When do comprehenders mentalize for pragmatic inference?

Sean Trott and Benjamin Bergen

Department of Cognitive Science, University of California, San Diego, 9500 Gilman Dr., La Jolla, CA 92093

Author Note

Sean Trott (Corresponding author):

Email address: sttrott@ucsd.edu

Mailing address:

Department of Cognitive Science

9500 Gilman Dr.

La Jolla, CA 92093-0515

Abstract

People often speak indirectly. For example, “It’s cold in here” might be intended not only as a comment on the temperature, but also as a request to turn on the heater. How are comprehenders’ inferences about a speaker’s intentions informed by their ability to reason about the speaker’s mental states, i.e., *mentalizing*? We introduce a mechanistic framework by which mentalizing might be recruited for pragmatic inference, then ask: is mentalizing recruited primarily for *sampling* mental state information, or also for the *deployment* of that information for pragmatic inference? We find that the role of mentalizing is modulated by how explicitly a task involves knowledge. Mentalizing correlates with task performance when comprehenders are asked to sample and report mental state information (Experiment 1b), or when given mental state information explicitly and asked to make an inference (Experiment 2-Explicit); in contrast, mentalizing does not correlate with task performance, or correlates only weakly, when participants are given mental state information implicitly and asked to make a pragmatic inference (Experiment 1a, Experiment 2-Implicit). These results suggest that mentalizing is recruited flexibly, allowing comprehenders to construct meaning from under-specified input.

When do comprehenders mentalize for pragmatic inference?

People often speak indirectly. For example, a speaker might say "It's cold in here" not just to comment on the temperature of the room, but also as an indirect request to turn on the heater. These *indirect requests* are demonstrably common; one study elicited requests from participants and found that over 80% of them were indirect in some way (Gibbs, 1981). Furthermore, they are ambiguous: in isolation, and often even in context, these utterances license more than one interpretation. Consequently, comprehenders must frequently infer which meaning was intended by the speaker in a given context. This inference could be challenging, as a speaker's intended interpretation may depend on what they want or what they know. How do comprehenders succeed under these conditions?

One possibility is that making inferences about speaker intent uses a form of *mentalizing* (Frith & Frith, 2006). That is, comprehenders may infer a speaker's intended interpretation by relying in part on inferences about that speaker's mental states, perhaps constructing a model of their interlocutor. This model could include, among other things, the speaker's preferences, current emotional state, and beliefs about the world (Gibbs, 1987). These inferred mental states might allow a comprehender to modulate their interpretation of ambiguous utterances not only as a function of their own contextual knowledge, but also according to their beliefs about the speaker's contextual knowledge. For example, if a speaker believes that a nearby heater is operational, then they might utter "It's cold in here" as an indirect request to turn on the heater. If a comprehender knows that the heater is in fact broken, but also that the speaker is unaware of this fact, then the comprehender might judge "It's cold in here" to still plausibly be a request to turn it on. Through the use of a model of the speaker, a comprehender could thus suppress their

egocentric perspective (they know the heater is broken), and interpret ambiguous language like "It's cold in here" from the perspective of what they believe the speaker to know.

This overall phenomenon is sometimes referred to as *perspective-taking* (Flavell, 1992; Batson et al., 1997; Epley, Morewedge, & Keysar, 2004; Dale et al., 2018). In the interest of clarity, for the remainder of this paper, we will use the term *perspective-taking* to refer to the general phenomenon in which a comprehender (or speaker) allows an interlocutor's perspective to modulate their interpretation (or production) of an utterance (Dale et al., 2018). In contrast, we will use the term *mentalizing* to refer to the ability of individuals to make inferences concerning, and reason about, the mental states of others (Frith & Frith, 2006). In other words, we view *mentalizing* as a cognitive ability comprising a wide set of related operations, which can be recruited for various purposes, potentially including (but not limited to) perspective-taking; whereas *perspective-taking* is a broad phenomenon that might rely on our ability to mentalize, but which is also known to draw on functions such as inhibitory control and working memory (Brown-Schmidt, 2009; Nilsen & Graham, 2009; Wardlow, 2013; Ryskin et al., 2015; Long et al., 2018). Thus, when we ask whether pragmatic inference depends in part on *mentalizing*, we aim to characterize the mechanisms by which the ability to reason about the mental states of others is recruited to adopt their perspective—and in turn, determine whether this perspective-taking is what allows comprehenders to infer the speaker's intended interpretation.

Current evidence is mixed on the extent to which pragmatic inference involves mentalizing. In what follows, we first describe the state of the field, then in the hope of understanding variable results, introduce a mechanistic account of how information about a speaker's mental states could theoretically influence pragmatic interpretation. Drawing inspiration from Apperly (2018), this account posits multiple component processes that must be

engaged in order for the phenomenon of *perspective-taking* to occur. In a pair of studies, we then ask whether and how *mentalizing* might play a role during any or all of the component processes.

Mentalizing for pragmatic inference

There is some evidence that comprehenders reason about the mental states of others to infer their intent. First, correlated difficulties in mentalizing and nonliteral language comprehension have been identified in select neurodivergent populations, including individuals diagnosed with schizophrenia (Brüne & Bodenstein, 2005; Champagne-Lavau & Stip, 2010) and right-hemisphere brain damage (Winner et al., 1998). Second, several recent studies using functional MRI found increased blood flow to brain regions associated with mentalizing (e.g., the medial prefrontal cortex, temporoparietal junctions) while participants processed indirect requests (van Ackeren et al., 2012; van Ackeren, Smaragdi, & Rueschemeyer, 2016) and indirect replies (Bašnáková et al., 2013). Third, theoretical and computational models of pragmatic inference almost always involve some kind of mental state reasoning (Frank & Goodman, 2012; Goodman & Stuhlmüller, 2013; Williams et al., 2014; Briggs et al., 2017; Trott & Bergen, 2017). These models do not demonstrate that human comprehenders *must* mentalize for pragmatic inference, but they do provide indirect evidence that doing so could be useful.

Finally, and most relevantly to our purposes here, a previous set of studies (Trott & Bergen, 2018) found that comprehenders modulated their pragmatic interpretations as a function of a speaker's inferable knowledge states, and that their likelihood to do so was predicted by their mentalizing ability, as measured by the Short Story Task (Dodell-Feder et al., 2013). In other words, Trott & Bergen (2018) observed evidence for the phenomenon of *perspective-taking*, as well as a predictive relationship between mentalizing ability and the extent to which an individual exhibited perspective-taking behavior.

However, there is also evidence that mentalizing may not play a critical role in pragmatic inference. For instance, pragmatic impairments are not universal among neurodivergent populations. Children with autism have been found to understand and comply with indirect requests (Kissine et al., 2015). Additionally, Schulze et al (2013) found that typically-developing 3-year-old children understood certain kinds of indirect speech acts, and argued that the ability to do so depends not on *mentalizing* per se but rather on the ability to establish joint attention. Finally, work on perspective-taking suggests that comprehenders sometimes fail to account for differences in knowledge states when interpreting a speaker's intentions (Keysar et al., 2003), or when predicting how a third-party lacking critically disambiguating knowledge will interpret a potentially sarcastic utterance (Keysar, 1994; Keysar, 2000). These failures of perspective-taking are exacerbated under time pressure (Epley et al., 2004b; Epley & Gilovich, 2006; Deliens et al., 2017). And in fact, even studies that have found evidence for perspective-taking behavior (Trott & Bergen, 2018) observed considerable differences in the degree to which participants adopt a speaker's perspective, depending on the *task*. Participants are more likely to answer in a manner consistent with a speaker's inferable knowledge states when asked to indicate their interpretation via *paraphrase judgment* (e.g., "Could you turn on the heater?" vs. "It's cold in here; too bad the heater is broken") than *explicit judgment* (e.g., "Is [the speaker] making a request?").

Further evidence on the role of mentalizing in pragmatic inference comes from work on individual differences. If pragmatic inference depends on mentalizing, then better mentalizers should also be better at successfully discriminating a speaker's intent. Once again, however, the picture is mixed. One study (Tromp, 2018) found no significant relationship between how accurately an individual identified indirect requests and their score on the communication subscale of the Autism Quotient, or AQ (Baron-Cohen et al., 2001). On the other hand, the same

study (Tromp, 2018) found that AQ scores did significantly correlate with pupil size during processing, taken as a proxy for processing effort. Other studies (Trott & Bergen, 2018; Fairchild, 2018) have found significant relationships between a participant's mentalizing ability (and in the case of Fairchild (2018), also executive function) and their ability to understand when an utterance was intended as a request.

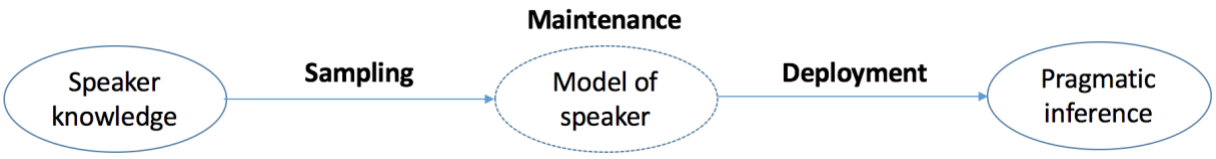
Thus, the existing evidence is mixed on whether and when comprehenders mentalize for pragmatic inference. Critically, we will now argue that this may be due in part to lack of clarity about the mechanisms by which mentalizing might (or might not) contribute to the process of inferring what a speaker means by what they say.

A mechanistic explanation: different component processes subserve perspective-taking for pragmatic inference

The studies surveyed above used different tasks. It is possible that these different tasks revealed the use or non-use of mentalizing on different *component processes* of perspective-taking during pragmatic inference.

Perspective-taking uncontroversially requires the comprehender to engage multiple component processes. Specifically, a comprehender must *sample* information about a speaker's perspective, *maintain* that information in memory with minimal decay, and *deploy* it for pragmatic inference (see *Figure 1* for a schematic of these component processes). These processes roughly correspond to what Apperly (2018) labels *inference*, *storage*, and *use*. As Apperly (2018) notes, individual differences among comprehenders may produce variability in their ability to successfully engage each process: "the likelihood that others' mental states will be inferred, stored, or used depends upon dispositional characteristics of the participants, their

motivation, and their cognitive resources" (Apperly, 2018, pg. 6). In principal, mentalizing could play a role during any or all of these processes.



This appeal to potential differences among component processes might explain variable evidence for mentalizing in previously reported pragmatic inference tasks. Here is how this could work, taking as a case study the series of experiments reported by Trott & Bergen (2018). Note that in the discussion below, we conflate sampling and maintenance, largely because of a lack of experimental data dissociating the process of sampling mental state information from maintaining that information over time.

In each experiment in Trott & Bergen (2018), participants read a series of passages, each ending with a character in the passage producing a potential indirect request (e.g., "It's cold in here"). In all the passages, there was an obstacle to fulfilling that request (e.g., a broken heater). However, the speaker only knew about this obstacle on half the trials (Speaker Aware); on the other half of trials, the speaker was unaware of an obstacle to fulfilling the request (Speaker Unaware). The speaker's knowledge states were never stated explicitly, but were implied by the events in the passage (e.g., the speaker was not present when the broken heater was discovered). The studies asked whether participants' pragmatic interpretations of the potential indirect request changed systematically as a function of the speaker's inferable knowledge states. Pragmatic interpretation was assessed in two different ways: in Experiments 1-2, participants were asked to make paraphrase judgments about the speaker's intent, whereas in Experiment 3, they were

asked to indicate explicitly whether they thought the speaker was making a request. In all experiments, participants were more likely to interpret an utterance as a request when the speaker was unaware of an obstacle to fulfilling that request. However, the effect of speaker awareness was considerably larger when participants made paraphrase judgments (Experiments 1-2) than when indicating their interpretation directly (Experiment 3). Why was the size of the main effect different across experiments?

