTs in incongruent trials but only when adopting the agent's perspective in the second block of

trials. These findings replicate two broad patterns of results observed in previous studies with the Dot task (see Qureshi et al., 2010; Nielsen et al., 2015; Ferguson et al., 2017, 2018; Furlanetto et al., 2016; Simpson et al., 2017): adopting someone else's visual perspective is more taxing than relying on one's own view, and the egocentric bias is normally stronger than the altercentric bias. Replicating these robust patterns confirm the validity of our simplified Dot task.

Unlike Surtees et al. (2012), who report comparable levels of egocentricity in children 6-10 years and adults, here we observed two developmental patterns: first, the longer RTs observed in the second block relative to the first one were modulated by age, with older children performing more efficiently in the second half of the task than younger children. Second, the egocentric bias observed in a Prakash girl in Experiment 1 and the 5-year-olds in Experiment 2 decreased during development, with the 10-year-olds in Experiment 2 and the adults in Experiment 3 not showing evidence of an egocentric bias. Contrary to Surtees et al.'s conclusions, these results suggest that visual perspective taking develops during childhood, with the characteristic egocentric bias of the early years diminishing over time (Piaget & Inhelder, 1956). These developmental patterns speak to the value of using a simplified design, rather than employing cognitively taxing versions of the Dot task that may mask Theory of Mind development.

Issues of experimental design and ecological validity

The results of our study may be questioned on the grounds that the design of our Dot task was so simple that all participants were able to overcome their altercentric bias (which is normally weaker), while older participants were even able to overcome their egocentric bias (which is

normally stronger). This interpretation of our findings rests on the assumption that the original design of the Dot task taps an automatic process of perspective taking.

In earlier studies, participants were given a perspective plus a number of dots (e.g., ‘You see two’ or ‘He sees three’) and had to verify that information in the ensuing display. By contrast, our participants did not have to switch perspectives across trials and could respond with the actual number of dots that they themselves saw or the agent could see. We readily acknowledge that this is a much simpler experimental design that may have allowed our participants to overcome both their altercentric and egocentric biases, if they had any. However, assuming that was the case, our results raise an important question about the ecological validity of the standard Dot task: in what everyday circumstances do people suffer altercentric interference from others’ perspectives?

Given the results of previous studies, the automatic perspective taking observed in the Dot task requires participants to switch between their own perspective and the avatar’s across trials, while verifying in each trial a description stored in short-term memory. If perspective switching and memory load are ‘methodological requirements’ for observing automatic perspective taking in children and adults (with participants not revealing altercentric interference in simpler tasks), the implications of this automatic process for everyday life seem rather moot. Or to put it differently: the ecological validity of the standard Dot task as a test of automatic perspective taking needs to be examined more closely.

In the simplified task used in this study, children and adults had to count or subitize the number of dots on a screen, either from their own perspective or from the man’s in the picture. Counting or subitizing is a much more common activity in everyday life than bearing in mind a certain description and verifying it against a visual display (which is the procedure of the standard Dot task). Therefore, even if we assume that the standard design taps an

automatic Theory of Mind process, it is questionable whether and when people engage in such a process in their everyday lives. On the other hand, our results confirm that counting or subitizing can be done without interference from another's perspective (at least in a low range between 1 and 2 dots). Importantly, our results also confirm that counting or subitizing from another's perspective is cognitively costly, with this egocentric bias decreasing with age in a simplified design. In conclusion, if children and adults only suffer altercentric interference when performing perspective-taking tasks with high switching and memory costs, the automaticity of perspective taking in everyday life seems rather limited.

What do Theory of Mind tasks actually measure?

We are echoing here the title of Quesque and Rossetti's (2020) review. In line with their conclusions, our results raise an important issue in Theory of Mind research; namely, the general tendency to overinterpret both children's and adults' performance as evidence of their social cognition skills, without a parallel assessment of the Executive Control demands of the task. This is a particularly problematic issue in Theory of Mind research because tasks in this field tend to contrast two different perspectives (e.g., the participant's and the avatar's in the Dot task), hence requiring not only social cognition skills, but also Executive Control (see Perner & Lang, 1999).

