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The Goal-Dependence of Level-1 *and* Level-2 Visual Perspective Calculation

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Does tracking another agent's visual perspective depend on having a goal—albeit a remote one—to do so? In 5 experiments using indirect measures of visual perspective taking with a cartoon avatar, we examined whether and how adult perceivers' processing goals shape the incidental tracking of *what* objects the avatar sees (Level-1 perspective taking) and *how* the avatar sees those objects (Level-2 perspective taking). Process dissociation analyses, which aim to isolate calculation of the avatar's perspective as the process of focal interest, revealed that both Level-1 and Level-2 perspective calculation were consistently weaker when the avatar's perspective was less relevant for participants' own processing goals. This pattern of goal-dependent perspective tracking was also evident in behavioral analyses of interference from the avatar's differing perspective when reporting one's own perspective (i.e., altercentric interference). These results suggest that, although Level-1 and Level-2 visual perspective calculation may operate unintentionally, both also appear to depend on perceivers' processing goals. More generally, these findings advance understanding of processes underlying visual perspective taking and the conditional automaticity with which those processes operate.

Keywords: automaticity, implicit mentalizing, perspective taking, process dissociation, theory of mind

Supplemental materials: http://dx.doi.org/10.1037/xlm0000973.supp

People routinely ascribe mental states to themselves and others. This capacity—variously labeled mentalizing, mindreading, perspective taking, and theory of mind—is crucial for communicating effectively and for coordinating one's own actions with those of other people. Although such mindreading activities have long been thought to require effort and deliberation (Epley, Keysar, Van Boven, & Gilovich, 2004), recent evidence suggests that people track other agents' views of the world without intending to do so (Schneider, Slaughter, & Dux, 2017; Scott & Baillargeon, 2017). One domain of so-called "implicit mentalizing" that has recently garnered attention involves the calculation of *what* other agents see and *how* they see it—Level-1 and Level-2 perspective taking, respectively (Flavell, 1977). With the development of indirect measurement procedures, evidence for the incidental tracking of others' visuospatial perspectives has steadily accumulated (e.g., Elekes, Varga, & Király, 2016; Freundlieb, Kovács, & Sebanz, 2016; Samson, Apperly, Braithwaite, Andrews, & Bodley Scott, 2010; Surtees, Apperly, & Samson, 2016; Tversky & Hard, 2009; Ward, Ganis, & Bach, 2019).

Consider, for example, a set of Level-1 and Level-2 visual perspective-taking (hereafter, L1-VPT and L2-VPT) tasks developed by Surtees, Samson, and Apperly (2016) in which participants view a three-dimensional room with a cartoon avatar standing next to a table. In the L1-VPT version of the task, which was modeled on a task introduced by Samson et al. (2010), a varying number of balloons float in the room. On some trials, participants and the avatar can see the same number of balloons; on other trials, the number of balloons the avatar can see differs from the number of balloons participants can see. The L2-VPT version of the task, which was modeled on a task introduced by Surtees, Butterfill, and Apperly (2012), is structurally identical to the L1-VPT task. Instead of balloons floating in the room, however, a numeral (6 or 9) appears on the table. On some trials, the numeral stands upright on the table and thus looks identical to the avatar and to participants

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(e.g., both see a 6); on other trials, the numeral lies flat on the table and thus looks different from avatar and self-perspectives (e.g., the avatar sees a 6, but participants see a 9). Of particular interest in both tasks are trials in which participants must verify their own perspective. Behavioral analyses of such self-perspective trials commonly reveal *altercentric-interference* effects: Verifying both the number of balloons in the room (in the L1-VPT task) and the identity of the numeral on the table (in the L2-VPT task) is more difficult (operationalized as slower correct responses or more errors) when the avatar's perspective conflicts with one's own perspective than when self and avatar perspectives are aligned.

Because participants' overt processing goal on the self-perspective trials in these tasks is to verify how many balloons they see or the identity of the numeral as they see it, any incidental tracking of the avatar's perspective should hinder this objective. For this reason, altercentric-interference effects have commonly been interpreted as reflecting the spontaneous, or unintentional, calculation of the avatar's visual perspective (e.g., Elekes et al., 2016; Smith & Mackie, 2016; Todd & Simpson, 2016). Note, however, that *unintentional* need not imply *goal-independent* (Bargh, 1989; Moors & De Houwer, 2006). It is possible, for example, that contextual factors (e.g., structural features of the tasks) inadvertently trigger in participants a *remote*, or distal, goal to process the avatar's perspective, despite participants' having a *proximal* task goal simply to report only their own perspective.

Here, we examined whether and how participants' more remote processing goals during these tasks shape their calculation of Level-1 and Level-2 visual perspectives. We note that some prior work has discussed perspective *calculation* (sometimes labeled *computation*) alongside perspective *selection*, with perspective calculation reflecting a process of registering the contents of both self and avatar perspectives and perspective selection reflecting a process of choosing between the two perspectives (e.g., Qureshi, Apperly, & Samson, 2010; Ramsey, Hansen, Apperly, & Samson, 2013; Samson et al., 2010). Our focus, by contrast, was specifically on calculation of the avatar's perspective (see Todd, Cameron, & Simpson, 2017; Todd, Simpson, & Cameron, 2019, for similar treatments of perspective calculation) and its potential dependence on participants' processing goals. We used a combination of behavioral analyses of altercentric interference and process analyses that isolate avatar-perspective calculation as the process of focal interest underlying altercentric-interference effects in L1-VPT and L2-VPT tasks. Our aim was to shed light on the automaticity with which the process of calculating other agents' visual perspectives operates.

Features of Automaticity and Visual Perspective Calculation

Approaches to the study of automaticity of mental phenomena abound (see Moors & De Houwer, 2006, for a review). Here, we adopt a decompositional, feature-based approach (Bargh, 1989, 1992, 1994; Moors & De Houwer, 2006) to the automaticity of visual perspective calculation. This approach holds that the operation of any behavioral effect or psychological process can be described vis-à-vis a set of conceptually separable features, including (*un*)*intentional*, (*in*)*efficient*, (*un*)*aware*, and (*un*)*controllable*. On this view, it is incomplete, and even misleading, to characterize a process like perspective calculation as either automatic or non-automatic without specifying in what way(s) it is automatic. Furthermore, because these automaticity features often do not co-occur (Bargh, 1989, 1992, 1994; Melnikoff & Bargh, 2018), it is problematic to assume that the presence of one feature (e.g., efficient) necessitates the presence of other features (e.g., unintentional). A more informative strategy is to identify which, if any, features of automaticity a process exhibits by testing the conditions under which it operates (e.g., determining the efficiency of a process by testing whether it is affected by time pressure or by concurrently performing a resource-consuming secondary task; Gawronski, Sherman, & Trope, 2014; Sherman, Krieglmeyer, & Calanchini, 2014).

Tracking whether or not an object is visible to another agent in L1-VPT entails tracing a line of sight between the agent and the object, whereas tracking how an object appears to another agent (i.e., the object's identity) or the object's location in relation to the agent (i.e., to the agent's left or right) in L2-VPT entails mentally rotating oneself into the agent's position (Kessler & Rutherford, 2010; Kessler & Thomson, 2010; Michelon & Zacks, 2006; Surtees, Apperly, & Samson, 2013a, 2013b). The so-called "two-systems" account of mindreading (Apperly & Butterfill, 2009; Butterfill & Apperly, 2013; Low, Apperly, Butterfill, & Rakoczy, 2016) offers some general predictions about the automaticity with which these different processes operate. According to this account, perspective tracking in L1-VPT should operate efficiently and "independently of a participant's task or motives" (Low et al., 2016, p. 185). Perspective tracking in L2-VPT, by contrast, should operate less efficiently and should depend more heavily on a perceiver's processing goals.

Several recent studies have tacitly, if not explicitly, embraced the feature-based approach to automaticity in testing these predictions of the two-systems account. For example, in a study of the efficiency of perspective calculation, Todd et al. (2019) constrained participants' processing opportunity by imposing a shortened response deadline in some conditions. Time pressure weakened perspective calculation, but only in L2-VPT; the effect of time pressure in L1-VPT was negligible (see also Todd et al., 2017). These results, which support predictions of the two-systems account, suggest that Level-2 perspective calculation may require sufficient processing opportunity, whereas Level-1 perspective calculation appears to be efficient (see Qureshi et al., 2010, for evidence on the efficiency of L1-VPT using a dual-task paradigm; but see Qureshi & Monk, 2018, for more mixed evidence).

More relevant for the current work are studies investigating the unintentional operation of visual perspective calculation. As noted earlier, altercentric interference in visual perspective-taking tasks is often described as unintentional because its presence suggests that participants are incidentally processing the avatar's perspective despite having an overt task goal on self-perspective trials of simply verifying their own perspective (see Uleman, 1999). It is important to note, however, that the typical procedure in these tasks also includes trials in which participants must explicitly verify the avatar's perspective, and these avatar-perspective trials are commonly intermixed with the self-perspective trials. The upshot of this procedure is that it arguably triggers within participants a remote/distal goal to process the avatar's perspective on the self-perspective trials. It is plausible that this secondary goal operates alongside participants' primary goal to report their own perspective. In this way, processing of the avatar's perspective on the self-perspective trials can be an unintended side effect of having recently processed the avatar's perspective in an intentional, goal-directed manner (on the avatar-perspective trials) and can thus be described as unintentional but goal-dependent (see Bargh, 1989, pp. 20–24; Moors & De Houwer, 2006, pp. 303–305, for in-depth discussions of unintentional goal-dependent automaticity; see Pincham & Szűcs, 2012; Uleman & Moskowitz, 1994, for empirical examples of the goal-dependent automaticity of subitizing and trait inference, respectively).

If calculation of the avatar's perspective is indeed unintentional but goal-dependent, then altercentric interference should be especially strong (and potentially only evident) when the avatar-perspective trials are intermixed with or appear prior to the self-perspective trials. In such cases, participants' task goal of processing the avatar's perspective on the avatar-perspective trials is operating in close temporal proximity to and may bleed into their task goal of reporting their own perspective on the self-perspective trials. In cases where the self-perspective trials appear separately from or prior to the avatar-perspective trials, it should be easier for participants to pursue their focal task goal of reporting their own perspective without interference from the avatar's perspective (see Conway, Lee, Ojaghi, Catmur, & Bird, 2017; Samson et al., 2010; Santiesteban, Catmur, Hopkins, Bird, & Heyes, 2014; Schurz et al., 2015, for similar reasoning).

In a recent test of the unintentional goal-dependent automaticity of perspective calculation, Surtees, Samson, et al. (2016) systematically varied the presentation of self-perspective trials and avatar-perspective trials in L1-VPT and L2-VPT tasks. One condition followed the typical procedure: In this mixed-blocking condition, the self-perspective trials and avatar-perspective trials were intermixed within the same blocks of trials (see also Conway et al., 2017, Experiment 3; Samson et al., 2010, Experiment 1), thus making the avatar's perspective (remotely) goal-relevant for participants throughout the task. Another condition altered the typical procedure: In this separate-blocking condition, the self-perspective trials and avatar-perspective trials appeared in separate blocks of trials (see also Conway et al., 2017, Experiment 2; Samson et al., 2010, Experiment 2), thus making it easier for participants to disregard the avatar's perspective while deliberately pursuing a focal task goal of verifying their own perspective on the self-perspective trials. Calculation of the avatar's perspective, as indexed by altercentric interference, was weaker in the separate-blocking condition (i.e., when the avatar's perspective was less task goal-relevant). Importantly, and consistent with predictions of the two-systems account, this effect of the blocking manipulation on altercentric interference was only evident in L2-VPT. In L1-VPT, the blocking manipulation did not significantly affect altercentric interference (see also Conway et al., 2017).[1] These results suggest that avatar-perspective calculation in L2-VPT may be dependent on having a remote task goal to process the avatar's perspective, whereas avatar-perspective calculation in L2-VPT may be less dependent on processing goals during the task.

On their face, Todd et al.'s (2019) and Surtees, Samson, et al. (2016) findings support the two-systems account's predictions about the differential automaticity of perspective calculation in L1-VPT versus L2-VPT. Note, however, that such a conclusion hinges on an interpretation of altercentric interference as providing a "process-pure" index of perspective calculation. This interpretation is questionable for several reasons. First, equating altercentric interference (the behavioral effect to be explained) with perspective calculation (the putative process that explains the effect) runs the risk of explanatory circularity (Gawronski & Bodenhausen, 2015). Second, altercentric interference, like any behavioral effect, emerges from the interplay of multiple, potentially conflicting processes (Jacoby, 1991). Thus, claims about perspective calculation require isolating this process and estimating its unique contribution to task performance (Payne & Cameron, 2014). Furthermore, claims about the automaticity of perspective calculation, like claims about the automaticity of any process, are empirical claims that require examining the conditions under which it operates (Gawronski et al., 2014; Sherman et al., 2014).