Critically, the paraphrase judgments in Experiments 1-2 made reference to a speaker's knowledge states (e.g., "It's cold in here; **too bad the heater is broken**"). This means that participants could answer in a manner congruent with what a speaker knew without ever using this knowledge to explicitly infer their intent. In other words, participants in Experiments 1-2 could show an effect of speaker awareness by simply sampling information about a speaker's knowledge states (and maintaining that information in memory long enough to answer a question about it); in contrast, participants in Experiment 3 had to both sample this information, and deploy it for pragmatic inference. Thus, it is possible that Experiments 1-2 measured only sampling and maintenance, whereas Experiment 3 measured the combined rates of sampling, maintenance, and deployment. Under this account, the differences across Experiments 1-2 and Experiment 3 could be attributed to *information loss* that occurred during the deployment of speaker knowledge. That is, it is possible that some participants in Experiment 3 correctly sampled a speaker's knowledge states, maintained that information in memory, but failed to successfully convert that information into a pragmatic interpretation congruent with what a speaker knew.

Breaking down the phenomenon into component processes is also helpful for explaining differences in the magnitude of the individual difference results across Experiments 2-3. While

Trott & Bergen (2018) observed a positive relationship between *mentalizing ability* and *congruent response* in both experiments, the magnitude of this relationship was larger in Experiment 2 than Experiment 3. It appears that mentalizing was more predictive of an individual's ability to sample and answer questions about knowledge states directly (Experiment 2), than their ability to sample, maintain, and deploy those knowledge states for pragmatic inference (Experiment 3). One interpretation is that mentalizing ability plays a central role in sampling information about a speaker's knowledge states and maintaining that information in memory, but a weaker role in deploying that information downstream. In fact, the weak relationship observed during Experiment 3 could be due to residual differences produced by mentalizing variability during the sampling and maintenance stages.

As mentioned earlier, a component-based account (sampling, maintaining, deploying) is consistent with distinctions others have made about the component processes underlying perspective-taking during language comprehension (Apperly, 2018). It is also consistent with one interpretation of perspective-taking failures demonstrated in previous findings—namely, that apparent failures to adopt a speaker's perspective when inferring their intended interpretation are due primarily to failures to successfully deploy this information, rather than encode it in the first place (Keysar, 2000; Keysar et al., 2003). For example, Keysar (2000) argued that participants' egocentric bias arises not because of encoding failures, but because of the *illusory transparency of intention*: having already interpreted an utterance as sarcastic (or not), comprehenders fail to recognize alternative interpretations of the same utterance, and project their interpretation onto a third-party comprehender—despite their knowledge that this third-party comprehender does not have access to critical disambiguating information.

To date, however, no studies have attempted to isolate the rates at which individuals sample, maintain, and deploy information about a speaker's knowledge states on the same task. Connecting variability in the successful completion of each component process to individual difference measures, such as mentalizing, should give us a more precise understanding of which cognitive mechanisms are recruited for pragmatic inference, as well as why comprehenders sometimes fail to adopt a speaker's perspective when interpreting their intentions.

Current work

In the current set of experiments, we aimed to measure the role of mentalizing in the key component processes argued to be involved in pragmatic inference: the sampling and maintenance of speaker knowledge, and the deployment of that knowledge on some downstream task. We do this both through a primary manipulation in which mentalizing would change a comprehender's judgment about speaker intent, and also by asking whether individual differences in mentalizing ability across participants predict variability during either component process. All data and code to replicate the critical analyses described below can be found on GitHub: https://github.com/seantrott/trott_bergen_mentalizing_paper2.

Experiment 1

In Experiment 1, we asked whether mentalizing is recruited primarily to sample and maintain information about a speaker's knowledge states, to deploy that information, or both. As a second-order question, we asked about the relative rates of information loss during both component processes: to what extent do comprehenders make errors while sampling and maintaining a speaker's knowledge states, vs. while also deploying it for pragmatic inference?

We attempted to measure these component processes using different tasks in a between-subjects design. The first task (Experiment 1a, "Inference") was identical to Experiment 3 from Trott & Bergen (2018). In the second task (Experiment 1b, "Knowledge"), participants read the same passages as those in the Inference group, but without the potential indirect request. Participants were asked a question about the character's inferable knowledge states, e.g., "Does he know the heater is broken?". Thus, answering correctly required sampling this information and maintaining it in memory, but not deploying it for pragmatic inference.

We also measured participants' mentalizing ability (and propensity) using the Short Story task, or SST (Dodell-Feder et al., 2013), which is described in more detail below. The SST has since been used to assess mentalizing ability in several other studies (Zucchelli et al., 2018; Giordano et al., 2019; Vargas et al., 2019; Licea-Haquet et al., 2019). The explicit mental state reasoning measure has been found to correlate with the Reading the Mind in the Eyes Test (RMET), another measure of Theory of Mind ability, in English-speaking (Dodell-Feder et al., 2013), Spanish-speaking (Giordano et al., 2019), and Italian-speaking populations (Zucchelli et al., 2018); it has also been found to negatively correlate with Autism Quotient scores (Zucchelli et al., 2018), as well as reaction time on a speech act recognition task (Licea-Haquet et al., 2019). Most relevantly, it also predicts participants' likelihood of sampling and deploying information about a speaker's knowledge states, over and above differences in Reading comprehension (Trott & Bergen, 2018). However, this previous work did not attempt to isolate the role of mentalizing ability in each component process.

Here, we asked whether mentalizing ability predicted performance in either the Inference or Knowledge group. If mentalizing is only recruited during sampling and maintenance, then this should predict performance in the Knowledge group, but not necessarily in the Inference group.

Theoretically, this could also predict a relationship in the Inference group—due to residual variability caused by better mentalizers being more likely to have sampled and retained mental state information in the first place—but it should be no larger than the effect seen in the Knowledge group. By contrast, if mentalizing is only recruited during deployment, there should be no effect in the Knowledge group, and a measurable effect only in the Inference group. And if mentalizing is recruited during all component processes, we should observe an effect in the Knowledge group, and an even larger effect in the Inference group.

Methods.

Participants. We aimed to recruit 160 native English speaking participants through Amazon Mechanical Turk, but Mechanical Turk under-sampled to only 156 participants. Participants were paid $3. We then removed 8 participants who answered that they had read the Hemingway story before, 1 participant who failed to respond to the SST, and 5 participants whose debriefing responses indicated they saw through the experimental manipulation. This resulted in a total of 142 participants (68 female, 74 male). The average age was 35 (SD=10), with ages ranging from 19 to 71.

Materials. For the primary task, there were 8 pairs of narrative passages, each featuring an interaction between the protagonist (addressed in the 2nd-person) and another character. In each passage, the 2nd-person protagonist learned of some obstacle (e.g., a broken heater). The manipulation across each pair of passages was whether the other character also learned of this obstacle (Speaker Aware), or remained unaware (Speaker Unaware). The full list of stimuli used in Experiment 1 are listed in the Supplementary Materials (items 1-8).

In the Inference group (1a), these passages ended with a potential indirect request, such as “It’s cold in here”. In the Knowledge group (1b), the passages were identical, but ended before the other character produced the potential indirect request.

Finally, there was also a web-adapted version of the Short Story Task (Dodell-Feder et al., 2013), consisting of 14 critical questions designed to measure Explicit mental state reasoning, Reading comprehension, and Spontaneous mental state inference.

The experiment was implemented using JsPsych (de Leeuw, 2015).

Procedure. Participants were randomly assigned using JsPsych’s randomization procedure to either the Inference (1a) or Knowledge (1b) group. Of the final 142 participants, 56 were assigned to 1a, and 86 to 1b. The experimental groups did not differ significantly in age [$F(1, 140)=.36, p=.6$] or gender [$X^2(1)=.33, p=.6$].

Within each group, participants were further assigned to one of two lists, counterbalanced for which items were in the Speaker Aware or Speaker Unaware condition.

Participants then read a series of 8 narrative passages. At the end of each passage, they advanced to the next page, and were asked to answer a question. In the Inference group, participants read a target utterance (e.g., “It’s cold in here”), and were asked “Is [the speaker] making a request?”). They indicated their response by pressing a button for “Yes” or “No”. In the Knowledge group, participants were not shown a target utterance, and were instead asked a question about a character’s knowledge states (e.g., “Does he know the heater is broken?”). Speaker Awareness was manipulated within-subject, while group (Inference vs. Knowledge) was manipulated between-subjects.

After completing the primary task, all participants completed the Short Story Task (Dodell-Feder et al., 2013). Participants read a short story by Ernest Hemingway called *The End*

of Something, then answered a series of questions designed to target three dimensions: 1) Explicit mental state reasoning, i.e., how well participants reasoned about the mental states of others when prompted; 2) Reading comprehension, i.e., how well participants understood the general events of the story; and 3) Spontaneous mental state inference, i.e., whether participants mentioned or made mental state inferences without prompting. As in the original version, participants were allowed to return to the story's text while answering the 14 critical questions. Unlike the original version, participants wrote their answers in a free-response box, rather than saying them aloud. In addition to the critical questions, participants were asked whether they had read the story before, and if so, how long ago, why they read it, how well they remembered it, whether it was familiar to them, and whether they'd discussed it with anyone.

Finally, we collected demographic information from each participant (reported age, self-identified gender, and whether or not they were a native English speaker), as well as what they thought the experiment was about. The experiment took on average 26 minutes to complete.

Results.

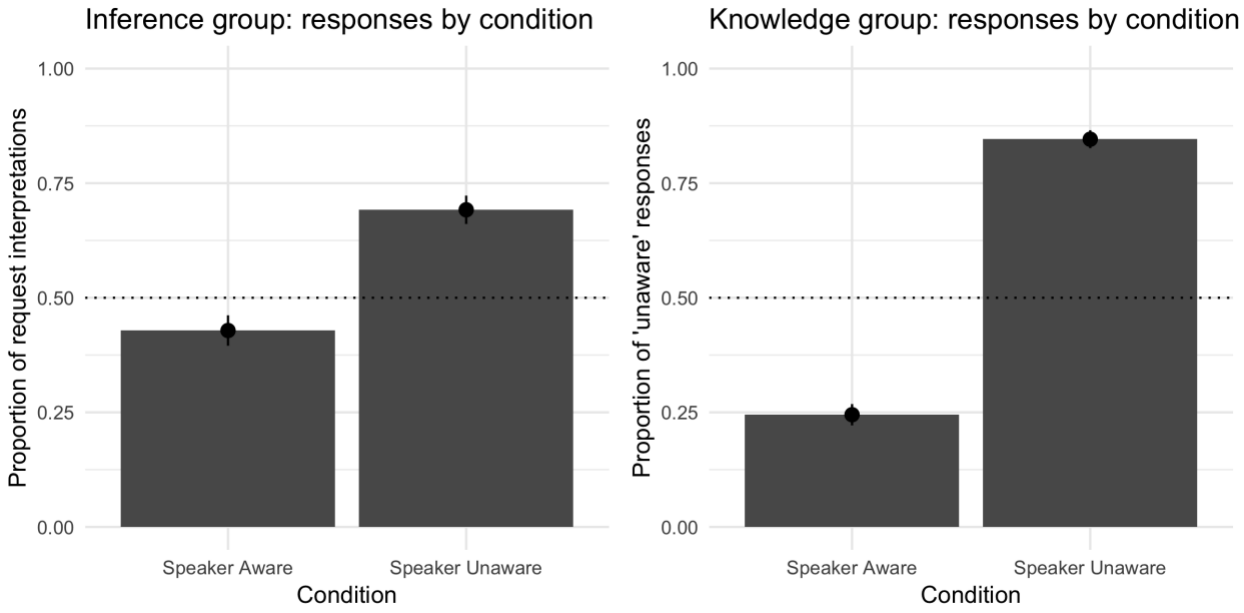
All analyses were performed in R (R Core Team, 2017). Generalized linear mixed effects models were run using the *glmer* command from the *lme4* package (Bates et al., 2015). Results were obtained using nested model comparisons. Random effects structure was determined by beginning with the maximal model, then reducing random effects as needed for model convergence (Barr et al., 2013). All categorical variables were coded alphabetically using R's default reference coding.