In the previous discussion, we assumed that the standard Dot task taps an automatic process of perspective taking (albeit one with low ecological validity). Here we will explore the alternative possibility that the altercentric interference observed with the Dot task reflects an Executive Control failure, rather than automatic Theory of Mind. Under this view, the altercentric interference that some have interpreted as evidence of automatic perspective taking in humans may result from perspective-switching costs. Compatible with this

interpretation, our results suggest that when the avatar's view is not made salient by intermixing perspective-taking trials in the task, it may not cause interference when participants perform the task from their own view (see also Ferguson et al., 2017; cf. Samson et al., 2010). Our results therefore disconfirm a rich interpretation of the results of the Dot task: the mere presence of another agent does not automatically trigger altercentric interference (cf. Surtees et al., 2016).

In the case of the classic false-belief task, children have to predict where a protagonist will look for an object that has been transferred to a new location while the protagonist was away (Baron-Cohen et al., 1985; Wellman, 2014). Children under 4 years tend to fail this task, predicting that the mistaken protagonist will search in the new location. This pattern of results has been interpreted as evidence that preschoolers acquire a Theory of Mind around age 4 (Rakoczy, 2017). However, like the standard Dot task, false-belief tasks pose Executive Control demands that may compromise young children's performance. For example, the standard test question 'Where will Sally look for her doll?' draws children's attention to the current location of the doll, increasing the salience of the wrong response (for eye-tracking evidence with adults, see Rubio-Fernandez, 2013). When children are asked a more neutral question (e.g., 'Where will Sally go now?'), 3 year olds are able to pass the false-belief task (Rubio-Fernandez & Geurts, 2013, 2016; although their performance may not reveal mental state attribution, see Rubio-Fernandez, 2019).

Another Theory of Mind task that has revealed an egocentric bias is the so-called *Director task* (Keysar et al., 2000, 2003). In this paradigm, participants need to take the speaker's visual perspective in order to disambiguate their requests (e.g., 'Move the small candle'), having to avoid interference from objects that are only visible to the participants (e.g., the smallest candle, which would be hidden from the speaker). Given the initial confusion that participants can experience in this task (which sometimes leads them to pick

up the hidden object), some researchers have argued that people only use their Theory of Mind as a correction mechanism, often communicating from an egocentric perspective (Keysar et al., 2000; Apperly & Butterfill, 2009; cf. Nadig & Sedivy, 2002; Hannah et al., 2003).

However, as in the case of the Dot task and the classic false-belief task, the Director task also poses heavy demands on participants' Executive Control. In particular, this paradigm rests on the highly artificial assumption that the speaker only knows about the objects they can see, and cannot refer to objects outside their visual field – a situation that very rarely applies in real life where we often talk about unseen objects. When the task is modified to avoid this unnatural assumption, people reveal sophisticated use of their Theory of Mind in the Director task (Rubio-Fernandez, 2017; Rubio-Fernandez & Jara-Ettinger, 2018, under review).

In summary, our results are compatible with an interpretation of the Dot task where the alleged evidence of involuntary visual perspective taking reveals, in fact, perspective-switching costs, rather than automatic Theory of Mind processes triggered by the mere presence of an agent. This lean interpretation of the Dot task supports Quesque and Rossetti's (2020) conclusion that the experimental methods employed in standard Theory of Mind tests need to be more closely examined in order to better understand their results.

Summary and conclusions

The three groups tested in our study with a highly simplified version of the Dot task – namely, newly sighted children, 5-10-year-old school children and adults, all showed evidence of perspective-taking costs in the second half of the task, but did not suffer altercentric interference when performing the task from their own perspective in the first half.

In addition, one of the newly sighted girls and the youngest children in our pool suffered from an egocentric bias that disappeared by age 9-10. Our results therefore suggest that visual perspective taking develops during childhood, probably supported by increasing experience with social interaction and the maturation of Executive Control.

For more than a decade, the results of the Dot task have been interpreted as evidence of automatic Theory of Mind. Under this rich interpretation, our results undermine the ecological validity of the standard task because observing these automatic processes seems to require additional switching costs and memory load (which do not characterize everyday situations of perspective taking). Under a lean interpretation, the altercentric interference observed with the Dot task results from perspective-switching costs and memory load, rather than automatic Theory of Mind processes. In conclusion, the results of our study undermine the rich interpretation of the Dot task, questioning the validity of this task as a direct test of Theory of Mind.

Acknowledgements

This research was supported by a FRIPRO grant (#275505) from the Research Council of Norway awarded to PRF, and by grant R01 EY020517 from NEI (NIH) awarded to PS. The authors gratefully acknowledge this funding.

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