Isolating Perspective Calculation via Process Dissociation

The process dissociation procedure (PDP; Jacoby, 1991) is a valuable analytical tool for distinguishing between processes underlying behavior on a single task. The PDP specifies a priori how different processes interact to drive task performance; it uses behavior—specifically, proportions of correct responses and errors—to estimate the probability that each process is operating. One strength of the PDP is its flexibility in quantifying processes underlying task behavior in any content domain. Originally developed for use with memory tasks (Jacoby, 1991), variants of the PDP (and other multinomial modeling approaches) have been applied to numerous other behavioral tasks in cognitive and social psychology, including tasks assessing racial stereotyping (Payne, 2001; Todd, Thiem, & Neel, 2016), attributional inference (McCarthy & Skowronski, 2011; Shimizu, Lee, & Uleman, 2017), moral judgment (Conway & Gawronski, 2013; Muda, Niszczota, Białek, & Conway, 2018), empathy for pain (Cameron, Spring, & Todd, 2017; Spring, Cameron, McKee, & Todd, 2019), and, most pertinent here, visual perspective taking (Qureshi & Monk, 2018; Todd et al., 2017).

The PDP proceeds from the assumptions that (a) multiple processes contribute to task behavior and (b) these processes can be dissociated by creating conditions that place them in concert and in opposition (Jacoby, 1991). Applying the logic of the PDP framework to altercentric-interference effects in L1-VPT and L2-VPT, on "consistent" self-perspective trials in which the content of self and avatar perspectives is the same (e.g., participants and the avatar both see two balloons/the numeral 6), accurately reporting one's own perspective (self-perspective *detection*) and incidentally tracking the avatar's perspective (avatar-perspective *calcula-*

[1] In a between-experiments comparison, Samson et al. (2010) also found negligible differences in altercentric interference in L1-VPT based on whether self-perspective trials and avatar-perspective trials were intermixed in the same blocks of trials (Experiment 1) or appeared in separate blocks of trials (Experiment 2).

tion[2,3]) lead to the same behavioral response. The probability of responding correctly on these trials is the probability of accurately reporting one's own perspective (self-perspective detection) plus the probability of tracking the avatar's perspective (avatar-perspective calculation) when self-perspective detection fails (1 – self-perspective detection):

$$p(\text{correct} \mid \text{consistent self-perspective trails}) = \text{self-perspective detection} + [\text{avatar-perspective calculation} \times (1 - \text{self-perspective detection})] \quad (1)$$

On "inconsistent" self-perspective trials in which the content of self and avatar perspectives differs (e.g., participants see two balloons/the numeral 6, but the avatar sees one balloon/the numeral 9), incidentally tracking the avatar's perspective and accurately reporting one's own perspective lead to different responses. The probability of responding incorrectly on these trials is the probability of tracking the avatar's perspective (avatar-perspective calculation) when self-perspective detection fails (1 – self-perspective detection):

$$p(\text{incorrect} \mid \text{inconsistent self-perspective trails}) = \text{avatar-perspective calculation} \times (1 - \text{self-perspective detection}) \quad (2)$$

With these two equations, it is possible to solve algebraically for separate estimates of self-perspective detection and avatar-perspective calculation:

$$\text{Self-perspective detection} = p(\text{correct} \mid \text{consistent self-perspective trails}) - p(\text{incorrect} \mid \text{inconsistent self-perspective trails} \quad (3)$$

$$\text{Avatar-perspective calculation} = p(\text{incorrect} \mid \text{inconsistent self-perspective trails}) / (1 - \text{self-perspective detection} \quad (4)$$

Thus, self-perspective detection reflects the accurate, task goal-consistent reporting of whether the numerical content cue matches the visual content in the room from one's own perspective. Avatar-perspective calculation, by contrast, reflects the biasing influence of the avatar's differing perspective,[4] despite having an overt task goal to report one's own perspective. This latter process of avatar-perspective calculation is of focal interest in research that treats altercentric interference as a proxy for "implicit mentalizing" (Qureshi & Monk, 2018; Simpson & Todd, 2017; Todd et al., 2017, 2019).

Revisiting the Goal-Dependence of Perspective Calculation

Our aim here was to revisit the goal-dependence of Level-1 and Level-2 visual perspective calculation through the lens of the PDP framework. Recall that Surtees et al.'s (2016) altercentric-interference findings suggested that calculation of the avatar's perspective depends on participants' processing goals in L2-VPT, whereas this process operates independently of participants' processing goals in L1-VPT. Before describing our experiments, it is useful to ask what value, if any, PDP analyses might provide above and beyond conventional behavioral analyses. By equating altercentric interference (a behavioral effect) with avatar-perspective calculation (the process of focal interest), this approach fails to recognize that at least two processes contribute to this behavioral effect, and that these processes may have opposing influences on task behavior. For example, the presence of altercentric interference could reflect high sensitivity to the avatar's conflicting perspective, low ability to detect one's own perspective, or some combination of the two. Similarly, the absence of altercentric interference could result from a combination of different processes (e.g., moderate sensitivity to the avatar's conflicting perspective that is overshadowed by high ability to detect one's own perspective). Without isolating avatar-perspective calculation from self-perspective detection, meaningful variation in the process of focal interest may go underdetected, potentially leading to an incomplete, or even inaccurate, understanding of its operating conditions.

To illustrate, consider Todd et al.'s (2019) research on the efficiency of perspective calculation in L1-VPT versus L2-VPT described earlier. PDP analyses revealed that time pressure weakened avatar-perspective calculation in L2-VPT, but not in L1-VPT,[5] suggesting that perspective calculation is a more efficient process in L1-VPT than in L2-VPT. Behavioral analyses, by contrast, indicated that time pressure did *not* significantly decrease altercentric interference in either task. This divergence in results across levels of analysis is noteworthy for both methodological and theoretical reasons: If Todd et al. (2019) had restricted their analyses to altercentric interference as a behavioral effect, as is customary in research on visual perspective taking, their conclusions about the efficiency of Level-1 and Level-2 perspective calculation (i.e., that both are efficient) would have been very different.

Applying this lesson to research on the goal-dependence of perspective calculation in L1-VPT and L2-VPT (Surtees, Samson, et al., 2016), it is possible that meaningful variation in Level-1 perspective calculation based on the blocking manipulation went

[2] Conceptual analogs of the self-perspective detection and avatar-perspective calculation parameters in other variants of the PDP have been variously labeled "intentional" and "automatic" (Jacoby, 1991), "controlled" and "automatic" (Payne, 2001), and "intentional" and "unintentional" (Cameron, Spring, & Todd, 2017), respectively. Such labels reflect operating conditions, or empirical claims about when each process operates (e.g., Is the process of calculating the avatar's perspective dependent on perceivers' task goals?). Following Todd et al. (2019), we use labels reflecting operating principles, or definitions of what each process does (e.g., "calculating" the avatar's perspective, "detecting" one's own perspective).

[3] We do not claim that this PDP parameter is the only valid operationalization of a perspective calculation process (for other operationalizations, see Ferguson, Brunsdon, & Bradford, 2018; McCleery, Surtees, Graham, Richards, & Apperly, 2011). In addition and as noted earlier, our approach departs from earlier work that discusses perspective calculation as entailing the registration of both self and avatar perspectives (e.g., Qureshi et al., 2010; Ramsey et al., 2013; Samson et al., 2010). Here, we focus specifically on calculation of the avatar's perspective.

[4] Characterizing this process parameter in this way clearly favors a mentalizing over a submentalizing interpretation of altercentric-interference effects (see Heyes, 2014). We return to this issue in the General Discussion.

[5] A likely explanation for this divergence is that time pressure also weakened self-perspective detection in both L1-VPT and L2-VPT, and this large reduction in self-perspective detection appears to have overshadowed the more modest reduction in avatar-perspective calculation.

underdetected in the behavioral analyses of altercentric interference. Alternatively, it is possible that presenting the self-perspective trials separately from the avatar-perspective trials altered the ability to detect one's own perspective in L2-VPT, while leaving sensitivity to the avatar's differing perspective unchanged. By isolating avatar-perspective calculation as the core process of interest in these tasks, the PDP framework affords more precise empirical tests of theoretical claims about the goal-dependence of Level-1 and Level-2 visual perspective calculation.

Overview of Experiments

We report five experiments investigating the goal-dependence of perspective calculation in indirect measures of L1-VPT and L2-VPT. Both tasks were adapted from Surtees, Samson, et al. (2016; see also Todd et al., 2019). In the L1-VPT task, participants verified whether a numerical cue matched the number of balloons floating in a virtual room, according to either a cartoon avatar's perspective or participants' own perspective. In the L2-VPT task, participants verified whether a numerical cue matched the identity of a numeral on a table in a virtual room, again according to either a cartoon avatar's perspective or participants' own perspective. Included within both tasks were trials in which the avatar's perspective and participants' own perspective were in unison (e.g., participants and the avatar both see two balloons/the numeral 6) and trials in which the avatar's perspective and participants' own perspective were in conflict (e.g., participants see two balloons/the numeral 6, but the avatar sees one balloon/the numeral 9).

We examined goal-dependence by varying the relevance of the avatar's perspective for participants' processing goal during the tasks (or during specific blocks of trials in the tasks). Experiment 1 was a replication of Surtees, Samson, et al. (2016, Experiment 1). Participants completed either the L1-VPT task or the L2-VPT task. Also, in one condition, the avatar-perspective trials and self-perspective trials were intermixed within the same blocks of trials, making the avatar's perspective goal-relevant throughout the task. In another condition, the avatar-perspective trials and self-perspective trials appeared in separate blocks of trials, making the avatar's perspective less goal-relevant in trial blocks in which only self-perspective trials appeared.

In Experiments 2 and 3, the avatar-perspective trials and self-perspective trials always appeared in separate trial blocks. In one condition, the avatar-perspective trials appeared before the self-perspective trials, making the avatar's perspective goal-relevant for participants prior to their completing the self-perspective trials. In another condition, the self-perspective trials appeared first, and thus the avatar's perspective was not yet relevant for participants' task goal prior to their completing these trials.

In Experiment 4, participants completed an L2-VPT task in which either the avatar-perspective trials or the self-perspective trials appeared first, as in Experiments 2 and 3. In addition, whereas Experiments 1–3 used a shortened response deadline to increase error rate variability and thus afford more powerful PDP analyses (as is customary in research using the PDP; see Payne, 2001), in Experiment 4, we manipulated the response deadline to determine whether the current findings hold even when participants had more time to respond.

Finally, in Experiment 5, participants completed an L1-VPT task in which the color of the balloons in the room (red vs. blue) varied from trial to trial. We retained the condition from Experiments 2–4 in which the avatar-perspective trials appeared first. We also included a different comparison condition in which participants indicated whether a color cue matched or mismatched the color of the balloons in the room. In this condition, as in the conditions from Experiments 2–4 in which the self-perspective trials appeared first, the avatar's perspective was not yet relevant to participants' task goal prior to their completing the self-perspective trials.

Across experiments, our primary interest was in the process analyses; however, following prior applications of the PDP to visual perspective taking (Qureshi & Monk, 2018; Simpson & Todd, 2017; Todd et al., 2017, 2019), we also report behavioral analyses on the error rates[6] from which the PDP estimates are derived. For each experiment, we describe our sample size rationale, and all data exclusions, manipulations, and measures. These experiments received IRB approval from the University of California, Davis.

Experiment 1

Method

Participants and power. We set a target sample size of at least 160 participants, which is 2.5 times the size of Surtees, Samson, et al. (2016, Experiment 1) sample of 64 (see Simonsohn, 2015, for elaboration on this rationale). In this and all subsequent experiments, data were collected until our target sample size was surpassed.[7] Undergraduates (n = 210) participated for course credit. Following prior work (e.g., Surtees, Samson, et al., 2016; Todd et al., 2019), we excluded data from 2 participants who performed at or below chance (≤50% accuracy), which indicates inattention or confusion about task instructions. Data were also excluded from one participant for whom a computer malfunction resulted in data loss and from 16 participants for whom an unexpected screen resolution issue resulted in smaller versions of the task stimuli appearing in the upper left quadrant of the computer screen. The final sample comprised 191 participants (152 women, 39 men; 62 White, 58 Latinx, 54 Asian, six Black, nine reporting more than one race/ethnicity, two unreported). A sensitivity analysis[8] indicated that this sample size afforded >99% power to detect the Level × Blocking × Consistency interaction on the error rates on self-perspective trials (η_p^2 = .135) reported by Surtees, Samson, et al. (2016, Experiment 1) and >80% power to detect a small-to-medium sized Level × Blocking interaction on the PDP estimates of avatar-perspective calculation (η_p^2 = .040).