Primary task. Our first question was whether participants assigned to the Inference group (1a) modulated their explicit pragmatic interpretations as a function of inferable speaker knowledge, and whether participants assigned to the Knowledge group (1b) correctly identified

the other character's inferable knowledge states. In both analyses, the full model included Response (Yes vs. No) as a dependent variable, Awareness (Speaker Aware vs. Speaker Unaware) as a fixed effect, and by-subject and by-item random slopes for the effect of Awareness (and random intercepts for both). We then compared this model to a model omitting the fixed effect of Awareness. A positive coefficient reflects an increased likelihood of a "Yes" response, while a negative coefficient reflects an increased likelihood of a "No" response.

In the Inference group, a model including a fixed effect of Awareness explained significantly more variance than a model omitting that fixed effect [$X^2(1)=14.9, p=.0001$]. Request responses were more likely in Speaker Unaware than Speaker Aware trials [$\beta=1.5, SE=.3, p=5.87*10^{-7}$]; 69% of Speaker Unaware trials had Request responses, compared to 43% of Speaker Aware trials. Adding an interaction between awareness and order (i.e., trial position) did not improve model fit over a model including only the main effects [$X^2(1)=.8, p=.4$]. However, a model predicting response on the first trial alone was not significantly improved by the addition of awareness [$X^2(1)=1.7, p=.19$].

Awareness also improved model fit for the Knowledge group [$X^2(1)=23.3, p=1.35*10^{-6}$]. Participants were more likely to answer "No", i.e., that the speaker did not know about the obstacle, on Speaker Unaware trials than Speaker Aware trials [$\beta=-3.65, SE=.46, p=3.5*10^{-15}$]; 85% of participants answered "No" on Speaker Unaware trials, compared to only 25% on Speaker Aware trials. An interaction with order did not significantly improve model fit [$X^2(1)=2.15, p=.14$]. Participants accurately identified a speaker's knowledge states from the first trial, as evidenced by comparing a model predicting response from Awareness on the first trial alone (with random intercepts for items) to a model omitting Awareness [$X^2(1)=42.67, p=6.5*10^{-11}$].



Finally, to assess whether participants sampled and maintained implicit information about speaker knowledge states at a higher rate than they also deployed that information, we analyzed data from both experimental groups together. A full model including an interaction between Awareness and Group (Knowledge vs. Inference) significantly improved model fit over a model omitting only that term [$X^2(1)=28.1$, $p=1.2*10^{-7}$]; specifically, the effect of speaker knowledge was larger for the Knowledge group than the Inference group [$\beta=2.04$, $SE=.38$, $p=1.13*10^{-7}$].

In sum, participants' responses in both groups showed a robust effect of a speaker's inferable knowledge states (see *Figure 2* for a visualization of this effect). These results replicate the effect of speaker knowledge on pragmatic interpretation reported previously (Trott & Bergen, 2018), and further demonstrate that participants sample and maintain speaker knowledge at a higher rate, at least when asked to, than they sample, maintain, and deploy it.

SST coding and analysis. See *Supplementary Analysis 1* for details on how the SST responses were coded and analyzed.

SST and primary task. Finally, we asked whether a participant's mentalizing ability (as measured by Explicit mental state reasoning) or propensity (as measured by Spontaneous mental state inference) predicted whether they would choose a response (e.g., pragmatic interpretation or knowledge assessment) consistent with Awareness (Speaker Aware vs. Speaker Unaware)—above and beyond that participant's binned Reading comprehension. All models below included by-item random slopes for the effect of Awareness, as well as random intercepts for items. All critical model comparisons asked whether adding an interaction between Awareness and the individual difference score (e.g., Explicit mental state reasoning) under consideration improved model fit over a model with only the fixed effects.

Mentalizing ability. In the Inference group (1a), a model including an interaction between Awareness and Explicit mental state reasoning did not explain more variance than a model with only the fixed effects [$X^2(1)=.07$, $p=.8$], indicating that better mentalizers were not more likely to choose a pragmatic interpretation consistent with a speaker's inferable knowledge states.

In the Knowledge group (1b), a model including an interaction between Awareness and Explicit mental state reasoning did explain more variance than the reduced model [$X^2(1)=5.5$, $p=.02$]. Because mental state reasoning correlated with Reading comprehension, we then compared a model including both interactions (Awareness and Explicit mental state reasoning, and Awareness and Reading comprehension) to a model omitting only the critical interaction with Explicit mental state reasoning, and found that the full model still explained more variance [$X^2(1)=4.9$, $p=.03$]. Better mentalizers were more likely to correctly answer "No" in the Speaker Unaware condition [$\beta=-.2$, $SE=.07$, $p=.03$]. In other words, participants who were better at reasoning about the mental states of others were more likely to correctly sample what a speaker knew or did not know and retain that information long enough to respond appropriately, even

when controlling for differences in Reading comprehension. See *Figure 3* below for an illustration of the effect of mentalizing on congruent responses in the *inference* and *knowledge* groups, respectively.

A three-way interaction between Awareness, Explicit mental state reasoning, and Group did not significantly improve model fit [$X^2(1)=2.4$, $p=.12$].

Mentalizing propensity. A model including an interaction between Spontaneous mental state inference and Awareness did not explain more variance than a model with only the fixed effects for either the Inference (1a) group [$X^2(1)=1.4$, $p=.2$] or the Knowledge (1b) group) [$X^2(1)=1.3$, $p=.25$]. Thus, participants who mentioned the mental states of others without prompting were not more likely to sample and maintain a speaker's mental states when asked to;

nor were they more likely to sample, maintain, and deploy that information for pragmatic inference.

Discussion.

There were several main findings of Experiment 1. First, we replicated the main effect of speaker knowledge on pragmatic interpretation observed in previous studies (Trott & Bergen, 2018); participants were more likely to interpret an ambiguous utterance as a request when the speaker was unaware of obstacles to fulfilling that request. This indicates that participants sampled, maintained, and deployed information about a speaker's knowledge states for pragmatic inference[1]. Second, the two-way interaction between Awareness and Group provides preliminary evidence for *lossy conversion* during the deployment of mental state information for pragmatic inference (though see the discussion below of a potential confounding factor).

Finally, individuals with better mentalizing ability were more likely to correctly assess a speaker's implied knowledge states (i.e., the Knowledge group). This boost in performance is unlikely to be solely attributable to attentiveness; mentalizing explained variability in participants' responses above and beyond reading comprehension. However, in contrast to previous results (Trott & Bergen, 2018), better mentalizers were not more likely to choose a pragmatic interpretation consistent with those knowledge states (Experiment 1a). Importantly, this difference in the effect of mentalizing is not attributable to the effect size being smaller for the Inference group than the Knowledge group; while the Inference group did display a smaller effect of Awareness (a cross-condition difference of 26% vs. 60%, respectively), the *variance* in the effect of condition by participants in both groups was almost identical (SD=.35 and SD=.36,

[1] Of course, request interpretations in the Speaker Aware condition do not necessarily entail that these participants failed to encode speaker knowledge; participants could have interpreted utterances like "It's cold in here" as a request for something other than turning on the heater (e.g., grabbing a blanket). However, the main effect of Speaker Awareness indicates that in general, a speaker's knowledge (or lack of knowledge) regarding an obstacle to a particular course of action remained a relevant variable for pragmatic interpretation.

respectively). In principle, then, there were equivalent amounts of variance for participants' mentalizing scores to explain across both tasks—but mentalizing only explained significant variability on the Knowledge task. One plausible interpretation, consistent with the **Component-Based Account** outlined in the Introduction, is that mentalizing plays a role during the sampling and/or maintenance of mental state information, but not in the deployment of that information for pragmatic inference; that is, better mentalizers are more likely to successfully infer what a speaker knows or does not know, but not necessarily more likely to deploy that knowledge for pragmatic inference.

However, due to the task differences between Experiment 1a-1b, there is actually at least one alternative explanation of these results. This explanation preserves the component processes described above, but posits an intervening variable—namely, how explicitly the task makes reference to the speaker's knowledge states. It is possible—even likely—that foregrounding knowledge state information in the task modulates the dynamics of each component process. We call this the **Knowledge Explicitness account**. Experiment 1b asked participants about speaker's knowledge states, which could have encouraged them to sample those knowledge states at a higher rate than Experiment 1a, which asked participants to make pragmatic inferences (and kept knowledge states implicit in the passage). Differences in outcomes across different tasks could thus be attributed to those tasks encouraging or discouraging mentalizing to different degrees. For instance, participants in Experiment 1a may not have experienced deployment loss at all, but simply failed to sample and maintain information about a speaker's knowledge in the first place. Similarly, we cannot conclude that mentalizing only plays a role in sampling and maintenance. It is plausible that Explicit mental state reasoning could confer a particular benefit when the task more explicitly involves reasoning about the knowledge states of others (as in Experiment 1b).

That is, because Explicit mental state reasoning is a measure of how well an individual reasons about the mental states of others, it might be particularly predictive of performance on any task that involves either sampling mental state information *or* using a representation of mental states in some other cognitive process (e.g., pragmatic inference). If this is true, mentalizing should play a stronger role on tasks that explicitly involve knowledge in some way—even including a task involving only deployment.

The results of Experiment 1 do not adjudicate between these two possibilities, as Experiments 1a-1b were not designed with the Knowledge Explicitness account in mind. The tasks in Experiments 1a-1b differed along multiple dimensions, including but not limited to whether the task made explicit reference to a speaker's knowledge states; participants were given different instructions, had different goals, and likely engaged a different, though overlapping, set of component processes to complete Experiment 1a (sampling, maintenance, and deployment) versus Experiment 1b (sampling and maintenance). In order to properly adjudicate between the Component-Based and Knowledge Explicitness accounts, all dimensions would have to be held constant other than how explicitly a task or trial made reference to a speaker's knowledge states.

Fortunately, the accounts do make distinct predictions. According to the Component-Based interpretation of the results from Experiment 1, any relationship found between mentalizing and deployment of speaker knowledge is primarily attributable to differences that arose during sampling and maintenance. Therefore, performance on a task involving *only* deployment should be less correlated with mentalizing ability than performance on a task requiring sampling, maintenance, and deployment. That is, if the process of sampling and maintaining mental state information were "clamped" in some way, little to no relationship between mentalizing and deployment should be observed. In contrast, the Knowledge

Explicitness account holds that mentalizing ability can play a role during each component process, and that this role is modulated by the extent to which a task explicitly involves knowledge. This account makes the opposite predictions from the purely component-based account: performance on a task involving only deployment should be more affected by mentalizing ability (provided this task makes a speaker's knowledge states explicit), than performance on a task involving sampling, maintenance, and deployment (in which mental state information is implicit). That is, clamping the sampling process by making that information explicit should *strengthen* the relationship between mentalizing and deployment of speaker knowledge. Critically, this manipulation would hold the task constant—determining whether or not the speaker is making a request—and manipulate only knowledge explicitness.

Note that from a theoretical perspective, these accounts are not entirely incompatible; the Knowledge Explicitness account still allows for the possibility of component processes. However, it also introduces an intervening variable—how explicitly the task involves knowledge—and therefore makes a set of distinct predictions.

To address these outstanding questions, we designed Experiment 2.

Experiment 2

Experiment 2 aimed to adjudicate between these two explanations of when and how mentalizing plays a role in pragmatic inference. Specifically, does mentalizing ability primarily affect the rate at which comprehenders sample and maintain information about a speaker's knowledge states (the Component-Based account), or can it also affect the rate at which they deploy this information, provided the task explicitly involves knowledge (the Knowledge Explicitness account)? As a second-order question, we were interested in characterizing the degree of

information loss during both component processes, and in replicating the overall effect of speaker awareness on pragmatic interpretation.

In order to adjudicate between these accounts, Experiment 2 again manipulated Awareness (Speaker Aware vs. Speaker Unaware) in addition to a new variable: how explicitly a character's knowledge states were delivered in the passage (Explicit vs. Implicit). The Implicit versions were identical to those in Experiment 1a, requiring the reader to sample mental state information. The Explicit versions clamped the sampling process by explicitly indicating the speaker's knowledge states (e.g., "Jonathan… doesn't know about the broken heater").