Procedure and materials. The general procedure and all task materials were similar to those used by Surtees, Samson, et al. (2016, Experiment 1). For all experimental conditions, the critical stimulus was a picture of a cartoon avatar standing in a room next

[6] Our use of a shortened response deadline restricts the variance of response times (RTs), limiting their validity as an outcome. For completeness, we report behavioral analyses of RTs for all experiments in the online supplemental material.

[7] Across experiments, we exceeded our target sample sizes (prior to data exclusions) due to overscheduling of experimental sessions.

[8] We conducted all power analyses with G*Power (Faul, Erdfelder, Lang, & Buchner, 2007).

to a table. Participants were randomly assigned to complete the L1-VPT task or the L2-VPT task. In the L1-VPT task, a varying number of balloons (0, 1, 2, or 3) appeared in the room. On consistent trials in this task, all balloons appeared in front of the avatar and thus were clearly visible both to the avatar and to participants; on inconsistent trials, some balloons appeared behind the avatar and thus were visible only to participants (see Figure 1, top panels). In the L2-VPT task, a numeral (6 or 9) appeared on the table. On consistent trials in this task, the numeral stood upright on the table and thus looked identical from the two perspectives; on inconsistent trials, the numeral lay flat on the table and thus appeared as a 6 (9) to the avatar but as a 9 (6) to participants (see Figure 1, bottom panels). Both tasks included trials in which participants verified the avatar's perspective (avatar-perspective trials) and trials in which participants verified their own perspective (self-perspective trials). Thus, the L1-VPT task entailed reporting the number of balloons in the room that were visible to the avatar or to oneself, whereas the L2-VPT task entailed reporting the identity of numerals on the table based on how they looked to the avatar or to oneself.

Participants were randomly assigned to one of two blocking conditions, which served as the goal-relevance manipulation. In the mixed-blocking condition, the self-perspective trials and avatar-perspective trials were intermixed within the same blocks of trials; thus, the avatar's perspective was salient and (remotely) goal-relevant on some trials in each trial block for the duration of the task. In the separate-blocking condition, the self-perspective trials and avatar-perspective trials appeared in separate, counterbalanced blocks of trials; thus, the avatar's perspective was less goal-relevant in the blocks containing the self-perspective trials.

Each trial sequence was as follows: (a) a fixation cross signaled the start of the trial (750 ms), (b) a perspective cue (He or You) indicated whose perspective (avatar or self) to verify (750 ms), (c) a numerical content cue indicated the number of balloons in the room to verify (0, 1, 2, or 3) in the L1-VPT task or the numeral on the table to verify (6 or 9) in the L2-VPT task (750 ms), and (d) the image of the avatar appeared in the room (on screen until participants responded). An interstimulus interval (500 ms) appeared after (b) and (c). Participants indicated by key press whether the numerical content cue "matches" or "does NOT match" how things look from the cued perspective. If participants took longer than 750 ms to respond, a message ("Please try to respond faster!") appeared for 1 s (Simpson & Todd, 2017; Todd et al., 2017). If participants responded incorrectly, a red X appeared for 1 s.

Both tasks comprised four blocks of experimental trials; trial order in each block was pseudorandomized based on parameters set by Samson et al. (2010; see also Surtees, Samson, et al., 2016). The L1-VPT task had 208 experimental trials (four blocks of 52 trials each), and the L2-VPT task had 192 experimental trials (four blocks of 48 trials each). The higher number of trials on the L1-VPT task reflects the inclusion of "filler" trials to ensure an equal number of "match" responses for each perspective and numerical cue (see Surtees, Samson, et al., 2016, for details). In the mixed-blocking condition, a single set of practice trials (26 in the L1-VPT task, 24 in the L2-VPT task) preceded the first of four blocks of experimental trials. In the separate-blocking condition, separate sets of practice trials preceded the first of two blocks of avatar-perspective trials and the first of two blocks of self-perspective trials.

Results

Analysis plan. We implemented the following analysis plan across experiments. Before conducting any behavioral or process analyses, we excluded "mismatch" trials (i.e., trials in which the correct response is "does NOT match") because specific task constraints lead to systematic differences across trial types that can inflate consistency effects (see Samson et al., 2010). Given our focus on the goal-dependence of altercentric interference, we only report analyses on the self-perspective trials in the main text (see

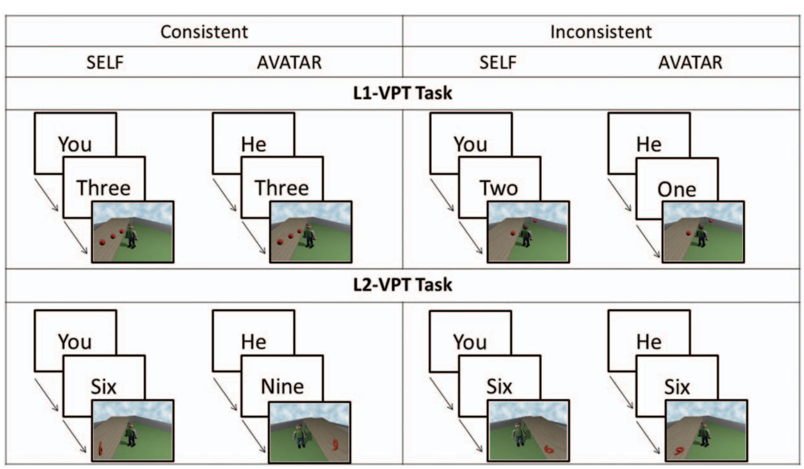

Figure 1. Examples of "match" trials on the Level-1 visual perspective taking (L1-VPT) task (top panel) and Level-2 visual perspective taking (L2-VPT) task (bottom panel). Participants verified if a numerical cue matched the number of balloons visible or the identity of the numeral either from their own perspective (You) or from the avatar's perspective (He). The number of balloons visible and the identity of the numeral from each perspective was either the same (consistent) or different (inconsistent). See the online article for the color version of this figure.

the online supplemental material for analyses of egocentric interference on the avatar-perspective trials).

Prior research has found that a similar blocking manipulation weakened altercentric interference in L2-VPT, but not in L1-VPT (Surtees, Samson, et al., 2016). To facilitate comparison with this prior work and with theoretical predictions of the two-systems account of mentalizing (Low et al., 2016), we report results separately for the L1-VPT and L2-VPT tasks, even in cases where the highest-order interaction involving the Level factor was not significant in the omnibus analysis. That is, our behavioral analyses examined error rates as a function of Blocking, Consistency, and their interaction, and our process analyses examined PDP estimates of avatar-perspective calculation as a function of Blocking, separately in L1-VPT and L2-VPT (see Todd et al., 2019, for a similar reporting strategy).

Behavioral analyses. Table 1 displays inferential statistics from the omnibus analysis of error rates in Experiment 1. A 2 (Level) × 2 (Blocking) × 2 (Consistency) mixed analysis of variance (ANOVA) yielded Level and Consistency main effects: Unexpectedly, errors were higher in L1-VPT than in L2-VPT. Given the inconsistency of this Level main effect across experiments, however, we hesitate to elaborate on it here. Errors were also higher on inconsistent trials than on consistent trials (i.e., altercentric interference). A Blocking × Consistency interaction further indicated that altercentric interference was weaker in the separate-blocking condition than in the mixed-blocking condition. Finally, the three-way interaction was not significant, suggesting comparable effects of blocking on altercentric interference in L1-VPT and L2-VPT.

To further unpack these effects, we conducted separate 2 (Blocking) × 2 (Consistency) ANOVAs on the two tasks. These analyses yielded Consistency main effects (i.e., altercentric interference) in both L1-VPT, $F(1, 93) = 30.63$, $p < .001$, $\eta_p^2 = .248$, and L2-VPT, $F(1, 94) = 29.72$, $p < .001$, $\eta_p^2 = .240$. Contrary to prior work (Conway et al., 2017; Samson et al., 2010; Surtees, Samson, et al., 2016), the Blocking × Consistency interaction was significant in L1-VPT, $F(1, 93) = 10.73$, $p = .001$, $\eta_p^2 = .103$ (see Figure 2, left side). Follow-up analyses revealed that altercentric interference was weaker (though still evident) in the separate-blocking condition ($M_{diff} = 2.70\%$, $SD = 9.01$), $t(50) = 2.14$, $p = .037$, $d_z = 0.30$, than in the mixed-blocking condition ($M_{diff} = 10.51\%$, $SD = 14.02$), $t(43) = 4.97$, $p < .001$, $d_z = 0.75$. The Blocking × Consistency interaction was not significant in L2-VPT, $F(1, 94) = 3.56$, $p = .062$, $\eta_p^2 = .037$ (see Figure 2, right side), though the underlying pattern of results was similar to that for L1-VPT.

Table 1
Omnibus Analysis of Error Rates on Self-Perspective Trials (Experiment 1)

Effect	$F(1, 187)$	p	η_p^2
Level	11.36	.001	.057
Blocking	<1	.324	<.01
Consistency	59.04	<.001	.240
Level × Blocking	<1	.358	<.01
Level × Consistency	1.87	.174	.010
Blocking × Consistency	14.22	<.001	.071
Level × Blocking × Consistency	2.51	.115	.013

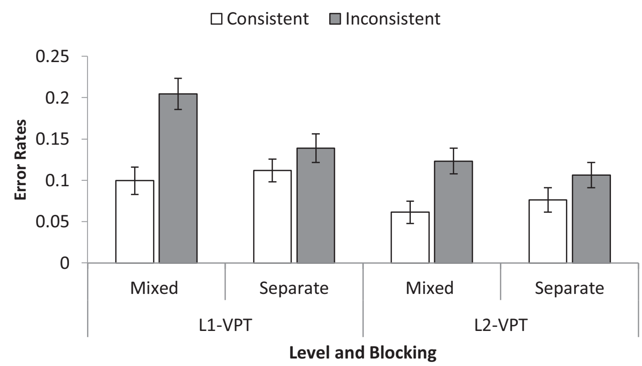

Figure 2. Error rates on self-perspective trials by level, blocking, and consistency; error bars depict ± 1 *SE* (Experiment 1). VPT = visual perspective taking.

Process analyses. Next, we conducted PDP analyses to isolate avatar-perspective calculation from self-perspective detection and to examine the effects of blocking on each process in both tasks. Using Equations (3) and (4) described earlier, we computed estimates of self-perspective detection and avatar-perspective calculation for each participant. In cases of perfect performance (self-perspective detection = 1), avatar-perspective calculation is undefined; thus, we applied an adjustment commonly used in PDP analysis (e.g., Payne, Lambert, & Jacoby, 2002; Todd et al., 2017, 2019; see also Snodgrass & Corwin, 1988, for an earlier application to signal detection analysis).[9] Because negative self-perspective detection estimates violate assumptions of the PDP that parameter estimates range from 0 to 1 (Jacoby, 1991), we replaced such instances with a value of 0 (Todd et al., 2019).[10] We used this same procedure to compute PDP estimates in Experiments 2–5.

Table 2 displays inferential statistics from the PDP analyses in Experiment 1. A 2 (Level) × 2 (Blocking) mixed ANOVA on the self-perspective detection estimates (see Figure 3, left side) yielded only a Level main effect: Self-perspective detection was weaker in L1-VPT than in L2-VPT. Neither the Blocking main effect nor the Level × Blocking interaction was significant.

An identical ANOVA on the avatar-perspective calculation estimates (see Figure 3, right side), the process of focal interest, yielded a significant Blocking main effect that was not moderated by Level. Calculation of the avatar's perspective was weaker in the separate-blocking condition than in the mixed-blocking condi-

[9] When computing the proportion of errors for a particular trial type, the adjustment entails adding 0.5 to the numerator (number of errors) and 1 to the denominator (number of trials). For example, if a participant made 0 errors on 24 inconsistent self-perspective trials, the adjustment would be: (0 + 0.5)/(24 + 1). Because error rates in these tasks are typically low, and perfect performance on one or more trial types is common, this adjustment was required in 42–64% of our samples (Experiment 1: 42%, Experiment 2: 44%, Experiment 3: 53%, Experiment 4: 64%, Experiment 5: 45%).

[10] This procedure of replacing negative self-perspective detection estimates with a value of 0 was required in no more than 1% of our sample in any experiment. Excluding these participants' data from the PDP analyses produced nearly identical results. In only one case did a previously significant effect become non-significant. The simple effect of blocking on avatar-perspective calculation in L2-VPT went from $p = .045$ to $p = .051$ in Experiment 1.

Table 2
Analyses of Self-Perspective Detection and Avatar-Perspective Calculation (Experiment 1)

Effect	F(1, 187)	p	η_p^2
Self-perspective detection			
Level	8.92	.003	.046
Blocking	1.06	.304	<.01
Level × Blocking	<1	.333	<.01
Avatar-perspective calculation			
Level	<1	.869	<.01
Blocking	13.21	<.001	.066
Level × Blocking	<1	.471	<.01

tion—an effect that emerged in both L1-VPT, $t(93) = 3.12$, $p = .002$, $d_s = 0.64$, and L2-VPT, $t(94) = 2.03$, $p = .045$, $d_s = 0.42$.

Finally, we tested for the presence of avatar-perspective calculation by comparing parameter estimates in each blocking condition against a value of .50, which, in this variant of the PDP, reflects the absence of avatar-perspective calculation (see Payne, Brown-Iannuzzi, & Loersch, 2016). One-sample t tests on the L1-VPT task revealed evidence of significant avatar-perspective calculation in the mixed-blocking condition ($M = .67$, $SD = .21$), $t(43) = 5.32$, $p < .001$, $d_z = 0.80$, but not in the separate-blocking condition ($M = .54$, $SD = .20$), $t(50) = 1.33$, $p = .189$, $d_z = 0.19$. In L2-VPT, significant avatar-perspective calculation emerged in both the mixed-blocking condition ($M = .65$, $SD = .22$), $t(48) = 4.97$, $p < .001$, $d_z = 0.71$, and the separate-blocking condition ($M = .57$, $SD = .21$), $t(46) = 2.10$, $p = .041$, $d_z = 0.31$.

Discussion

Several findings of theoretical interest emerged in Experiment 1: First, behavioral analyses revealed evidence of altercentric interference both in L1-VPT, replicating numerous prior studies, and in L2-VPT, replicating several prior studies (e.g., Elekes et al., 2016; Surtees, Apperly, et al., 2016; Surtees, Samson, et al., 2016; Todd et al., 2019; but see Surtees et al., 2012). Second, behavioral analyses also indicated that altercentric interference was weaker when the avatar's perspective was less goal-relevant in some blocks of trials (separate-blocking condition) than when the avatar's perspective was goal-relevant in all blocks of trials (mixed-blocking condition). That this effect of goal-relevance on altercentric interference did not differ between L1-VPT and L2-VPT contrasts with Surtees, Samson, et al. (2016) and with predictions of the two-systems account (Apperly & Butterfill, 2009; Butterfill & Apperly, 2013; Low et al., 2016).

Finally, the results of the PDP analyses, which aim to disentangle processes underlying altercentric interference, generally aligned with the results of the behavioral analyses: Calculation of the avatar's perspective was weaker when the self-perspective trials and avatar-perspective trials were in separate trial blocks than when they were intermixed within the same trial blocks. Importantly, this effect of goal-relevance on avatar-perspective calculation emerged in both tasks, which suggests that incidentally calculating other agents' perspectives may be goal-dependent in both L1-VPT and L2-VPT.

In Experiment 1, we used a blocking manipulation to make the avatar's perspective less goal-relevant in one experimental condition. Specifically, in the separate-blocking condition, the self-perspective trials and avatar-perspective trials appeared in different trial blocks, and block order was counterbalanced across participants. Thus, for participants who completed the self-perspective trials first, a remote goal to process the avatar's perspective had not yet been activated. Restricting analyses to the separate-blocking condition and testing for effects of block order arguably affords an even stronger test of goal-dependence. When submitting the data from this condition to analyses that were analogous to the primary analyses, the results mirrored those reported above: Altercentric interference and avatar-perspective calculation in L1-VPT and L2-VPT were generally weaker, though not always significantly so given the reduced statistical power, when the self-perspective trials appeared first (full details for these analyses appear in the online supplemental material). Because these analyses were exploratory, however, we felt it important to replicate these findings in a separate experiment.

Experiment 2

Experiment 2 was a close replication of the separate-blocking condition from Experiment 1. Participants completed either an L1-VPT task or an L2-VPT task; both tasks contained 2 blocks of avatar-perspective trials in which participants verified the avatar's perspective and 2 blocks of self-perspective trials in which they verified their own perspective. Some participants completed the avatar-perspective trials first, meaning that the avatar's perspective was salient and goal-relevant prior to completing the self-perspective trials. Other participants completed the self-perspective trials first, meaning that the avatar's perspective was less goal-relevant prior to completing the self-perspective trials.

Method

Participants and power. Aiming for 80% a priori power to detect a small-to-medium sized Level × Block Order × Consistency interaction on the error rates in a mixed design ($\eta_p^2 = .03$), we set a target sample size of at least 258 participants. Undergraduates ($N = 263$) participated for course credit. Data were excluded from 2 participants who performed at or below chance and 1

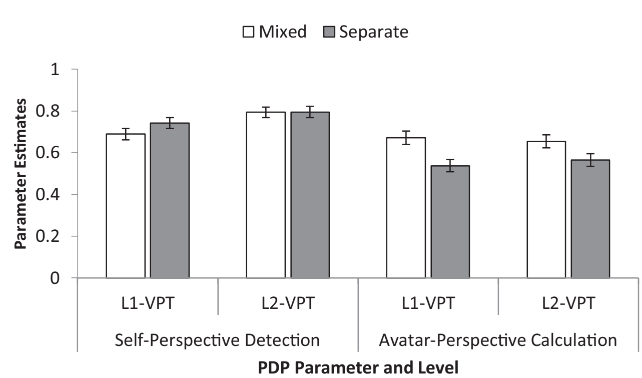

Figure 3. Process dissociation procedure (PDP) estimates of self-perspective detection and avatar-perspective calculation by level and blocking; error bars depict ± 1 *SE* (Experiment 1). VPT = visual perspective taking.

participant for whom a computer malfunction resulted in data loss, leaving a final sample of 260 (210 women, 43 men, seven unreported; 141 Asian, 53 Latinx, 38 White, three Black, 18 reporting more than one race/ethnicity, seven unreported). A sensitivity analysis indicated that this sample size afforded >80% power to detect a small-to-medium sized Level × Blocking interaction on the PDP estimates of avatar-perspective calculation ($\eta^2_p = .03$).

Procedure and materials. The general procedure and all task materials were identical to those from the separate-blocking condition in Experiment 1. Participants were randomly assigned to one of four experimental conditions based on Level (L1-VPT task vs. L2-VPT task) and Block Order within the task (avatar-perspective trials first vs. self-perspective trials first).

Results

Behavioral analyses. Table 3 displays inferential statistics from the omnibus analysis of error rates in Experiment 2. A 2 (Level) × 2 (Block Order) × 2 (Consistency) mixed ANOVA yielded a level main effect: Unlike Experiment 1, error rates were higher in L2-VPT than in L1-VPT. There was also a Consistency main effect (i.e., altercentric interference), a Level × Consistency interaction indicating that altercentric interference was stronger in L2-VPT than in L1-VPT, and a Block Order × Consistency interaction indicating that altercentric interference was weaker when the self-perspective trials appeared first than when the avatar-perspective trials appeared first. Finally, the three-way interaction was not significant, suggesting comparable effects of block order on altercentric interference in L1-VPT and L2-VPT.

As in Experiment 1, we further unpacked these effects by conducting separate 2 (Block Order) × 2 (Consistency) ANOVAs on the two tasks to facilitate comparison with prior empirical work (Surtees, Samson, et al., 2016) and with theoretical predictions of the two-systems account of mentalizing (e.g., Low et al., 2016). A significant Block Order × Consistency interaction emerged in both L1-VPT, $F(1, 128) = 6.26$, $p = .014$, $\eta^2_p = .047$, and L2-VPT, $F(1, 128) = 7.64$, $p = .007$, $\eta^2_p = .056$. In L1-VPT (see Figure 4, left side), there was significant altercentric interference when the avatar-perspective trials appeared first ($M_{diff} = 1.92\%$, $SD = 7.07$), $t(64) = 2.19$, $p = .032$, $d_z = 0.27$, but not when the self-perspective trials appeared first ($M_{diff} = -1.22\%$, $SD = 7.24$), $t(64) = -1.36$, $p = .180$, $d_z = -0.17$. Similarly, in L2-VPT (see Figure 4, right side), there was significant altercentric interference when the avatar-perspective trials appeared first ($M_{diff} = 5.64\%$, $SD = 11.35$), $t(64) = 4.01$, $p < .001$, $d_z = 0.50$, but not when the self-perspective trials appeared first ($M_{diff} = 0.90\%$, $SD = 7.92$; $t < 1$, $p = .364$, $d_z = 0.11$).

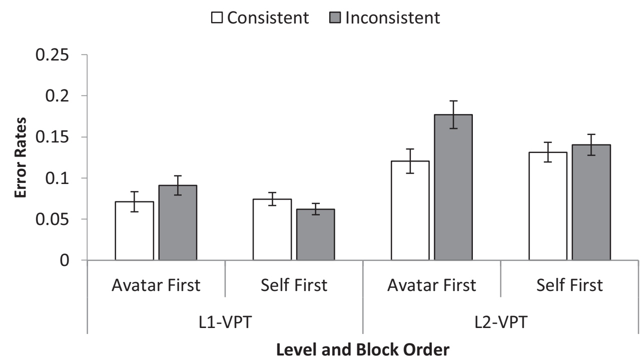

Figure 4. Error rates on self-perspective trials by level, block order, and consistency; error bars depict ± 1 *SE* (Experiment 2). VPT = visual perspective taking.

Process analyses. Table 4 displays inferential statistics from the PDP analyses in Experiment 2. A 2 (Level) × 2 (Block Order) ANOVA on the self-perspective detection estimates (see Figure 5, left side) yielded only a Level main effect: Unlike in Experiment 1, here detection of one's own perspective was weaker in L2-VPT than in L1-VPT.

An identical ANOVA on the avatar-perspective calculation estimates (see Figure 5, right side) yielded a significant Block Order main effect that was not moderated by Level. Calculation of the avatar's perspective was weaker when the self-perspective trials appeared first than when the avatar-perspective trials appeared first—an effect that emerged in both L1-VPT, $t(128) = 2.67$, $p = .009$, $d_s = 0.47$, and L2-VPT, $t(128) = 2.23$, $p = .027$, $d_s = 0.38$.

Finally, as in Experiment 1, we tested for the presence of avatar-perspective calculation by comparing estimates of this parameter in each block order condition against a value of .50. In L1-VPT, there was significant avatar-perspective calculation when the avatar-perspective trials appeared first ($M = .58$, $SD = .20$), $t(64) = 3.06$, $p = .003$, $d_z = 0.38$, but not when the self-perspective trials appeared first ($M = .48$, $SD = .22$; $t < 1$, $p = .417$, $d_z = -0.10$). The same pattern emerged in L2-VPT: There was significant avatar-perspective calculation when the avatar-perspective trials appeared first ($M = .59$, $SD = .20$), $t(64) = 3.59$, $p = .001$, $d_z = 0.45$, but not when the self-perspective trials appeared first ($M = .52$, $SD = .18$; $t < 1$, $p = .507$, $d_z = 0.08$).