The manipulation of Knowledge Explicitness allows us to adjudicate between the Component-Based and Knowledge Explicitness accounts of how mentalizing ability contributes to the sampling, maintenance, and deployment of speaker knowledge. According to the Component-Based account, variance in mentalizing ability only contributes to variance in sampling and maintenance; thus, there should be no correlation between mentalizing ability and performance on the Explicit trials (which probe only deployment), and a weak or null effect on Implicit trials (as in Experiment 1a). According to the Knowledge Explicitness Account, mentalizing ability helps primarily when the task explicitly involves knowledge; thus, mentalizing ability should correlate most strongly with performance on the Explicit trials—i.e., when participants are deploying a speaker's knowledge states. Theoretically, it might also predict performance on Implicit trials, but the effect should be weaker or harder to detect. Thus, the critical difference—both in aggregate, and in terms of individual variability—concerns performance on trials in which a speaker's knowledge states are made explicit.

This within-subject manipulation of Knowledge Explicitness also allows us to characterize the question of information loss during the sub-processes. Any differences in the

main effect of speaker knowledge across Implicit and Explicit versions are attributable to errors made during sampling and maintenance—that is, if participants choose congruent responses (i.e., request in Speaker Unaware, non-request in Speaker Aware) more when knowledge is made explicitly available, it suggests that their failure to do so on Implicit trials is because they failed to infer that information in the first place. And failures to choose congruent responses on Explicit trials—i.e., when participants no longer have to sample—must logically be due to information loss during the deployment of speaker knowledge.

Methods.

Participants. 80 participants, all native English speakers, were recruited through Amazon Mechanical Turk; they were paid $3 for participating. We removed 10 participants who failed to complete the Short Story Task, as well as 1 participant whose debriefing responses indicated they understood the experiment's manipulation, resulting in 69 participants (40 female, 28 male, 1 non-binary). The average age was 34 (SD=10.5), and ranged from 21 to 66.

Materials. The materials included the 8 pairs of narrative passages used in Experiment 1, as well as an additional 8 pairs with the same manipulation. All 16 passages ended with a potential indirect request (e.g., "It's cold in here"); the primary manipulation was whether the speaker was aware of an obstacle to fulfilling that request (Speaker Aware vs. Speaker Unaware).

There was also a manipulation of Knowledge Explicitness: each item had an Implicit version, in which the speaker's knowledge states had to be inferred (identical to Experiment 1), as well as an Explicit version, in which the speaker's knowledge states were given explicitly in the passage. For example, the passage might directly point out that a character is unaware of the

obstacle ("[Jonathan] is still inside and doesn't know about the broken heater"). The full list of items used in Experiment 2 can be found in the Supplementary Materials (items 1-16).

There was also a web-adapted version of the Short Story Task (Dodell-Feder et al., 2013), identical to the version used in Experiment 1 and in previous studies (Trott & Bergen, 2018). The experiment was implemented using jsPsych (de Leeuw, 2015).

Procedure. Participants were randomly assigned to one of four lists, counterbalanced for which items were in the Speaker Aware or Speaker Unaware condition, as well as which items were in the Explicit or Implicit knowledge condition. Both factors were manipulated within-subjects.

The procedure was identical to Experiment 1a. Participants read a series of 16 passages, each ending with a potential request. Trial order was randomized. After a participant read a passage, they advanced to the next page, which contained only the target utterance (e.g., "It's cold in here"), and were asked to indicate their pragmatic interpretation: "Is [the speaker] making a request?" Participants indicated their response by clicking either "Yes" or "No".

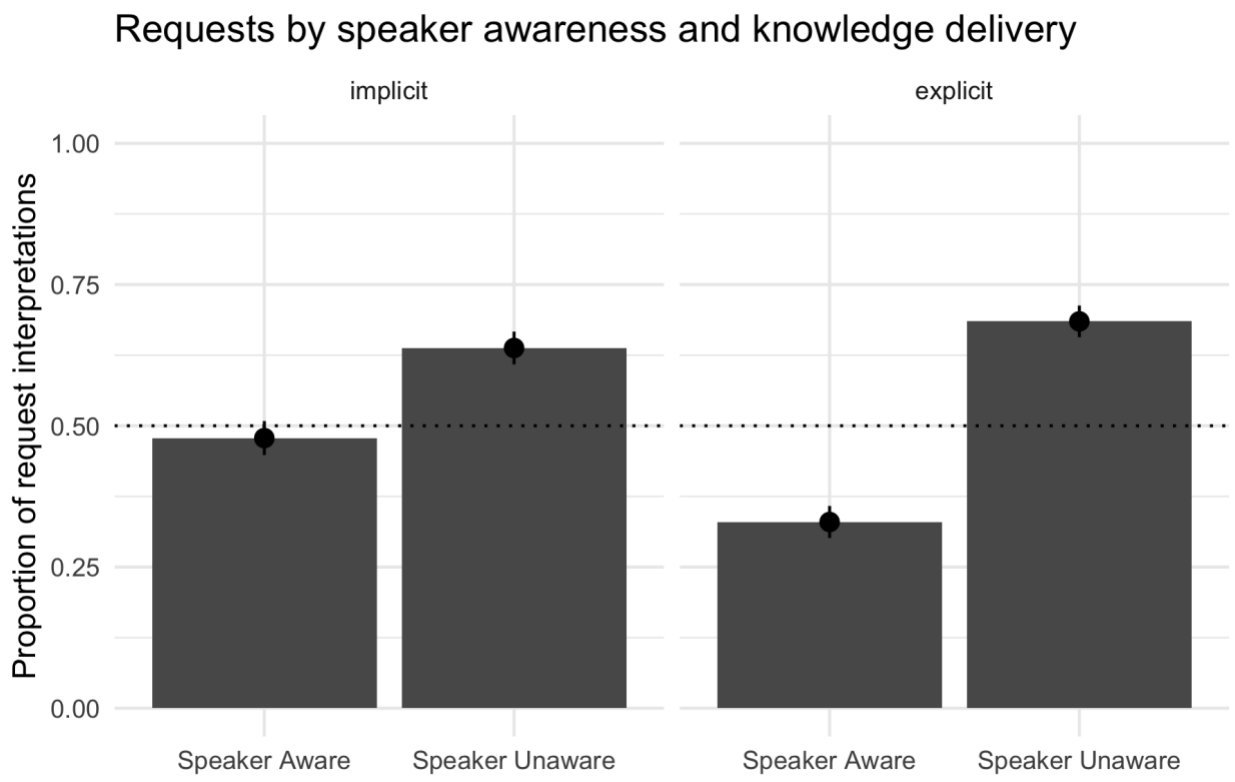
Participants then completed the web version of the SST (Dodell-Feder et al., 2013), provided demographic information (gender, age, and whether or not they were a native English speaker), and answered what they thought the experiment was about. The experiment took on average 35 minutes to complete.

Results.

As in Experiment 1, analyses were performed in R (R Core Team, 2017), using the *lme4* package (Bates et al., 2015), and random effects structure was determined by beginning with a maximal model (Barr et al., 2013).

Indirect requests task. Our first question was whether a speaker's knowledge states modulated participants' pragmatic interpretations. To ask this, we built a model with Response (Yes vs. No) as a dependent variable, Awareness as a fixed effect (Speaker Aware vs. Unaware), by-subject and by-item random slopes for the effect of Awareness, and random intercepts for subjects, items, and list. Awareness improved model fit over a model omitting that term [$X^2(1)=21.7, p=3.1*10^{-6}$]; Request responses were significantly more likely in the Speaker Unaware condition [$\beta=1.38, SE=.23, p=3*10^{-9}$]. A model including an interaction between Awareness and Order explained more variance in pragmatic interpretations than a model with only the fixed effects [$X^2(1)=4.5, p=.03$]. The likelihood of Request responses in Speaker Unaware trials increased as trial order increased [$\beta=.07, SE=.03, p=.03$], though there was still a main effect of Awareness overall [$\beta=.8, SE=.36, p=.03$].

A second-order question was whether the magnitude of the effect of speaker knowledge depended on how explicitly that knowledge was given in the passage. We found that a model including an interaction between Awareness and Knowledge Explicitness explained more variance than a model with only the fixed effects of each [$X^2(1)=12.2, p=.0005$]. Participants showed a smaller effect of speaker knowledge when that knowledge was given implicitly, as opposed to explicitly [$\beta= -1.03, SE=.3, p=.0004$]. This difference is illustrated in *Figure 3,* and is consistent with the hypothesis that participants experienced some degree of information loss during the sampling process.



Furthermore, as depicted in *Figure 4*, aggregate performance on the Explicit trials was far from ceiling—suggesting that even when the sampling of speaker knowledge is clamped, participants still fail to successfully deploy this information. In other words, comprehenders experience information loss in both the sampling and deployment of a speaker's knowledge states. The remaining question is: *why* does this information loss occur? Here, we turn to the individual difference results.

SST coding and analysis. See *Supplementary Analysis 1* for details on how the SST responses were coded and analyzed.

SST and Indirect Requests Task. We asked whether differences in mentalizing modulated the effect of a speaker's knowledge states on pragmatic interpretation—and whether this modulation depended on the explicitness of speaker knowledge. All models below included

by-item random slopes for the effect of Awareness, as well as random intercepts for items. In each case, nested model comparisons were used to determine whether the interaction between a given variable (e.g., Reading comprehension), improved model fit.

Explicit mental state reasoning and pragmatic interpretation. A model including an interaction between Awareness and mentalizing ability explained more variability in pragmatic interpretation than a model with only the fixed effects [$X^2(1)=17.9, p=2.3*10^{-5}$], indicating that mentalizing ability predicted a comprehender's likelihood of integrating a speaker's knowledge state into their interpretation. Specifically, better mentalizers were more likely to interpret the target utterances as requests on Speaker Unaware trials [$\beta=.16, SE=.04, p=2.5*10^{-5}$].

To control for the correlation between mentalizing and reading comprehension ($r = .62$), we constructed a model including interactions between Awareness and Explicit mental state reasoning, as well as Awareness and binned Reading comprehension. Nested model comparisons revealed that the interaction with Explicit mental state reasoning substantially improved model fit [$X^2(1)=10.3, p=.001$], while the interaction with Reading comprehension did not [$X^2(1)=1.41, p=.23$], suggesting that mentalizing in particular was responsible for improved performance. Better mentalizers were more likely to give Request responses on Speaker Unaware trials [$\beta=.14, SE=.04, p=.001$].

Finally, we asked whether mentalizing played a stronger role on the Implicit or Explicit trials. A three-way interaction between Explicit mental state reasoning, Awareness, and knowledge did not improve model fit [$X^2(1)=1.44, p=.23$]. However, we also conducted separate analyses of the Implicit and Explicit trials by running the same model described above (interactions between both Awareness and Explicit mental state reasoning, as well as Awareness and Reading comprehension), and found that the interaction with Explicit mental state reasoning

significantly improved model fit on the Explicit trials [$X^2(1)=9.1$, $p=.003$], but not on Implicit trials [$X^2(1)=2.44$, $p=.12$]. For the Explicit trials, mentalizing increased the likelihood of Request responses in the Speaker Unaware conditions [$\beta=.19$, $SE=.06$, $p=.003$]; for the Implicit trials, the interaction between mentalizing and Awareness was trending in the same direction but was not significant [$\beta=.09$, $SE=.06$, $p=.12$]. This difference is illustrated in *Figure 5* below.

Spontaneous mental state inference and pragmatic interpretation. An interaction between Spontaneous mental state inference and Awareness marginally improved model fit overall [$X^2(1)=3$, $p=.09$], but not over and above a model including an interaction between Reading comprehension and Awareness [$X^2(1)=1.6$, $p=.2$]. There was also no significant improvement in model fit on the Implicit trials [$X^2(1)=.9$, $p=.3$] or Explicit trials [$X^2(1)=2.3$, $p=.13$].

Discussion.