Table 3
Omnibus Analysis of Error Rates on Self-Perspective Trials (Experiment 2)

Effect	$F(1, 256)$	p	η^2_p
Level	37.55	<.001	.128
Block Order	1.31	.254	<.01
Consistency	11.60	.001	.043
Level × Block Order	<1	.988	<.01
Level × Consistency	7.53	.007	.029
Block Order × Consistency	13.75	<.001	.051
Level × Block Order × Consistency	<1	.452	<.01

Table 4
Analyses of Self-Perspective Detection and Avatar-Perspective Calculation (Experiment 2)

Effect	$F(1, 256)$	p	η^2_p
Self-perspective detection			
Level	36.07	<.001	.123
Block Order	1.23	.269	<.01
Level × Block Order	<1	.956	<.01
Avatar-perspective calculation			
Level	1.03	.312	<.01
Block Order	12.11	.001	.045
Level × Block Order	<1	.637	<.01

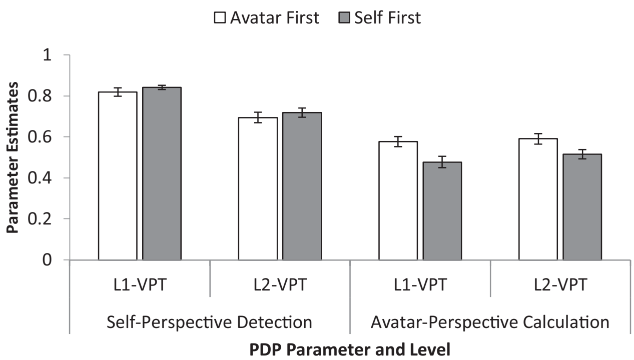

Figure 5. Process dissociation procedure (PDP) estimates of self-perspective detection and avatar-perspective calculation by level and block order; error bars depict ± 1 *SE* (Experiment 2). VPT = visual perspective taking.

Discussion

The results of Experiment 2 generally replicated those from Experiment 1, though the effects of block order here were even more pronounced than the effects of blocking were in Experiment 1. When the avatar's perspective was salient and goal-relevant prior to completing trials that entailed responding from one's own perspective, there was robust behavioral evidence of altercentric interference in both L1-VPT and L2-VPT. When the avatar's perspective was less goal-relevant prior to responding from one's own perspective, however, there was no behavioral evidence of altercentric interference in either task. Furthermore, this same pattern of results emerged in the PDP analyses: Calculation of *what* objects the avatar sees (L1-VPT) and *how* the avatar sees those objects (L2-VPT) were both weaker when the relevance of the avatar's perspective to participants' task goal was reduced. The results of Experiments 1 and 2, therefore, suggest that, contrary to predictions of the two-systems account (Apperly & Butterfill, 2009; Butterfill & Apperly, 2013; Low et al., 2016), incidentally calculating other agents' visual perspectives may be goal-dependent in *both* L1-VPT and L2-VPT.

Experiment 3

Experiments 1 and 2 are not without limitations. For example, the set of relevant numerical stimuli in both experiments was smaller in the L2-VPT task (6, 9) than in the L1-VPT task (0, 1, 2, and 3), which may have resulted in lower task demands in the former task than in the latter task. On one hand, altercentric interference was stronger and errors were greater overall in L1-VPT than in L2-VPT in Experiment 1. On the other hand, the opposite pattern emerged in Experiment 2 (i.e., stronger altercentric interference and more errors overall in L2-VPT than in L1-VPT). We addressed this issue in Experiment 3 (and Experiment 4) by modifying the L2-VPT task so that the stimulus set comprised four numerals instead of two. We retained the asymmetrical numerals (6, 9), which when lying flat on the table have different identities when viewed from one's own versus the avatar's physical vantage point (i.e., inconsistent trials), and we added two symmetrical numerals (1, 8), which have the same identity when viewed from either vantage point (i.e., consistent trials; Elekes et al., 2016; Surtees et al., 2012; Surtees, Samson, et al., 2016, Experiment 2; Todd et al., 2019; Experiments 3A and 3B).

Based on the results of Experiments 1 and 2, we predicted that completing the self-perspective trials first, thereby making the avatar's perspective less relevant to participants' task goal on these trials, would weaken both altercentric interference as a behavioral effect and PDP estimates of avatar-perspective calculation. We also expected that these effects of block order would be comparable in L1-VPT and L2-VPT.

Method

Participants and power. We set a target sample size of at least 258 participants for 80% a priori power to detect a small-to-medium sized Level × Block Order × Consistency interaction on the error rates ($\eta_p^2 = .03$). The preregistered analysis plan for this experiment is available at https://aspredicted.org/blind.php?x=k4xa9i. Undergraduates ($N = 312$) participated for course credit. We excluded data from 14 participants for whom a computer malfunction resulted in data loss, leaving a final sample of 298 (219 women, 72 men, seven unreported; 146 Asian, 64 Latinx, 58 White, 7 Black, 12 reporting more than one race/ethnicity, 11 unreported). A sensitivity analysis indicated that this sample size afforded >80% power to detect a small-to-medium sized Level × Block Order interaction on the PDP estimates of avatar-perspective calculation ($\eta_p^2 = .026$).

Procedure and materials. The procedure and materials were identical to those from Experiment 2, except the L2-VPT task included a larger set of numeric stimuli, and all numerals lay flat on the table (as in Todd et al., 2019, Experiments 3A and 3B). On consistent trials in the L2-VPT task, the numeral (1 or 8) was symmetrical and thus looked identical from the avatar's perspective and from participants' own perspective; on inconsistent trials, the numeral (6 or 9) was asymmetrical and thus looked different from the two perspectives. The numerical cues were uniquely paired with the specific trial types; that is, consistent trials were cued with 1 or 8, and inconsistent trials were cued with Six or Nine. The L1-VPT task was identical to the one from Experiment 2. In sum, as in Experiment 2, participants were randomly assigned to one of four experimental conditions based on Level (L1-VPT task vs. L2-VPT task) and Block Order within the task (avatar-perspective trials first vs. self-perspective trials first).

Results

Behavioral analyses. Table 5 displays inferential statistics from the omnibus analysis of error rates in Experiment 3. A 2 (Level) × 2 (Block Order) × 2 (Consistency) mixed ANOVA yielded a Consistency main effect (i.e., altercentric interference). A Block Order × Consistency interaction indicated that altercentric interference was weaker when the self-perspective trials versus the avatar-perspective trials appeared first. The three-way interaction was not significant, suggesting comparable effects of block order on altercentric interference in the two tasks.

Once again, we further unpacked these effects by conducting separate 2 (Block Order) × 2 (Consistency) ANOVAs in L1-VPT and L2-VPT to facilitate comparison with prior empirical work (Surtees, Samson, et al., 2016) and with theoretical predictions of the two-systems account (e.g., Low et al., 2016). A significant

Table 5
Omnibus Analysis of Error Rates on Self-Perspective Trials (Experiment 3)

Effect	F(1, 294)	p	η_p^2
Level	1.56	.213	<.01
Block Order	<1	.397	<.01
Consistency	8.72	.003	.029
Level × Block Order	<1	.650	<.01
Level × Consistency	2.87	.091	.010
Block Order × Consistency	5.76	.017	.019
Level × Block Order × Consistency	<1	.654	<.01

Table 6
Analyses of Self-Perspective Detection and Avatar-Perspective Calculation (Experiment 3)

Effect	F(1, 294)	p	η_p^2
Self-perspective detection			
Level	1.51	.221	<.01
Block Order	<1	.488	<.01
Level × Block Order	<1	.724	<.01
Avatar-perspective calculation			
Level	<1	.352	<.01
Block Order	13.56	<.001	.044
Level × Block Order	1.94	.165	<.01

Consistency main effect, $F(1, 148) = 11.43$, $p = .001$, $\eta_p^2 = .072$, and a significant Block Order × Consistency interaction, $F(1, 148) = 4.29$, $p = .040$, $\eta_p^2 = .028$, emerged in L1-VPT (see Figure 6, left side). Follow up analyses revealed significant altercentric interference when the avatar-perspective trials appeared first ($M_{\text{diff}} = 4.11\%$, $SD = 9.06$), $t(73) = 3.91$, $p < .001$, $d_z = 0.45$, but not when the self-perspective trials appeared first ($M_{\text{diff}} = 0.99\%$, $SD = 9.40$; $t < 1$, $p = .363$, $d_z = 0.11$). In L2-VPT (see Figure 6, right side), neither the Consistency main effect ($F < 1$, $p = .388$, $\eta_p^2 < .01$) nor the Block Order × Consistency interaction was significant, $F(1, 146) = 1.80$, $p = .182$, $\eta_p^2 = .012$.

Process analyses. Table 6 displays inferential statistics from the PDP analyses in Experiment 3. A 2 (Level) × 2 (Block Order) ANOVA on the self-perspective detection estimates (see Figure 7, left side) revealed no significant effects.

An identical ANOVA on the avatar-perspective calculation estimates (see Figure 7, right side) revealed a significant Block Order main effect that was not moderated by Level. Calculation of the avatar's perspective was weaker when the self-perspective trials appeared first than when the avatar-perspective trials appeared first. However, this effect only emerged in L1-VPT, $t(148) = 3.66$, $p < .001$, $d_s = 0.60$; it was not significant in L2-VPT, $t(146) = 1.59$, $p = .114$, $d_s = 0.26$.

Finally, as in Experiments 1 and 2, we tested for the presence of avatar-perspective calculation by comparing estimates of this parameter in each block order condition against a value of .50. In L1-VPT, significant avatar-perspective calculation emerged when the avatar-perspective trials appeared first ($M = .61$, $SD = .22$), $t(73) = 4.39$, $p < .001$, $d_z = 0.51$, but not when the self-perspective trials appeared first ($M = .49$, $SD = .20$; $t < 1$, $p = .529$, $d_z = -0.07$). Similarly, in L2-VPT, significant avatar-perspective calculation emerged when the avatar-perspective trials appeared first ($M = .55$, $SD = .22$), $t(70) = 2.02$, $p = .047$, $d_z = 0.24$, but not when the self-perspective trials appeared first ($M = .50$, $SD = .21$; $t < 1$, $p = .890$, $d_z = -0.02$).

Discussion

The results of Experiment 3 generally replicated those of Experiment 2 using a larger numerical stimulus set in the L2-VPT task: Overall, altercentric interference and avatar-perspective calculation were both weaker when the goal-relevance of the avatar's perspective was reduced prior to responding from one's own perspective. Additionally, as in Experiment 2, there was no behavioral evidence of altercentric interference when participants completed the self-perspective trials first (i.e., when the avatar's perspective was less relevant to participants' overt task goal). Indeed, altercentric interference in L2-VPT failed to emerge at all in Experiment 3. Given the unexpectedness of this null effect, we refrain from speculating about a potential explanation pending replication, which Experiment 4 afforded.

Experiment 4

A main objective of the current work was to examine goal-relevance effects on PDP estimates of avatar-perspective calculation.

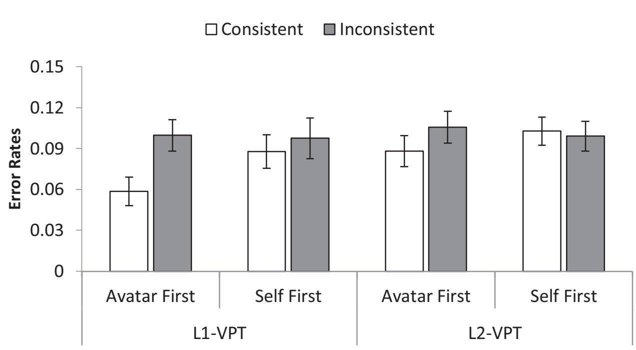

Figure 6. Error rates on self-perspective trials by level, block order, and consistency; error bars depict ± 1 *SE* (Experiment 3). VPT = visual perspective taking.

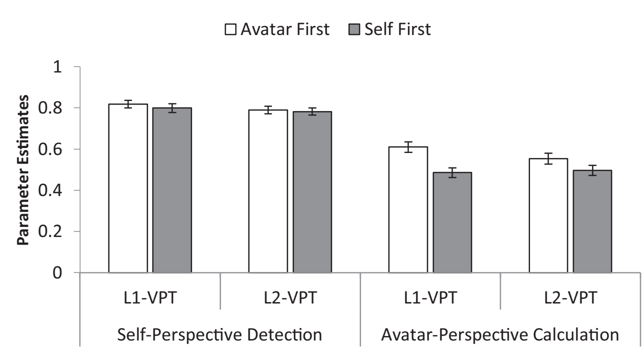

Figure 7. Process dissociation procedure (PDP) estimates of self-perspective detection and avatar-perspective calculation by level and block order; error bars depict ± 1 *SE* (Experiment 3). VPT = visual perspective taking.

Accordingly, in Experiments 1–3, we used a response deadline (750 ms) that is considerably shorter than what is typically used in visual perspective-taking tasks (2000 ms; e.g., Samson et al., 2010; Surtees, Samson, et al., 2016), with the goal of increasing variability in error rates and thereby afford more powerful PDP analyses (e.g., Payne, 2001; Todd et al., 2016). As noted earlier, however, prior work has found that avatar-perspective calculation in L2-VPT, though not in L1-VPT, varies based on the duration of the response deadline (Todd et al., 2019). Therefore, to determine whether the effects of goal-relevance reported thus far also emerge when participants have more time to process the visual scene before responding, in Experiment 4, we manipulated both (a) the goal-relevance of the avatar's perspective by varying the order of the self-perspective and avatar-perspective trials (as in Experiments 2 and 3) and (b) the response deadline (750 ms vs. 2000 ms). All participants completed the variant of the L2-VPT task from Experiment 3 only.