Experiment 2 had three critical findings. First, the results replicated the main effect of speaker knowledge on pragmatic interpretation found in both Experiment 1a and previous work (Trott & Bergen, 2018). Second, the interaction between Awareness and Knowledge Explicitness provides additional evidence that individuals experience information loss during the sampling of speaker knowledge, and the presence of incongruent pragmatic interpretations on Explicit trials indicates that at least some comprehenders failed to deploy knowledge state information.

Most importantly, mentalizing ability was correlated with performance in an analysis of all trials combined, as well as Explicit trials alone—above and beyond differences in Reading comprehension—but was only weakly related to performance on Implicit trials. Together with the results of Experiment 1, this provides evidence for the Knowledge Explicitness account: mentalizing predicts either sampling and maintenance (Experiment 1b), or deployment of speaker knowledge (Experiment 2 Explicit), when the task explicitly involves knowledge. When knowledge is implicit in the task (Experiment 1a, Experiment 2 Implicit), the relationship between mentalizing and task performance is either weak and hard to detect, or nonexistent. This makes sense, given the dimension of mentalizing found to be predictive—Explicit mental state reasoning, i.e., the ability to reason about the emotional states and beliefs of others.

That said, the three-way interaction between Speaker Awareness, Explicit mental state reasoning, and Knowledge Explicitness was not significant; this issue will be explored in greater detail in the section below.

Further Analysis of Previous Work

The results of Experiment 2 suggest that mentalizing ability predicts a comprehender's likelihood of deploying mental state information for pragmatic inference, but only (or primarily)

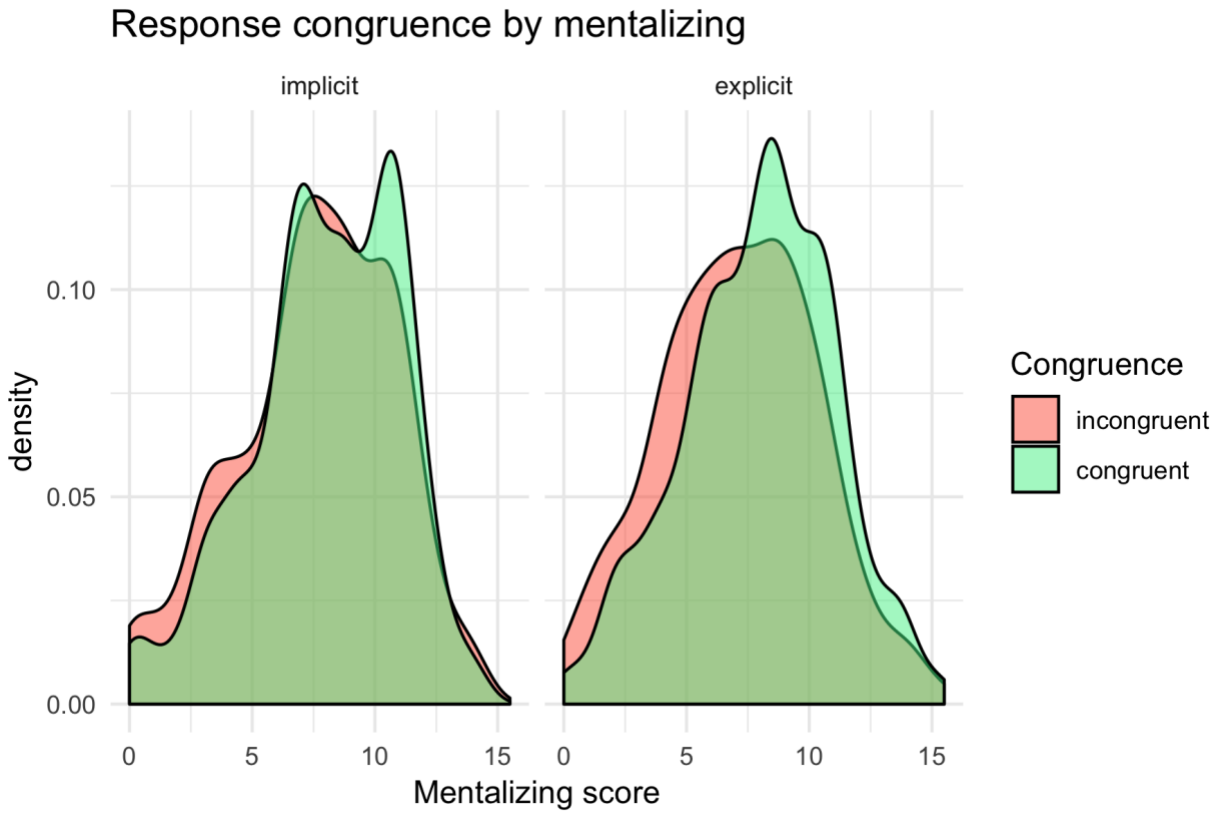
when that information is made explicit in the task. This is consistent with the Knowledge Explicitness account, which holds that the ability to reason about the mental states of others is recruited flexibly—situations or tasks that emphasize or otherwise call attention to a speaker's mental states as a valid cue could increase the likelihood of recruiting this strategy, meaning that individual differences in mentalizing ability will contribute to variability in task performance.

Further evidence for this conclusion comes from a post-hoc analysis combining these results with those reported in a previous paper (Trott & Bergen, 2018). We recoded each experiment in terms of how explicitly the tasks involved knowledge. "Explicit" tasks included Experiment 2 from Trott & Bergen (2018) (which contained explicit language about knowledge in the prompts), and both Experiment 1b (which did the same) and Experiment 2-Explicit (which provided explicit statements of speaker knowledge in the passages) from the current work. "Implicit" tasks were Experiment 3 from Trott & Bergen (2018), and both Experiment 1a and Experiment 2-Implicit from the current work, none of which mentioned speaker knowledge in the passages or response prompts. We asked whether Knowledge Explicitness modulated the extent to which mentalizing predicted a participant's likelihood of integrating a speaker's knowledge states into their response.

First, we constructed a model with response as a dependent variable (Yes/No), a three-way interaction between Awareness, mentalizing, and Knowledge Explicitness (and fixed effects for all), an interaction between Awareness and Reading comprehension, and random intercepts for experiments and items. Nested model comparisons indicated that the three-way interaction term modestly improved model fit [$X^2(1)=4.18$, $p=.04$].

Second, we conducted separate analyses on the Implicit vs. Explicit tasks, using the same full model used to assess the impact of mentalizing in Experiments 1-2 above: interactions

between both Awareness and mentalizing and Awareness and Reading comprehension (and fixed effects of all terms), and random intercepts for experiments and items. The interaction between Awareness and mentalizing substantially improved model fit for experiments in which knowledge was explicit [$X^2(1)=11.55$, $p=.0007$], but only weakly improved model fit for experiments in which knowledge was implicit [$X^2(1)=2.8$, $p=.09$].



Of course, this analysis is post-hoc, and as in Experiment 1, the tasks are not held constant across each comparison. However, the results are consistent with the results of Experiment 2, in which the task was held constant and only knowledge explicitness was manipulated. As depicted in *Figure 6* above, better mentalizers were more likely to make congruent responses when the task explicitly involved knowledge—either because relevant knowledge states were made explicit in the passage, or because the prompt made reference to a

character's knowledge states. The relationship with mentalizing was weaker, and more variable, when the task only implicitly involved knowledge; here, successful performance is less differentiated by mentalizing ability, perhaps because comprehenders are relying on alternative sources of information, or other cognitive capacities, to infer intent.

One question that arises is why the models containing three-way interactions in Experiments 1-2 (between Mentalizing, Speaker Awareness, and Group / Knowledge Explicitness) did not explain significantly more variance than reduced models, while the three-way interaction in the meta-analysis did (albeit only modestly). The absence of separate three-way interactions in Experiments 1-2 is all the more surprising since the Mentalizing by Speaker Awareness interaction was significant for Explicit but not Implicit trials in both studies. One possible explanation for the lack of a significant three-way interaction in Experiments 1-2 could be insufficient power to detect the effect. Post-hoc power analyses using the *simR* package (Green & MacLeod, 2016) indicate that, given the respective sample sizes in each study, our observed power to detect a three-way interaction was *78% [68.61%, 85.67%]* in Experiment 1, only *66% [55.85%, 75.18%]* in Experiment 2, and *91% [83.6%, 95.8%]* in the meta-analysis. This is consistent with an account that posits a small, but consequential, role of knowledge explicitness in modulating the relationship between mentalizing and task performance. Future work could follow up on this finding with a larger sample size and more power to detect an ordinal three-way interaction.

General Discussion

Our central question was whether, and how, comprehenders recruit their mentalizing ability to infer a speaker's intentions—specifically, whether they use information about the

mental states of a speaker to determine whether or not the speaker is making a request. We presented a mechanistic account of the component processes that must be engaged in order for perspective-taking to occur: a comprehender must first sample a speaker's knowledge states, maintain that information with minimal decay, then deploy that information downstream during pragmatic inference. We then asked whether and how variance in mentalizing ability correlated with performance on tasks designed to probe these component processes.

In Experiment 1, we found that variability in mentalizing predicted a participant's likelihood of correctly answering questions about a character's knowledge states (Inference group), but not their likelihood of using this information for pragmatic inference (Inference group). One interpretation of this result is that mentalizing is primarily recruited in order to sample information about a speaker's knowledge states, not to deploy that information.

An alternative interpretation, however, is that Experiment 1b encouraged participants to mentalize, and thus participants who were better at reasoning about the mental states of others (when prompted) were more successful. Under this interpretation, mentalizing is recruited flexibly as a function of how explicitly a task involves the knowledge states of others. This Knowledge Explicitness account makes opposite predictions from the purely Component-Based account: mentalizing ability should also predict a participant's likelihood of deploying knowledge states for downstream pragmatic inference, provided those knowledge states are made explicit in the task. We tested these accounts in Experiment 2 by holding the tasks constant (e.g., pragmatic inference) and clamping the sampling process in half the trials for each participant; we then compared the impact of mentalizing on these Explicit trials to trials on which knowledge was Implicit (as in Experiment 1a). Consistent with the Knowledge

Explicitness account, we found that mentalizing significantly predicted performance on Explicit trials, but was only weakly predictive on Implicit trials.

These results suggest that the ability to reason about the mental states of others is recruited flexibly in order to determine their intentions. Mentalizing can play a role not only in sampling and maintaining mental state information, but also in deploying this information to adjudicate between (or constrain among) competing interpretations of the same utterance. Critically, the extent to which better mentalizers exhibited better performance was modulated by the explicitness of knowledge in the task: when the task more explicitly involved knowledge—either because participants were directly asked about knowledge states (Experiment 1b), or because they were given those knowledge states directly in the passages (Experiment 2, Explicit trials)—mentalizing was more predictive of task performance. This finding is also supported by the results of a post-hoc meta-analysis combining the results of the current work and previous studies (Trott & Bergen, 2018).

Limitations and Future Work

One potential limitation to our results is that an absence of filler items could have created demand characteristics, with participants realizing that they were meant to attend to speaker knowledge throughout the experiment. Indeed, there was a significant interaction between Awareness and Order in Experiment 2, suggesting that some participants improved throughout the experiment. An anonymous reviewer highlighted a further complication resulting from this design: it could be that better mentalizers were more adept at recognizing what the primary task was testing—i.e., they mentalized with the experimenters, not just the characters in each passage. We attempted to mitigate the effect of demand characteristics by removing participants whose

debriefing responses suggested they saw through the task, but future work should also make use of filler items to distract from the key manipulation.

Importantly, these results also do not speak to the *persistence* of the variability we observed across participants, both in terms of differences in mentalizing and performance on the primary task. Concretely, our results indicate that variability on the SST predicts variability on the primary task (at least when task-relevant knowledge states are made explicit). But to the extent that people differ in their mentalizing ability across sessions, the same reader might score differently on the SST, and also on the primary task. Indeed, recent work has demonstrated that perspective-taking ability within individuals varies as a function of sleep deprivation (Deliens et al., 2018); future work could continue to investigate to what extent mentalizing is a stable construct across time points, and to what extent variability in this construct consistently predicts variability in pragmatic inferencing abilities.