Method

Participants and power. We set a target sample size of at least 258 participants for 80% a priori power to detect a small-to-medium sized Deadline × Block Order × Consistency interaction on the error rates in a mixed design ($\eta_p^2 = .03$). Undergraduates ($n = 280$) participated for course credit. We excluded data from 8 participants for whom a computer malfunction resulted in data loss, leaving a final sample of 272 (217 women, 48 men, two reporting a nonbinary gender identity, five unreported; 133 Asian, 65 Latinx, 50 White, five Black, 15 reporting more than one race/ethnicity, four unreported). A sensitivity analysis indicated that this sample size afforded >80% power to detect a small-to-medium sized Deadline × Block Order interaction on the avatar-perspective calculation estimates ($\eta_p^2 = .029$).

Procedure and materials. The procedure and materials were identical to those for the L2-VPT task in Experiment 3, the only difference being the inclusion of a response deadline manipulation. In the short-deadline condition, the response deadline was 750 ms, as in Experiments 1–3. In the long-deadline condition, the response deadline was 2,000 ms, as in prior work examining goal-relevance effects in L2-VPT (Surtees, Samson, et al., 2016).

Results

Behavioral analyses. Table 7 displays inferential statistics from the omnibus analysis of error rates in Experiment 4. A 2 (Deadline) × 2 (Block Order) × 2 (Consistency) mixed ANOVA yielded a significant Deadline main effect: Errors were higher in the short-deadline condition than in the long-deadline condition. There was also a significant Consistency main effect (i.e., altercentric interference) and a significant Block Order × Consistency interaction. Follow-up analyses collapsing across deadline conditions revealed significant altercentric interference when the avatar-perspective trials appeared first ($M_{\text{diff}} = 3.22\%$, $SD = 8.75$), $t(136) = 4.31$, $p = .001$, $d_z = 0.37$, but not when the self-perspective trials appeared first ($M_{\text{diff}} = -0.15\%$, $SD = 6.88$; $t < 1$, $p = .795$, $d_z = -0.12$). The three-way interaction was not significant, suggesting comparable effects of block order on altercentric interference in the short-deadline (see Figure 8, left side) and long-deadline conditions (see Figure 8, right side).

Process analyses. Table 8 displays inferential statistics from the PDP analyses in Experiment 3. A 2 (Deadline) × 2 (Block Order) ANOVA on the self-perspective detection estimates (see Figure 9, left side) yielded a Deadline main effect: Detection of one's own perspective was weaker in the short-deadline versus the long-deadline condition.

Table 7
Omnibus Analysis of Error Rates on Self-Perspective Trials (Experiment 4)

Effect	F(1, 268)	p	η_p^2
Deadline	30.42	<.001	.102
Block Order	3.60	.059	.013
Consistency	10.19	.002	.037
Deadline × Block Order	1.12	.292	<.01
Deadline × Consistency	<1	.502	<.01
Block Order × Consistency	12.59	<.001	.045
Deadline × Block Order × Consistency	<1	.413	<.01

An identical ANOVA on the avatar-perspective calculation estimates (see Figure 9, right side) revealed a significant Block Order main effect that was not moderated by Deadline. Calculation of the avatar's perspective was weaker when the self-perspective trials appeared first than when the avatar-perspective trials appeared first.

Finally, we tested for the presence of avatar-perspective calculation by comparing parameter estimates in each block order condition against a value of .50. Collapsing across deadline condition, significant avatar-perspective calculation emerged when the avatar-perspective trials appeared first ($M = .58$, $SD = .21$), $t(136) = 4.39$, $p < .001$, $d_z = 0.38$, but not when the self-perspective trials appeared first ($M = .48$, $SD = .19$; $t < 1$, $p = .152$, $d_z = -0.12$).

Discussion

The results of Experiment 4 indicate that altercentric interference and avatar-perspective calculation in L2-VPT were both weaker when the avatar's perspective was less goal-relevant. Unlike Experiment 3, there was robust evidence of both altercentric interference and avatar-perspective calculation when participants completed the avatar-perspective trials first; however, these effects were eliminated when participants completed the self-perspective trials first. Importantly, these goal-relevance effects emerged with comparable strength regardless of how much time participants had to process the visual scene and register a response, which suggests that the goal-relevance effects observed in the previous experiments are unlikely to be attributable to the specific timing constraints we imposed in the visual perspective-taking tasks.

Experiment 5

In Experiments 2–4, we manipulated the goal-relevance of the avatar's perspective by varying the order in which the avatar-perspective trials and the self-perspective trials appeared. We attribute the results to the increased salience and task goal-relevance of the avatar's perspective when the avatar-perspective trials appeared before the self-perspective trials. Another possibility, however, is that completing *any* task—including one that does not entail processing the avatar's perspective—prior to completing the self-perspective trials is sufficient to strengthen incidental perspective tracking. Although we considered this explanation

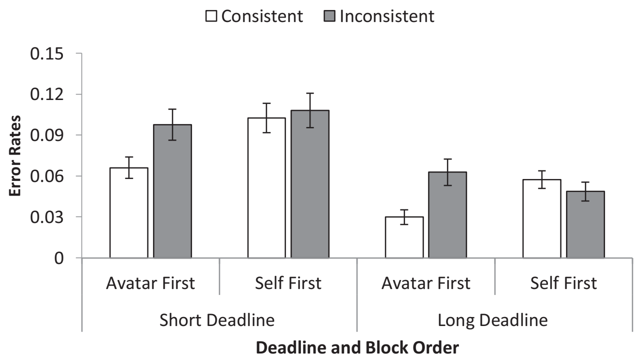

Figure 8. Error rates on self-perspective trials in Level-2 visual perspective taking (L2-VPT) by deadline, block order, and consistency; error bars depict ± 1 *SE* (Experiment 4).

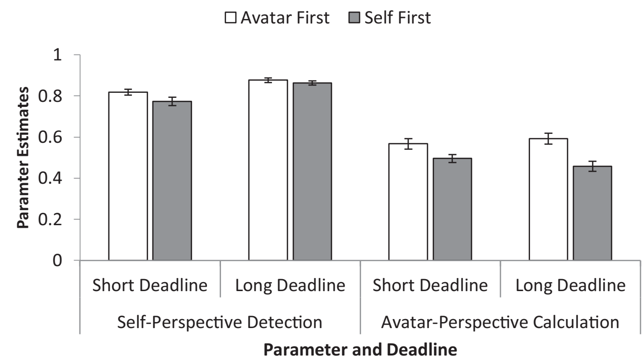

Figure 9. Process dissociation procedure (PDP) estimates of self-perspective detection and avatar-perspective calculation in Level-2 visual perspective taking (L1-VPT) by deadline and block order; error bars depict ± 1 *SE* (Experiment 4).

unlikely, we addressed this possibility in Experiment 5 by having all participants complete the self-perspective trials after completing trials that either did or did not make the avatar's perspective salient and goal-relevant. Because the effects of goal-relevance on L2-VPT in Experiments 1–4 were generally consistent with those reported by Surtees, Samson, et al. (2016), in Experiment 5, all participants completed only the L1-VPT task with the shorter (750 ms) response deadline.

Importantly, in Experiment 5, we also modified the L1-VPT task so that the balloons varied in color (red vs. blue) on a trial-by-trial basis. As in Experiments 2 and 3, some participants first completed trials in which they verified the number of balloons that were visible to the avatar, thus making the avatar's perspective salient and goal-relevant prior to completing the self-perspective trials. Other participants instead first completed trials in which they verified the color of the balloons. Although the avatar still appeared in the room in this condition, there was no mention of the avatar, thus making his perspective less salient and goal-relevant prior to completing the self-perspective trials. Finally, because the color of the balloons was identical from the two perspectives, we removed the perspective cues (He or You) from all trials.

We expected that the goal-relevance of the avatar's perspective would moderate L1-VPT task performance. Specifically, we predicted that reducing the goal-relevance of the avatar's perspective by having participants complete color-identification trials (vs. avatar-perspective trials) prior to completing the self-perspective trials would weaken both altercentric interference in behavioral analyses and avatar-perspective calculation in PDP analyses.

Table 8
Analyses of Self-Perspective Detection and Avatar-Perspective Calculation (Experiment 4)

Effect	$F(1, 268)$	p	η_p^2
Self-perspective detection			
Deadline	24.61	<.001	.084
Block Order	3.73	.055	.014
Deadline × Block Order	1.15	.285	<.01
Avatar-perspective calculation			
Deadline	<1	.779	<.01
Block Order	18.21	<.001	.064
Deadline × Block Order	1.71	.192	<.01

Method

Participants and power. We set a target sample size of at least 180 participants for 80% a priori power to detect the smallest effect of the goal-relevance manipulation on avatar-perspective calculation in L1-VPT in Experiments 1–3 ($d_s = 0.42$, from the exploratory analyses in the separate-blocking condition in Experiment 1 reported in the online supplemental material). Undergraduates ($N = 195$) participated for course credit. Data were excluded from 1 participant who performed below chance and 4 participants for whom a computer malfunction resulted in data loss, leaving a final sample of 190 (152 women, 37 men, 1 unreported; 103 Asian, 44 Latinx, 21 White, 5 Black, 16 reporting more than one race/ethnicity, 1 unreported). A sensitivity analysis indicated that this sample size afforded >80% power to detect a small-to-medium sized effect of first block on the PDP estimates of avatar-perspective calculation ($d_s = 0.41$).

Procedure and materials. The procedure and materials were identical to those for the L1-VPT task in Experiments 1–3, with several differences. First, all the balloons floating in the room varied in color (red vs. blue) on a trial-by-trial basis throughout the task. Second, the blocks of self-perspective trials, which entailed reporting the number of balloons that were visible to oneself, always appeared after blocks of trials that either made the avatar's perspective salient and goal-relevant or made the avatar's perspective less goal-relevant. Finally, no perspective cues (You or He) appeared on any of the trials in either condition.

Participants were randomly assigned to one of two experimental conditions that varied the processing objective in the first blocks of trials. The avatar-perspective condition was identical to the condition from Experiments 2 and 3 in which the avatar-perspective trials appeared first in the L1-VPT task: Participants in this condition first reported the number of balloons that were visible to the avatar, thus making the avatar's perspective goal-relevant prior to their completing self-perspective trials. In the color-identification condition, by contrast, participants first identified the color of the balloons, thus ensuring that the avatar's perspective was less goal-relevant prior to their completing the self-perspective trials.

Results

Behavioral analyses. A 2 (First Block) × 2 (Consistency) ANOVA yielded a First Block main effect, $F(1, 188) = 6.13$, $p = .014$, $\eta^2_p = .032$: Error rates were higher when the avatar-perspective trials appeared first than when the color-identification trials appeared first. The Consistency main effect was also significant (i.e., altercentric interference), $F(1, 188) = 6.27$, $p = .013$, $\eta^2_p = .033$. Finally, the First Block × Consistency interaction was significant, $F(1, 188) = 5.94$, $p = .016$, $\eta^2_p = .031$: Altercentric interference was weaker when the color-identification trials appeared first than when the avatar-perspective trials appeared first (see Figure 10). Follow-up analyses revealed reliable altercentric interference when the avatar-perspective trials appeared first ($M_{\text{diff}} = 3.16\%$, $SD = 10.64$), $t(94) = 2.89$, $p = .005$, $d_z = 0.30$, but not when the color-identification trials appeared first ($M_{\text{diff}} = 0.04\%$, $SD = 6.47$; $t < 1$, $p = .947$, $d_z = 0.01$).

Process analyses. Contrary to Experiments 1–4, detection of one's own perspective (see Figure 11) was weaker when the avatar-perspective trials appeared first than when the color-identification trials appeared first, $t(188) = 2.56$, $p = .011$, $d_s = 0.37$. In line with Experiments 1–3, however, calculation of the avatar's perspective (see Figure 11) was weaker when the color-identification trials appeared first than when the avatar-perspective trials appeared first, $t(188) = 1.99$, $p = .048$, $d_s = 0.29$.

Finally, as in Experiments 1–4, we tested for the presence of avatar-perspective calculation by comparing parameter estimates in each condition against a value of .50. Significant avatar-perspective calculation emerged when the avatar-perspective trials appeared first ($M = .56$, $SD = .21$), $t(94) = 2.87$, $p = .005$, $d_z = 0.30$, but not when the color-identification trials appeared first ($M = .50$, $SD = .21$; $t < 1$, $p = .969$, $d_z = 0.004$).

Discussion

Experiment 5 used a different manipulation of goal-relevance and conceptually replicated the L1-VPT results observed in Experiments 1–3. Once again, when the avatar's perspective was relevant to participants' task goal prior to completing the self-perspective trials, there was behavioral evidence of altercentric interference in L1-VPT. When the avatar's perspective was less goal-relevant, however, there was no behavioral evidence of altercentric interference in L1-VPT. The same general pattern emerged in the PDP analyses of avatar-perspective calculation: Calculation of what was visible to the avatar was slightly weaker when the avatar's perspective was never goal-relevant prior to completing the self-perspective trials. There was also an unexpected effect of goal-relevance on self-perspective detection, with weaker parameter estimates emerging when the avatar's perspective was less goal-relevant prior to completing the self-perspective trials. This effect was not present in any of the other experiments (and was in the opposite direction in Experiment 4), nor was it present meta-analytically (see the Internal Meta-Analysis section below); nevertheless, we return to this issue in the General Discussion.

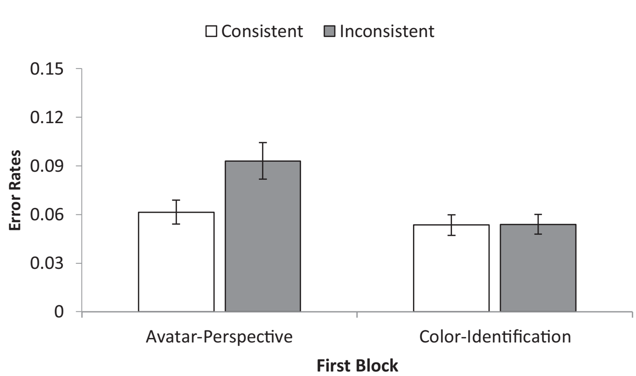

Figure 10. Error rates on self-perspective trials in Level-1 visual perspective taking (L1-VPT) by first block and consistency; error bars depict ± 1 *SE* (Experiment 5).

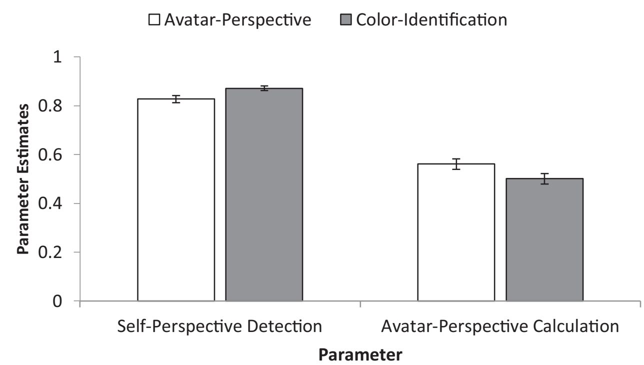

Figure 11. Process dissociation procedure (PDP) estimates of self-perspective detection and avatar-perspective calculation in Level-1 visual perspective taking (L1-VPT) by first block; error bars depict ± 1 *SE* (Experiment 5).

Internal Meta-Analysis

Following recommendations to consider the totality of evidence from a program of research rather than from single experiments in isolation (e.g., Braver, Thoemmes, & Rosenthal, 2014; Ledgerwood, 2019), we ran several sets of meta-analytic tests to quantify the cumulative effect of the relevance of the avatar's perspective for participants' task goal (hereafter, goal-relevance)[11] on (a) estimates of avatar-perspective calculation and self-perspective detection from the PDP analyses and (b) indices of altercentric interference from the behavioral analyses in the L1-VPT and L2-VPT tasks. We used McShane and Böckenholt's (2017) single-paper meta-analysis tool[12] to examine several contrasts of theoretical interest.

A first set of contrasts tested the simple effect of goal-relevance on avatar-perspective calculation separately in L1-VPT (contrast code: 1 −1 0 0) and L2-VPT (contrast code: 0 0 1 −1). Both

[11] We treated the mixed-blocking condition (Experiment 1) and the conditions in which the avatar-perspective trials appeared first (Experiments 2–5) as "goal-relevant," and we treated the separate-blocking condition (Experiment 1) and the conditions in which the self-perspective trials (Experiments 2–4) or the color-identification trials (Experiment 5) appeared first as "less goal-relevant." In addition, because the goal-relevance effects in Experiment 4 were comparable across response deadline conditions, we collapsed across this variable in all meta-analytic tests.

[12] http://www.singlepapermetaanalysis.com

contrasts were significant (L1-VPT: Estimate = 0.093, 95% CI [0.056, 0.130], $z = 4.93$, $p < .001$; L2-VPT: Estimate = 0.086, 95% CI [0.054, 0.117], $z = 5.36$, $p < .001$), indicating that calculation of the avatar's perspective was weaker when the avatar's perspective was less goal-relevant. Furthermore, a contrast testing the Level × Goal Relevance interaction (contrast code: 1 −1 −1 1) was not significant (Estimate = 0.008, 95% CI [−0.041, 0.056], $z < 1$, $p = .761$), suggesting comparable effects of goal-relevance on avatar-perspective calculation in L1-VPT and L2-VPT. None of these same contrasts on self-perspective detection was significant (zs < 1, ps > .464), suggesting that detection of one's own perspective was relatively unaffected by the goal-relevance of the avatar's perspective.

Next, we examined the same contrasts testing the simple effect of goal-relevance on behavioral indices of altercentric interference (errors on inconsistent trials minus errors on consistent trials) separately in L1-VPT and L2-VPT. Both contrasts were significant (L1-VPT: Estimate = 3.53%, 95% CI [1.76, 5.29], $z = 3.92$, $p < .001$; L2-VPT: Estimate = 3.24%, 95% CI [1.53, 4.94], $z = 3.72$, $p < .001$), indicating that altercentric interference was weaker when the avatar's perspective was less goal-relevant. The Level × Goal Relevance interaction was not significant (Estimate = 0.29%, 95% CI [−2.16, 2.74], $z < 1$, $p = .817$), which further suggests that the goal-relevance manipulations had comparable effects on altercentric interference in L1-VPT and L2-VPT.

Finally, because evidence for the presence of altercentric interference was inconsistent across experiments, we conducted a final set of contrasts testing the simple effect of consistency (i.e., more errors on inconsistent trials vs. consistent trials) within each goal-relevance condition separately for L1-VPT and L2-VPT. When the avatar's perspective was goal-relevant, the simple effect of consistency was significant both in L1-VPT (Estimate = 4.00%, $CI_{95\%}$ [2.15, 5.85], $z = 4.23$, $p < .001$) and in L2-VPT (Estimate = 4.00%, $CI_{95\%}$ [1.73, 6.26], $z = 3.45$, $p < .001$), thus providing robust evidence for the presence of altercentric interference in both tasks. When the avatar's perspective was less goal-relevant, however, the simple effect of consistency was not significant in L1-VPT (Estimate = −0.006%, $CI_{95\%}$ [−1.56, 1.55], $z < 1$, $p = .994$) or in L2-VPT (Estimate = 0.77%, $CI_{95\%}$ [−1.35, 2.89], $z < 1$, $p = .476$), suggesting no cumulative behavioral evidence for the presence of altercentric interference in either task.

In sum, both the focal process of avatar-perspective calculation as measured via process dissociation as well as altercentric interference as a behavioral effect were considerably weaker when the avatar's perspective was less relevant to participants' task goal. Furthermore, these effects of goal-relevance emerged—and with comparable strength—in both L1-VPT and L2-VPT. Finally, it was only when the avatar's perspective was salient and goal-relevant that there was any evidence of altercentric interference in either L1-VPT or L2-VPT.[13]

General Discussion

We explored whether the incidental tracking of *what* objects another agent sees—L1-VPT—and the tracking of *how* the agent sees those objects—L2-VPT—are dependent on having a goal, albeit a remote one, to process the agent's perspective. Prior work found that Level-2 perspective tracking was weaker when the agent's perspective was less relevant to perceivers' task goal, whereas Level-1 perspective tracking operated regardless of the goal-relevance of the avatar's perspective (Samson et al., 2010; Surtees, Samson, et al., 2016; see also Conway et al., 2017). In five experiments, we partially replicated these earlier findings, in that decreasing the salience and goal-relevance of the avatar's perspective consistently weakened perspective tracking in L2-VPT. Contrary to this prior work, however, decreasing the goal-relevance of the avatar's perspective also reduced perspective tracking in L1-VPT, and the strength of this goal-relevance effect in L1-VPT was comparable to that observed in L2-VPT.

Notably, these results were robust across several levels of analysis: They were evident not only in behavioral analyses of altercentric interference but also in process analyses using the process dissociation procedure (PDP; Jacoby, 1991), which aims to isolate avatar-perspective calculation as the process of focal interest underlying altercentric interference (Qureshi & Monk, 2018; Todd et al., 2017, 2019). Furthermore, across experiments, these goal-relevance effects emerged more consistently in the process analyses than in the behavioral analyses, which further attests to the utility of the PDP for uncovering differences in underlying processes that might go underdetected in behavioral analyses. The collective findings, therefore, indicate that calculating other agents' perspectives may be a goal-dependent process in both L1-VPT and L2-VPT.

Theoretical Implications and Connections With Prior Research

The current research complements and extends prior theoretical and empirical work on visual perspective taking and theory of mind in several ways. First, our findings have important implications for the two-systems account of mindreading (Apperly & Butterfill, 2009; Butterfill & Apperly, 2013; Low et al., 2016), which predicts that Level-1 perspective calculation should display more features of automaticity than should Level-2 perspective calculation. Consistent with this account, some prior research suggests that perspective calculation may operate efficiently in L1-VPT (Todd et al., 2017, 2019; cf. Qureshi & Monk, 2018), but not in L2-VPT (Todd et al., 2019). Insofar as one assumes alignment, or even modest covariation, among the various features of automaticity (e.g., between goal-independence and efficiency; Kahneman, 2003), it would not be unreasonable to expect perspective calculation to operate independent of participants' processing goals in L1-VPT, but not in L2-VPT (cf. Low et al., 2016). The current findings paint a more nuanced picture, however—one that comports with mounting evidence that the various automaticity features often do not co-occur (Melnikoff & Bargh, 2018): Whereas Level-2 visual perspective calculation appears to be goal-dependent and effortful, Level-1 visual perspective calculation appears to be goal-dependent but relatively more efficient. Thus, the current work highlights the utility of a feature-based approach (Bargh, 1989, 1992, 1994; Moors & De Houwer, 2006) for testing

[13] We conducted meta-analytic tests on the RTs that were analogous to those conducted on the error rates reported above. The results of these analyses, which appear in the online supplemental material, were nearly identical to the results of the error rate analyses: There was no behavioral evidence of altercentric interference in either L1-VPT or L2-VPT when the avatar's perspective was less goal-relevant.

theoretical claims and drawing conclusions about the automaticity of processes underlying L1-VPT and L2-VPT.

Second, using a process-oriented framework with the PDP allowed us to isolate avatar-perspective calculation as the process of focal interest underlying altercentric interference, and in a way that avoids the explanatory circularity that arises from equating altercentric interference (the behavioral effect to be explained) with calculation of a target agent's perspective (the putative process that explains the effect; Gawronski & Bodenhausen, 2015). Furthermore, although the PDP can be helpful for clarifying *what* a process underlying a behavioral effect does (operating *principles*), it cannot specify *when* the process occurs (operating *conditions*; Gawronski et al., 2014; Sherman et al., 2014). In other words, the mathematical formalization of the PDP, on its own, is unable to directly address questions about the automaticity of perspective calculation; such questions are more appropriately answered empirically by testing the conditions under which it operates (Gawronski et al., 2014; Sherman et al., 2014). For example, prior work has examined the efficiency of perspective calculation in L1-VPT and L2-VPT by imposing time pressure (Todd et al., 2019), and the current experiments tested whether it is goal-dependent by altering the relevance of the avatar's perspective for participants' focal task goal. Future research could use this approach to examine whether Level-1 and Level-2 visual perspective calculation display other features of automaticity (e.g., controllability, awareness).