These results inform the broader literature on perspective-taking and pragmatic inference. The first implication comes from our characterization, following Apperly (2018), of the phenomenon of perspective-taking as engaging multiple component processes. While others (Keysar, 2000; Keysar et al., 2003; Apperly, 2018) have made similar distinctions, previous work has not characterized the progression of mental state information throughout these component processes in the same task, nor how this progression is influenced by individual variability in mentalizing. We found that comprehenders lose information during each component process; further, we found that mentalizing can play a role in both sets of component processes, but that the size of this role depends on task demands. Future work could aim to further dissociate sampling from maintenance, perhaps by probing a participant's representation of a character's mental states at different time intervals.

The second implication is that mentalizing is a flexible strategy, recruited as needed. We found that the extent to which mentalizing correlates with task performance may depend on how explicitly the task involves knowledge—either because comprehenders are asked to sample directly, or because the cue is made readily available. Beyond task demands, the role of mentalizing in pragmatic inference may be impacted by the availability of alternative cues to meaning, such as prosody (Deliens et al., 2017). Notably, the current studies involved written stimuli; in multi-modal interaction, comprehenders have access to a wide variety of cues known to disambiguate the intent of potential indirect requests, including gesture and eye gaze (Kelly et al., 1999; Kelly, 2001), prosody (Trott, Reed, Ferreira, & Bergen, 2019), and more. In these cases, it could be that comprehenders use "frugal" strategies to infer intent and bypass mentalizing (Deliens et al., 2017). This raises an open question: how does the availability (and reliability) of different cues to a speaker's intended meaning influence the role of mentalizing in pragmatic inference, and how are these cues integrated over time, particularly when in competition?

Third, this work contributes to a wide body of literature demonstrating that comprehenders have difficulty overcoming the so-called illusory transparency of intention (Keysar, 1994; Keysar, 2000) and the related curse of knowledge (Birch, 2005; Birch & Bloom, 2007; Damen et al., 2018). Once comprehenders have interpreted an utterance (e.g., as sarcastic), they imagine that interpretation as "transparent" and project it to a third-party comprehender, even when that third-party does not possess critically disambiguating information (Keysar, 1994; Keysar, 2000). Our task involved a similar challenge—namely, participants reading utterances in the Speaker Unaware condition had to suppress their own knowledge of an obstacle and interpret (or re-interpret) an utterance from a speaker's perspective. By clamping the sampling process in

Experiment 2, we found that a participant's ability to successfully overcome this challenge was predicted by their mentalizing ability. That is, better mentalizers were less likely to fall victim to the curse of knowledge—and not simply because they were better at encoding the knowledge states of others, but because they were better at integrating those knowledge states into their pragmatic interpretations of what others said. However, this does not necessarily indicate that better mentalizers are better able to overcome the illusory transparency of intention, which is usually assessed by asking participants to predict the interpretation of a third-party. Based on the current design, we cannot determine whether mentalizing helps constrain pragmatic interpretation from the earliest stages of processing, such that comprehenders avoid an egocentric interpretation altogether; or whether mentalizing helps comprehenders recover from an initial "egocentric anchor" (Epley et al., 2004b). Future work could attempt to adjudicate between these possibilities by tracking the time course along which information about a speaker's knowledge states is integrated, using continuous measures like mouse-tracking (Freeman & Ambady, 2010). Mouse-tracking can be used to measure the relative attraction towards one of multiple response options over time (Spivey, Grosjean, & Knoblich, 2005; Dale & Duran, 2011; Koop, 2013). Here, the critical question would be whether individual differences in mentalizing, as well as other factors known to influence perspective-taking, such as working memory and executive function (Wardlow, 2013; Ryskin et al 2015; Brown-Schmidt, 2009; Nilsen & Graham, 2009; Long et al., 2018), predict the extent to which participants experience attraction to an egocentric response during processing. Better mentalizers may experience less deviation towards an egocentric response altogether, indicating that mentalizing helps constrain among competing interpretations early on; alternatively, better mentalizers might experience the same amount of deviation towards the egocentric response, but display more successful

corrections from this deviation, indicating that mentalizing helps comprehenders overcome the illusory transparency of intention.

Conclusion

Pragmatic ambiguity pervades language use. Comprehenders likely recruit a variety of cognitive resources and draw on multiple sources of information to infer a speaker's intent. One such resource may be mentalizing, the ability to reason about the mental states of others. Across two experiments, we found that individual differences in mentalizing predicted a participant's success at sampling information about a speaker's knowledge states (Experiment 1b), as well as their reliability in deploying this information when it was explicitly given (Experiment 2-Explicit). Critically, the extent to which mentalizing predicted task performance was modulated by how explicitly the task involved knowledge, as indicated by the present studies and a meta-analysis including previous work (Trott & Bergen, 2018). This suggests that mentalizing may be recruited *flexibly* and as needed, ultimately providing further support for the notion that language comprehension is a dynamic, highly context-dependent process, with comprehenders exploiting various cognitive resources and information sources to construct meaning from a sparse, often under-specified input—and that variability among individuals could in turn influence the rate at which particular strategies are recruited.

Acknowledgments

We are grateful to Stefanie Reed, Alex Labranche, and Alex Liebscher for their help in coding the Short Story Task answers. We are also grateful to anonymous reviewers, as well as members of the Center for Research in Language (CRL) at UC San Diego, for feedback on early versions of this work. This work was funded by the UC San Diego Chancellor's Research Excellence Scholarship (CRES).

References

Apperly, I. (2018). Mindreading and Psycholinguistic Approaches to Perspective Taking: Establishing Common Ground. *Topics in cognitive science*, *10*(1), 133-139.

Bašnáková, J., Weber, K., Petersson, K. M., van Berkum, J., & Hagoort, P. (2013). Beyond the language given: the neural correlates of inferring speaker meaning. *Cerebral Cortex*, *24*(10), 2572-2578.

Baron-Cohen, S. (1988). Social and pragmatic deficits in autism: Cognitive or affective?. *Journal of autism and developmental disorders*, *18*(3), 379-402.

Barr, D. J. (2008). Pragmatic expectations and linguistic evidence: Listeners anticipate but do not integrate common ground. *Cognition*, *109*(1), 18-40.

Barr, D. J., & Keysar, B. (2006). Perspective taking and the coordination of meaning in language use. In *Handbook of psycholinguistics* (pp. 901-938). Academic Press.

Barr, D. J., Levy, R., Scheepers, C., & Tily, H. J. (2013). Random effects structure for confirmatory hypothesis testing: Keep it maximal. *Journal of memory and language*, *68*(3), 255-278.

Bates, D., Mächler, M., Bolker, B., & Walker, S. (2014). Fitting linear mixed-effects models using lme4. *arXiv preprint arXiv:1406.5823*.

Batson, C. D., Early, S., & Salvarani, G. (1997). Perspective taking: Imagining how another feels versus imaging how you would feel. *Personality and social psychology bulletin*, *23*(7), 751-758.

Blader, S. L., Shirako, A., & Chen, Y. R. (2016). Looking out from the top: Differential effects of status and power on perspective taking. *Personality and Social Psychology Bulletin*, *42*(6), 723-737.

Birch, S. A. (2005). When knowledge is a curse: Children's and adults' reasoning about mental states. *Current directions in psychological science*, *14*(1), 25-29.

Birch, S. A., & Bloom, P. (2007). The curse of knowledge in reasoning about false beliefs. *Psychological Science*, *18*(5), 382-386.

Briggs, G., Williams, T., & Scheutz, M. (2017). Enabling robots to understand indirect speech acts in task-based interactions. *Journal of Human-Robot Interaction*, *6*(1), 64-94.

Brown-Schmidt, S. (2009). The role of executive function in perspective taking during online language comprehension. *Psychonomic bulletin & review*, *16*(5), 893-900.

Brown-Schmidt, S., Yoon, S. O., & Ryskin, R. A. (2015). People as contexts in conversation. In *Psychology of Learning and Motivation* (Vol. 62, pp. 59-99). Academic Press.

Brown-Schmidt, S., & Heller, D. (2018). Perspective-taking during conversation. *Oxford handbook of psycholinguistics*.

Brüne, M., & Bodenstein, L. (2005). Proverb comprehension reconsidered—'theory of mind'and the pragmatic use of language in schizophrenia. *Schizophrenia research*, *75*(2-3), 233-239.

Champagne-Lavau, M., & Stip, E. (2010). Pragmatic and executive dysfunction in schizophrenia. *Journal of Neurolinguistics*, *23*(3), 285-296.

Dale, R., & Duran, N. D. (2011). The cognitive dynamics of negated sentence verification. *Cognitive science*, *35*(5), 983-996.

Damen, D., van der Wijst, P., van Amelsvoort, M., & Krahmer, E. (2018). The Curse of Knowing: The Influence of Explicit Perspective-Awareness Instructions on Perceivers' Perspective-Taking. *Frontiers in Psychology*.

De Leeuw, J. R. (2015). jsPsych: A JavaScript library for creating behavioral experiments in a Web browser. *Behavior research methods*, *47*(1), 1-12.

Deliens, G., Antoniou, K., Clin, E., & Kissine, M. (2017). Perspective-taking and frugal strategies: Evidence from sarcasm detection. *Journal of Pragmatics, 119*, 33-45.

Deliens, G., Papastamou, F., Ruytenbeek, N., Geelhand, P., & Kissine, M. (2018). Selective Pragmatic Impairment in Autism Spectrum Disorder: Indirect Requests Versus Irony. *Journal of autism and developmental disorders*, 1-15.

Deliens, G., Bukowski, H., Slama, H., Surtees, A., Cleeremans, A., Samson, D., & Peigneux, P. (2018). The impact of sleep deprivation on visual perspective taking. *Journal of sleep research*, *27*(2), 175-183.

Dodell-Feder, D., Lincoln, S. H., Coulson, J. P., & Hooker, C. I. (2013). Using fiction to assess mental state understanding: a new task for assessing theory of mind in adults. *PLoS One*, *8*(11), e81279.

Epley, N., Morewedge, C. K., & Keysar, B. (2004a). Perspective taking in children and adults: Equivalent egocentrism but differential correction. *Journal of Experimental Social Psychology*, *40*(6), 760-768.

Epley, N., Keysar, B., Van Boven, L., & Gilovich, T. (2004b). Perspective taking as egocentric anchoring and adjustment. *Journal of personality and social psychology*, *87*(3), 327.

Epley, N., & Gilovich, T. (2006). The anchoring-and-adjustment heuristic: Why the adjustments are insufficient. *Psychological science*, *17*(4), 311-318.

Fairchild, S. C. (2018). *Speaker and listener effects on the processing of pragmatic meaning* (Doctoral dissertation, University of Delaware).

Ferreira, V. S. (2008). Ambiguity, accessibility, and a division of labor for communicative success. *Psychology of Learning and motivation*, *49*, 209-246.

Flavell, J. H. (1992). *Perspectives on perspective taking* (pp. 107-139). Hillsdale, NJ: Erlbaum.

Frank, M. C., & Goodman, N. D. (2012). Predicting pragmatic reasoning in language games. *Science*, *336*(6084), 998-998.

Freeman, J. B., & Ambady, N. (2010). MouseTracker: Software for studying real-time mental processing using a computer mouse-tracking method. *Behavior research methods*, *42*(1), 226-241.

Frith, C. D., & Frith, U. (2006). The neural basis of mentalizing. *Neuron*, *50*(4), 531-534.

Gibbs Jr, R. W. (1981). Your wish is my command: Convention and context in interpreting indirect requests. *Journal of Verbal Learning and Verbal Behavior*, *20*(4), 431-444.

Gibbs Jr, R. W. (1987). Mutual knowledge and the psychology of conversational inference. *Journal of pragmatics*, *11*(5), 561-588.

Giordano, M., Licea-Haquet, G., Navarrete, E., Valles-Capetillo, E., Lizcano-Cortés, F., Carrillo-Peña, A., & Zamora-Ursulo, A. (2019). Comparison between the Short Story Task and the Reading the Mind in the Eyes Test for evaluating Theory of Mind: A replication report. *Cogent Psychology*, *6*(1), 1634326.

Goodman, N. D., & Stuhlmüller, A. (2013). Knowledge and implicature: Modeling language understanding as social cognition. *Topics in cognitive science*, *5*(1), 173-184.

Green, P., & MacLeod, C. J. (2016). SIMR: an R package for power analysis of generalized linear mixed models by simulation. *Methods in Ecology and Evolution*, *7*(4), 493-498.

Hanna, J. E., Tanenhaus, M. K., & Trueswell, J. C. (2003). The effects of common ground and perspective on domains of referential interpretation. *Journal of Memory and Language*, *49*(1), 43-61.

Hanna, J. E., & Tanenhaus, M. K. (2004). Pragmatic effects on reference resolution in a collaborative task: Evidence from eye movements. *Cognitive Science*, *28*(1), 105-115.

Hansen Lagattuta, K., Sayfan, L., & Harvey, C. (2014). Beliefs about thought probability: Evidence for persistent errors in mindreading and links to executive control. *Child Development*, *85*(2), 659-674.

Kelly, S. D., Barr, D. J., Church, R. B., & Lynch, K. (1999). Offering a hand to pragmatic understanding: The role of speech and gesture in comprehension and memory. *Journal of memory and Language*, *40*(4), 577-592.

Kelly, S. D. (2001). Broadening the units of analysis in communication: Speech and nonverbal behaviours in pragmatic comprehension. *Journal of child language*, *28*(2), 325-349.

Keysar, B. (1994). The illusory transparency of intention: Linguistic perspective taking in text. *Cognitive Psychology*, *26*(2), 165-208.

Keysar, B. (2000). The illusory transparency of intention: Does June understand what Mark means because he means it?. *Discourse Processes*, *29*(2), 161-172.

Keysar, B., Lin, S., & Barr, D. J. (2003). Limits on theory of mind use in adults. *Cognition*, *89*(1), 25-41.

Keysar, B. (2007). Communication and miscommunication: The role of egocentric processes. *Intercultural Pragmatics*, 4(1), 71-84.

Keysar, B. (2008). Egocentric processes in communication and miscommunication. *Intention, common ground and the egocentric speaker-hearer*, 227-296.

Kissine, M., Cano-Chervel, J., Carlier, S., De Brabanter, P., Ducenne, L., Pairon, M., Deconinck, N., Delvenne, V., & Leybaert, J. (2015). Children with autism understand indirect speech acts: Evidence from a semi-structured act-out task. *PLoS One*, 10(11), 1–13.

Koop, G. J. (2013). An assessment of the temporal dynamics of moral decisions. *Judgment and Decision Making*, *8*(5), 527.

Kruger, J., Epley, N., Parker, J., & Ng, Z. W. (2005). Egocentrism over e-mail: Can we communicate as well as we think?. *Journal of personality and social psychology*, *89*(6), 925.

Licea-Haquet, G. L., Velásquez-Upegui, E. P., Holtgraves, T., & Giordano, M. (2019). Speech act recognition in Spanish speakers. *Journal of Pragmatics*, *141*, 44-56.

Long, M. R., Horton, W. S., Rohde, H., & Sorace, A. (2018). Individual differences in switching and inhibition predict perspective-taking across the lifespan. *Cognition*, *170*, 25-30.

Nilsen, E. S., & Graham, S. A. (2009). The relations between children's communicative perspective-taking and executive functioning. *Cognitive psychology*, *58*(2), 220-249.

Pickering, M. J., & Garrod, S. (2004). Toward a mechanistic psychology of dialogue. *Behavioral and brain sciences*, *27*(2), 169-190.

R Core Team (2017). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Ryskin, R. A., & Brown-Schmidt, S. (2014). Do adults show a curse of knowledge in false-belief reasoning? A robust estimate of the true effect size. *PloS one*, *9*(3), e92406.

Ryskin, R. A., Benjamin, A. S., Tullis, J., & Brown-Schmidt, S. (2015). Perspective-taking in comprehension, production, and memory: An individual differences approach. *Journal of Experimental Psychology: General*, *144*(5), 898.

Schulze, C., Grassmann, S., & Tomasello, M. (2013). 3-Year-old children make relevance inferences in indirect verbal communication. *Child development*, *84*(6), 2079-2093.

Spivey, M. J., Grosjean, M., & Knoblich, G. (2005). Continuous attraction toward phonological competitors. *Proceedings of the National Academy of Sciences*, *102*(29), 10393-10398.

Tromp, J. (2018). *Indirect request comprehension in different contexts* (Doctoral dissertation, Radboud University Nijmegen Nijmegen).

Trott, S., & Bergen, B. (2017, October). A theoretical model of indirect request comprehension. In *2017 AAAI Fall Symposium Series*.

Trott, S., & Bergen, B. (2018). Individual Differences in Mentalizing Capacity Predict Indirect Request Comprehension. *Discourse Processes*, 1-33.

Trott, S., Reed, S., Ferreira, V., & Bergen, B. (2019) Prosodic cues signal the intent of potential indirect requests. In *Proceedings of the 41st Annual Conference of the Cognitive Science Society*. Montréal, Canada: Cognitive Science Society.

Van Ackeren, M. J., Casasanto, D., Bekkering, H., Hagoort, P., & Rueschemeyer, S. A. (2012). Pragmatics in action: indirect requests engage theory of mind areas and the cortical motor network. *Journal of Cognitive Neuroscience*, *24*(11), 2237-2247.

Van Ackeren, M. J., Smaragdi, A., & Rueschemeyer, S. A. (2016). Neuronal interactions between mentalising and action systems during indirect request processing. *Social cognitive and affective neuroscience*, *11*(9), 1402-1410.

Vargas, T., Damme, K. S., Hooker, C. I., Gupta, T., Cowan, H. R., & Mittal, V. A. (2019). Differentiating implicit and explicit theory of mind and associated neural networks in youth at Clinical High Risk (CHR) for psychosis. *Schizophrenia research*, *208*, 173-181.

Wardlow, L. (2013). Individual differences in speakers' perspective taking: The roles of executive control and working memory. *Psychonomic bulletin & review*, *20*(4), 766-772.

Williams, T., Núñez, R. C., Briggs, G., Scheutz, M., Premaratne, K., & Murthi, M. N. (2014, November). A dempster-shafer theoretic approach to understanding indirect speech acts. In *Ibero-American Conference on Artificial Intelligence* (pp. 141-153). Springer, Cham.

Winner, E., Brownell, H., Happé, F., Blum, A., & Pincus, D. (1998). Distinguishing lies from jokes: Theory of mind deficits and discourse interpretation in right hemisphere brain-damaged patients. *Brain and language, 62*(1), 89-106.

Zucchelli, M. M., Nori, R., Gambetti, E., & Giusberti, F. (2018). The influence of high autistic personality traits on the attribution of intentionality in typically developing individuals. *Journal of Cognitive Psychology*, *30*(8), 840-853.

Supplementary Materials: Experimental Stimuli

Stimuli for Experiment 1 and Experiment 2. Text in parentheses for items 1-8 represents the target utterance for the Inference group (1a), which was not shown to the Knowledge group (1b). Items 9-16 are for Experiment 2 only. Bolded text represents the Implicit/Explicit knowledge manipulation; by extension, the bolded text was also not present in Experiment 1.

(1)

Speaker Aware

You and your friend Jonathan are taking a road trip. You began in California, and are now passing through Michigan. It's almost winter, so it's very cold outside - especially for Southern California dwellers like you and Jonathan. You see that you're almost out of gas, so you stop at a gas station in a small town.

You fill up the tank, and then the two of you go inside the gas station to buy some water and snacks. When you return to the car and start up the engine, you and Jonathan **both** notice with some dismay a blinking light, which indicates that the car's heating system is broken. You both bundle up.

As you leave the station, Jonathan shivers in his seat. (He turns to you and says, "Man, it's really cold in here.")

Speaker Unaware

You and your friend Jonathan are taking a road trip. You began in California, and are now passing through Michigan. It's almost winter, so it's very cold outside - especially for Southern California dwellers like you and Jonathan. You see that you're almost out of gas, so you stop at a gas station in a small town.

While you fill up the tank, Jonathan goes inside to buy some water and snacks. As you're checking the meter, you notice with some dismay a blinking light, which indicates that the car's heating system is broken. You finish filling up the gas and wait for Jonathan, **who is still inside and doesn't know about the broken heater**.

Jonathan returns with some snacks, and you both set off. As you leave the station, he shivers in his seat. (He turns to you and says, "Man, it's really cold in here.")

Prompt for Experiment 1a and Experiment 2:

Do you think he is making a request?

Prompt for Experiment 1b:

Does he know the heater is broken?

(2)

Speaker Aware

You've been renting a house with your two roommates, Lisa and Brian, for three months now. Things are going well, though both you and Lisa are not very responsible about cleaning;

consequently, the house has a tendency to get dirty quickly - unwashed dishes in the sink, cluttered counters, the whole shebang.

Even worse, you and Lisa are directly responsible for the latest mess, which is the product of a recent dinner party. Brian's something of a neat freak, so he's pretty anxious about the mess.

This morning, during a house meeting with you and Brian, Lisa volunteered to take the lead on cleaning the kitchen when she gets home from work this evening. **Brian seems satisfied by this plan.**

In the afternoon, while Lisa is still at work, you and Brian are standing in the kitchen doorway, gazing in. (Brian turns to you and says, "You guys really did a number on the kitchen.")

Speaker Unaware

You've been renting a house with your two roommates, Lisa and Brian, for three months now. Things are going well, though both you and Lisa are not very responsible about cleaning; consequently, the house has a tendency to get dirty quickly - unwashed dishes in the sink, cluttered counters, the whole shebang.

Even worse, you and Lisa are directly responsible for the latest mess, which is the product of a recent dinner party. Brian's something of a neat freak, so he's pretty anxious about the mess.

This morning, Lisa volunteered to take the lead on cleaning the kitchen when she gets home from work this evening. **Brian was still sleeping, so he's unaware of this plan.**

In the afternoon, while Lisa is still at work, you and Brian are standing in the kitchen doorway, gazing in. (Brian turns to you and says, "You guys really did a number on the kitchen.")

Prompt for Experiment 1a and Experiment 2:

Do you think he is making a request?

Prompt for Experiment 1b:

Does Brian know Lisa has already promised to clean the kitchen?

(3)

Speaker Aware

You accompany your teenage daughter, Sarah, to the doctor so that she can be tested for allergies. She's quite reluctant to go, but you promise her that after the appointment, you can go out to her favorite hamburger joint. The appointment goes well, and is very informative; as it turns out, Sarah does have several major food allergies. The doctor gives you a pamphlet containing more detailed information. Then, as promised, you take Sarah to a nearby diner to buy some hamburgers. You order a hamburger and some fries for yourself, a cheeseburger for Sarah, then sit down.

When Sarah sits down, you flip through the pamphlet together; you're both surprised to learn that she's allergic to members of the "nightshade" family, which includes eggplant and potatoes. **Sarah seems saddened by the news**.

About five minutes later, your food is served. (Sarah eyes your plate of fries and says, "Man, those fries look delicious...")

Speaker Unaware

You accompany your teenage daughter, Sarah, to the doctor so that she can be tested for allergies. She's quite reluctant to go, but you promise her that after the appointment, you can go out to her favorite hamburger joint. The appointment goes well, and is very informative; as it turns out, Sarah does have several major food allergies. The doctor gives you a pamphlet containing more detailed information. Then, as promised, you take Sarah to a nearby diner to buy some hamburgers. You order a hamburger and some fries for yourself, a cheeseburger for Sarah, then sit down.

While Sarah is washing her hands in the restroom, you flip through the pamphlet; you're surprised to learn that she's allergic to members of the "nightshade" family, which includes eggplant and potatoes. **Sarah returns to the table, unaware that she's allergic to potatoes.**

About five minutes later, your food is served. (Sarah eyes your plate of fries and says, "Man, those fries look delicious...")

Prompt for Experiment 1a and Experiment 2:

Do you think she is making a request?

Prompt for Experiment 1b:

Does Sarah know she has an allergy to potatoes?