Third, not only did we consistently observe that altercentric interference was weaker when the avatar's perspective was less relevant to participants' task goal; we also consistently failed to observe any evidence of altercentric interference in L1-VPT in these conditions. These findings conceptually replicate similar null effects reported in several other studies. For example, one study reported evidence of altercentric interference in a standard mixed-blocking variant of the L1-VPT task, but only when self-perspective trials were immediately preceded by an avatar-perspective trial; when self-perspective trials were preceded by another self-perspective trial, there was no evidence of altercentric interference (Ferguson, Apperly, & Cane, 2017). Another study also failed to observe altercentric interference in a variant of the L1-VPT task that comprised only self-perspective trials and no references to the avatar (Gardner, Hull, Taylor, & Edmonds, 2018), which suggests that altercentric interference in L1-VPT may be most likely to emerge when the avatar's perspective is salient and goal-relevant.

These findings notwithstanding, several other studies have reported behavioral evidence of altercentric interference in variants of the L1-VPT task in which self-perspective trials appeared in isolation or were otherwise separated from avatar-perspective trials (Cole, Atkinson, Le, & Smith, 2016; Conway et al., 2017; Gardner, Bileviciute, & Edmonds, 2018; Langton, 2018; Samson et al., 2010; Santiesteban et al., 2014; Schurz et al., 2015; Surtees, Samson, et al. 2016; Wilson, Soranzo, & Bertamini, 2017). Furthermore, both Conway et al. (2017) and Surtees, Samson, et al. (2016) varied the task goal-relevance of the avatar's perspective within the same experiment and found no differences in the strength of altercentric interference based on goal-relevance.

One possible explanation for our failure to find evidence of altercentric interference when the avatar's perspective was less goal-relevant is that these effects are modest in size in such conditions, and perhaps our experiments were underpowered to detect them. It is always important to consider issues of statistical power when interpreting null effects; however, given that the current participant samples were considerably larger than what is typical in this literature, we do not view insufficient power as a likely explanation. Indeed, our use of relatively larger samples may help explain why, unlike some prior studies (e.g., Conway et al., 2017; Samson et al., 2010; Surtees, Samson, et al., 2016), we consistently did observe goal-relevance effects on altercentric interference in both L1-VPT and L2-VPT. Granted, statistical power is governed by more than just sample size, and there may be other aspects of our experiments that contributed to the absence of altercentric-interference effects when the goal-relevance of the avatar's perspective was dampened. For example, the avatars in our L1-VPT task were front/back facing (see also Surtees, Samson, et al., 2016), and it is possible that such stimuli provide weaker perspective cues than the original left/right facing avatar stimuli in Samson et al. (2010) and in most other studies. Future research will be needed to determine the precise conditions needed for altercentric interference in L1-VPT and L2-VPT to emerge.

Finally, a growing literature has examined whether characteristics of perceivers affect altercentric interference in indirect measures of visual perspective taking. Examples of such perceiver characteristics include both relatively stable conditions, such as psychopathy (Drayton, Santos, & Baskin-Sommers, 2018) and autism spectrum disorder (Schwarzkopf, Schilbach, Vogeley, & Timmermans, 2014), as well as more transitory experiential states, such as sleep deprivation (Deliens et al., 2018), cognitive load (Qureshi et al., 2010; Qureshi & Monk, 2018; Todd et al., 2017, 2019), and integral (Bukowski & Samson, 2016) and incidental emotions (Todd & Simpson, 2016). Our work adds to this literature by exploring whether and how perceivers' momentary goals shape processes underlying visual perspective taking.

Limitations and Additional Directions for Future Research

We acknowledge several limitations of the current work, each of which suggests avenues for future research. First, in Experiment 5, self-perspective detection in L1-VPT was unexpectedly weaker when the self-perspective trials were preceded by avatar-perspective trials versus color-identification trials. One potential explanation for this effect is that the avatar-perspective trials are more resource-consuming than the color-identification trials, perhaps because there are no perspective differences to resolve in the latter trials. Indeed, RTs and error rates were higher overall on the avatar-perspective trials than on the color-identification trials ($ps < .001$), which indicates that the former trials may be more cognitively taxing than the latter trials. However, findings from other work suggest that a cognitive load explanation is unlikely to fully account for the results of Experiment 5. For example, Qureshi and Monk (2018) found that concurrently performing a resource-consuming secondary task has negligible effects on, and might even *decrease*, avatar-perspective calculation in L1-VPT. In Experiment 5, by contrast, completing the (ostensibly more resource-consuming) avatar-perspective trials *increased* avatar-perspective calculation in L1-VPT. Furthermore, a cognitive load explanation cannot account for the results of Experiments 1–4, in which there were no significant goal-relevance effects on self-perspective detection in either L1-VPT or L2-VPT.

Second, although providing evidence for how perceivers' processing goals shape perspective calculation, our experiments are silent on how the putative processing goals of the target agent affect visual perspective calculation. Moreover, because all our experiments used variants of the same visual perspective-taking tasks with a cartoon avatar, it is unclear how participants' processing goals shape perspective calculation in other visual perspective-taking tasks, including ones that involve a face-to-face interaction with a live human agent whose processing goal during the task differs from that of participants.

In one such study (Elekes et al., 2016), participants interacted with a live partner who had either an identical task goal (e.g., verifying the identity of a numeral that looked different from self and other perspectives) or a different task goal (e.g., verifying the color of the numeral). Altercentric interference emerged when participants thought their partner also had a task goal of verifying the identity of the numeral, but not when participants thought their partner was focused on the color of the numeral, suggesting that perspective tracking in L2-VPT may be dependent on the target agent's having the same processing goal as participants do.

In a similar live interaction study, however, Surtees, Apperly, et al. (2016) found evidence of altercentric interference (i.e., more difficulty verifying the identity of a numeral that looked different to a partner), even when participants thought their partner had a different task goal (i.e., verifying a surface feature of the numeral). These results suggest that Level-2 perspective tracking may not be dependent on the target agent's sharing one's own processing goals (see also Freundlieb, Sebanz, & Kovács, 2017). Future research will be needed for a more complete understanding of how processing goals—both those of the perceiver and those of the target agent—shape calculation of the agent's perspective.

Third, we have claimed that the current research is an investigation of the *goal-dependence* of visual perspective-taking processes. Specifically, we assert that, even though participants' focal/proximal task goal on the self-perspective trials is simply to report their own perspective, intermixing the avatar-perspective trials with the self-perspective trials (in Experiment 1) or completing the avatar-perspective trials prior to the self-perspective trials (in Experiments 2–5) activates within participants a distal/remote goal to process the avatar's perspective on the self-perspective trials. Conversely, we suggest that this remote goal to process the avatar's perspective should be less likely to be operating on the self-perspective trials when participants complete the avatar-perspective trials after or otherwise separately from the self-perspective trials. Our findings that altercentric interference and avatar-perspective calculation were both absent in such conditions are consistent with this goal-dependence interpretation; however, these findings are also consistent with other interpretations. For example, the avatar's perspective is arguably more salient, or attention-eliciting, on the self-perspective trials when participants complete the avatar-perspective trials beforehand. We do not view a salience interpretation as being contradictory to or mutually exclusive with a goal-dependence interpretation, particularly given that one might reasonably expect activated task goals to shape attention during the task. Disentangling these interpretations will require future research.

Another possibility is that the self-perspective trials are more demanding on executive resources when they are intermixed with the avatar-perspective trials or when they appear after the avatar-perspective trials. Evidence that taxing participants' executive resources meaningfully affects PDP estimates of avatar-perspective calculation in L1-VPT is mixed, however: One study has reported decreased avatar-perspective calculation (Qureshi & Monk, 2018), and others have reported no differences in avatar-perspective calculation (Qureshi & Monk's, 2018, PDP analysis of Qureshi et al., 2010; Todd et al., 2017, 2019). Consequently, we tend to favor a goal-dependence explanation of the current findings over one based on executive function. Nevertheless, we recognize that we are observing the activity of a remote goal indirectly via its impact on a behavioral outcome (i.e., altercentric interference) and a process parameter (i.e., avatar-perspective calculation). Future research should consider ways to assess the operation of a remote task goal (or lack thereof) more directly.

Fourth, a limitation of the PDP approach is that it treats avatar-perspective calculation in L1-VPT and L2-VPT as reflecting one and the same process. As noted earlier, however, avatar-perspective calculation in L1-VPT entails tracing a line of sight between the avatar and the object, whereas avatar-perspective calculation in L2-VPT entails mentally rotating oneself into the avatar's position. Because this parameter functionally entails calculation of the avatar's perspective in both tasks, even granting qualitative differences in the strategies used for calculating Level-1 versus Level-2 perspectives, we deem it apt to use the same term for this process parameter in L1-VPT and L2-VPT (see also Todd et al., 2019). Insofar as Level-2, but not Level-1, perspective tracking varies based on angular disparity between the avatar and oneself (Kessler & Rutherford, 2010; Michelon & Zacks, 2006; Surtees et al., 2013a, 2013b), the avatar-perspective calculation parameter should be more responsive to angular disparity manipulations in L2-VPT than in L1-VPT. Future research should examine this possibility.

Another limitation of the PDP approach is that it only models participants' ultimate decisions, as reflected in their error rates. By not considering decision speed, the PDP overlooks cases of altercentric interference in which participants respond correctly but more slowly on inconsistent self-perspective trials than on consistent self-perspective trials. Future studies could address this limitation by using alternative multinomial modeling approaches that simultaneously consider both decisions and decision speed (e.g., Heck & Erdfelder, 2016).

It will also be important for future research to incorporate approaches besides PDP analysis and other multinomial modeling techniques to extract processes underlying visual perspective-taking task performance. To be sure, avatar-perspective calculation and self-perspective detection may not be the only processes operating during the L1-VPT and L2-VPT tasks used here. For example, Bukowski and Samson (2017) identified two performance indices in L1-VPT tasks that map onto two dimensions of interest: One index captures the ability to handle conflicting perspectives, and the other index captures a relative attentional focus on one's own perspective versus another agent's perspective. Although we are not aware of studies that have applied this approach to L2-VPT tasks, future studies could investigate whether (and to what extent) these performance indices display features of automaticity in L1-VPT and L2-VPT tasks. Future work might also parameterize additional processes to account for other possibilities.

Finally, the construct at issue in altercentric-interference effects in L1-VPT is a matter of debate, much of which centers on whether these effects reflect something that is specifically social (i.e., the mentalizing account) versus more domain-general, such as attentional cueing (i.e., the submentalizing account; Heyes, 2014). Although adjudicating between these accounts was not a goal of the current work,[14] a tacit assumption of our use of the PDP is that the avatar-perspective calculation parameter reflects a social process. Granted, if altercentric-interference effects reflect a more domain-general process, as the submentalizing account maintains, then the process captured by the "avatar-perspective calculation" parameter may reflect the calculation of something inclusive of but more general than the content of the avatar's perspective.

One challenge to this interpretation, however, is evidence that estimates of this parameter are greater when the entity in the room is a human agent than when it is nonagentic (Todd et al., 2017). Furthermore, research outside the domain of visual perspective taking suggests that the processes captured by analogs of both PDP parameters may reflect a combination of domain-specific and domain-general processes (Payne, 2001, 2005). Insofar as reasoning about other entities' perspectives reflects a specialized use of a more domain-general mechanism or set of mechanisms (Spunt & Adolphs, 2015), future work may profit from trying to understand how domain-general processes function in specific social contexts (Michael & D'Ausilio, 2015) rather than from trying to settle the mentalizing/submentalizing debate.

Conclusion

Accumulating evidence from indirect measures of visual perspective taking attests to the seeming ease with which people track what others see (Level-1 perspective taking) and how they see it (Level-2 perspective taking). Here, we examined whether and how perceivers' processing goals shape the incidental tracking of other agents' visual perspectives. Results from five experiments and an internal meta-analysis revealed that reducing the goal-relevance of a cartoon avatar's perspective weakened both Level-1 and Level-2 visual perspective calculation. These results were robust across two levels of analysis, emerging both in behavioral analyses of interference from the avatar's differing perspective (i.e., altercentric interference) and in process analyses using the process dissociation procedure, which aims to isolate calculation of the avatar's perspective as the process of focal interest underlying altercentric interference. The collective findings suggest that both Level-1 and Level-2 visual perspective calculation may be dependent on having a (remote) goal to process a target agent's perspective.

[14] The absence of altercentric-interference effects in L1-VPT when the avatar's perspective was less goal-relevant may be just as problematic for the sub-mentalizing account as it is for the mentalizing account. An attentional cueing-based variant of the submentalizing account, for example, predicts that altercentric interference should emerge even when the avatar (or any entity, for that matter) is not salient or otherwise relevant for participants' task goal (Heyes, 2014; Santiesteban et al., 2014).

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