(4)

Speaker Aware

After a long week, you decide to treat yourself to a dinner for one at the fanciest restaurant in town. Just for the occasion, you break out your black and white tuxedo. Your spirits are high, but when you arrive at the restaurant, you're somewhat embarrassed to realize that you're wearing the exact same outfit as the restaurant's waitstaff.

While you're waiting in line, you encounter another guest, who initially mistakes you for a waiter. You laugh about the misunderstanding, and then an actual waiter shows you to your table.

Later, as you walk to the kitchen to pay your compliments to the chef, you pass by the same guest's table. He is staring down at his meal with irritation. You pass by and **he recognizes you as the guest from the line, whom he'd formerly mistaken for a waiter**.

(He says, "This steak is so overdone!")

Speaker Unaware

After a long week, you decide to treat yourself to a dinner for one at the fanciest restaurant in town. Just for the occasion, you break out your black and white tuxedo. Your spirits are high, but when you arrive at the restaurant, you're somewhat embarrassed to realize that you're wearing the exact same outfit as the restaurant's waitstaff.

While you're waiting in line, you encounter another guest, who initially mistakes you for a waiter. You laugh about the misunderstanding, and then an actual waiter shows you to your table.

Later, as you walk to the kitchen to pay your compliments to the chef, you pass by another guest's table. He is staring down at his meal with irritation. **As you pass by, he looks up at you and catches your eye, perhaps fooled by your tuxedo into thinking that you are a waiter.**

(He says, "This steak is so overdone!")

Prompt for Experiment 1a and Experiment 2:

Do you think he is making a request?

Prompt for Experiment 1b:

Does he know you are not actually a waiter?

(5)

Speaker Aware

After your first year of college, you move back home for the summer. Your parents are glad to have you home, but your dad insists that you do some weekly chores to "earn your keep". You'd prefer to just relax, but it does keep you occupied, which isn't all bad. Besides, the house is in need of some repairs; your parents are both busy people, so some chores have fallen by the wayside while you've been away. Most notably, the lawn has gotten overgrown, and the paint on the backyard fence is beginning to peel. During the first couple of weeks, you mow the lawn, rake the driveway, and water the garden, but you keep putting off painting the fence.

One day, your mom decides to take matter into her own hands.

With your dad's encouragement, she calls a painting company to come and paint the fence; they schedule a time two days from now. **This seems to satisfy your dad.**

Later in the day, you're reading in the living room. Your dad walks in and peers out the window with a slightly displeased expression on his face.

(He turns to you, his hands on his hips, and says, "Man, that fence is looking worse than ever; a new paint-job couldn't come soon enough.")

Speaker Unaware

After your first year of college, you move back home for the summer. Your parents are glad to have you home, but your dad insists that you do some weekly chores to "earn your keep". You'd

prefer to just relax, but it does keep you occupied, which isn't all bad. Besides, the house is in need of some repairs; your parents are both busy people, so some chores have fallen by the wayside while you've been away. Most notably, the lawn has gotten overgrown, and the paint on the backyard fence is beginning to peel. During the first couple of weeks, you mow the lawn, rake the driveway, and water the garden, but you keep putting off painting the fence.

One day, your mom decides to take matter into her own hands.

While your dad's away at work, she calls a painting company to come and paint the fence; they schedule a time two days from now. **Unfortunately, your dad hasn't yet heard about this plan.**

Later in the day, you're reading in the living room when your dad returns from work. He walks in and peers out the window with a slightly displeased expression on his face.

(He turns to you, his hands on his hips, and says, "Man, that fence is looking worse than ever; a new paint-job couldn't come soon enough.")

Prompt for Experiment 1a and Experiment 2:

Do you think he is making a request?

Prompt for Experiment 1b:

Does your dad know someone is coming to paint the fence?

(6)

Speaker Aware

You and your friend are exhausted and sweaty from playing tennis. After playing, you invite him back to your apartment to hang out.

When you return to your apartment, you both see a notice taped to your apartment door: unfortunately, the water in your apartment building will be shut off for the next 24 hours. **Your friend seems disconcerted by the news.**

(Once inside the kitchen, your friend turns to you and says: "I'm so thirsty…")

Speaker Unaware

You and your friend are exhausted and sweaty from playing tennis. After playing, you invite him back to your apartment to hang out.

When you return to your apartment, **you go to your room**, and privately check your email. You see that your landlord has sent you a message: unfortunately, the water in your apartment building will be shut off for the next 24 hours. **Your friend, of course, doesn't know about this yet.**

(You return to the kitchen. Your friend turns to you and says: "I'm so thirsty…")

Prompt for Experiment 1a and Experiment 2:

Do you think he is making a request?

Prompt for Experiment 1b:

Does your friend know the water isn't working?

(7)

Speaker Aware

After some deliberation, you invite a new acquaintance over for a dinner date. You prepare a feast, which you serve alongside some red wine. There's only a small amount of wine left in the bottle, but you assure your date you have another bottle stashed away, which you can open if she likes this wine.

About halfway through dinner, you excuse yourself to go to the bathroom. On the way back, you stop in the kitchen to grab the other bottle of wine. You're surprised and irritated to find that there is no other bottle; you must have been mistaken.

Sadly, you call out from the kitchen that the wine is all gone. **Your date murmurs something in reply, sounding disappointed.**

When you return to the dining room, your date sips the last of her glass of wine. (She looks up at you and says, "This wine is excellent.")

Speaker Unaware

After some deliberation, you invite a new acquaintance over for a dinner date. You prepare a feast, which you serve alongside some red wine. There's only a small amount of wine left in the bottle, but you assure your date you have another bottle stashed away, which you can open if she likes this wine.

About halfway through dinner, you excuse yourself to go to the bathroom. On the way back, you stop in the kitchen to grab the other bottle of wine. You're surprised and irritated to find that there is no other bottle; you must have been mistaken.

You walk back towards the dining room, unsure about what to tell your date, **who doesn't yet know that there's no more wine.**

When you return to the dining room, your date sips the last of her glass of wine. (She looks up at you and says, "This wine is excellent.")

Prompt for Experiment 1a and Experiment 2:

Do you think she is making a request?

Prompt for Experiment 1b:

Does she know there is no more wine?

(8)

Speaker Aware

You and your friend Rob get along well; your only complaint is that since he doesn't have a car, you almost always have to pick him up and give him rides. Whenever you're both going somewhere, it's generally expected that you'll drive him - but he treats you to coffee sometimes, so it all evens out.

One day, after classes get out, you walk together to get some coffee at nearby coffee shop.

While you and Rob are sitting talking, you're surprised to see your mechanic at the coffee shop. He walks up and informs you that your car, which you recently took in for a tune-up, will be under repair for at least another week. **Rob knows how much you rely on that car, so he understands your frustration.**

Once the mechanic leaves, you and Rob get to talking. Rob realizes you've both been invited to the same party later on in the week.

(Rob says, "So… how are you planning on getting there?")

Speaker Unaware

You and your friend Rob get along well; your only complaint is that since he doesn't have a car, you almost always have to pick him up and give him rides. Whenever you're both going somewhere, it's generally expected that you'll drive him - but he treats you to coffee sometimes, so it all evens out.

One day, after classes get out, you walk together to get some coffee at a nearby coffee shop.

Before you sit down, Rob steps outside to take a phone call. While he's outside, you're surprised to see your mechanic at the coffee shop. He walks up and informs you that your car, which you recently took in for a tune-up, will be under repair for at least another week. You rely on that car, so this is very frustrating.

Anyway, Rob finishes his phone call and returns to the table, and you both get to talking. Rob realizes you've both been invited to the same party later on in the week, but **missed the conversation with your mechanic about your car still being in the shop.**

(Rob says, "So… how are you planning on getting there?")

Prompt for Experiment 1a and Experiment 2:

Do you think he is making a request?

Prompt for Experiment 1b:

Does Rob know your car is in the shop?

(9)

Speaker Aware

After a relatively uneventful day, you decide you need to get out and see a movie. You call up your best friend, who agrees to accompany you.

Later, you arrive at the theater at the same time as your friend. You greet each other, then head towards the pay-stand. As you walk together, you check your pockets; you realize you don't have any cash, and you left your credit card at home. You curse, saying, "I can't believe I left my wallet at home." **Your friend looks surprised that you forgot your money, since that is very unlike you**.

Then, just as your friend is about to pay, her face suddenly falls. She groans, then turns back to you in disbelief.

She says, "Um, I forgot my wallet..."

Speaker Unaware

After a relatively uneventful day, you decide you need to get out and see a movie. You call up your best friend, who agrees to accompany you.

Later, just after you arrive at the theater, you realize you don't have any cash on you, and you left your credit card at home. You curse, saying to yourself, "I can't believe I left my wallet at home."

Your friend shows up just after your realization, greets you, and heads right to the pay-stand**, not yet aware that you don't have any money**.

As your friend is about to pay, her face suddenly falls. She groans, then turns back to you sheepishly.

She says, "Um, I forgot my wallet..."

Prompt for Experiment 2:

Do you think she is making a request?

(10)

Speaker Aware

The roof of your garage is in bad shape. Fortunately, one of your good friends generously offers to come over and help you fix it up.

The two of you spend the day toiling under the hot sun, working up a sweat. It takes a few hours, but eventually, the roof starts looking somewhat decent.

You both go inside the house, where fortunately, the AC is on. Feeling a thirst coming on, you head into the kitchen, closely followed by your friend. You check the refrigerator, and find that there's one beer left. A little guilty, you take it for yourself; your friend watches and shakes his head disapprovingly, **seeing that there are no beers left**.

Later, back in the living room, you drain your beer and set it down on the table. Your friend smacks his lips. He says, "A cold beer sounds pretty great right now."

Speaker Unaware

The roof of your garage is in bad shape. Fortunately, one of your good friends generously offers to come over and help you fix it up.

The two of you spend the day toiling under the hot sun, working up a sweat. It takes a few hours, but eventually, the roof starts looking somewhat decent.

You both go inside the house, where fortunately, the AC is on. Your friend collapses onto the couch, breathing a sigh of relief. Feeling a thirst coming on, you head into the kitchen and check the refrigerator, and find that there's one beer left. A little guilty, you take it for yourself.

You return to the living room. Your friend sees you holding the beer**, but isn't aware that there are no more left**. He says, "A cold beer sounds pretty great right now."

Prompt for Experiment 2:

Do you think he is making a request?

(11)

Speaker Aware

It's Monday evening, which is when you and your parents ordinarily watch your favorite television series.

You all gather together in your usual spots: you sit in a chair closest to the television, and your parents sit on the couch. But when you turn on the TV, there's a crackling noise from the speakers. After some fiddling around, you **all** realize that they're broken.

Still, you decide to watch anyway, using the built-in speakers on the TV. The show starts, but the built-in speakers just don't project at all.

Your father groans and looks over at you. He says, "I can barely hear what they're saying!"

Speaker Unaware

It's Monday evening, which is when you and your parents ordinarily watch your favorite television series.

Before your parents arrive, you get settled in your usual spot: the chair closest to the television. But when you turn on the TV, there's a crackling noise from the speakers. You realize that they're broken, so you decide to just use the built-in speakers on the TV.

Later, your parents come into the room and sit on the couch. The show starts, but the built-in speakers just don't project at all. **Your parents don't realize that this is the loudest it will get, since the other speakers are broken**.

Your father groans and looks over at you. He says, "I can barely hear what they're saying!"

Prompt for Experiment 2:

Do you think he is making a request?

(12)

Speaker Aware

You and your friend Claire just got a new apartment in a nice area of town. You're good roommates: you both do your dishes, keep things tidy, and take turns taking out the trash and recycling.

One day, however, you and Claire both run into your landlord, who gives you some surprising news: the town's recycling services are temporarily suspended. A few days go by, and your recycling bin starts to overflow. It's your turn to empty the bin, but unfortunately, there's nowhere to drop it off. **You and Claire both know you'll have to wait to empty it until the services start up again**.

While she's washing the dishes, Claire looks over at the recycling bin and shakes her head. She says, "The bin is sure getting full."

Speaker Unaware

You and your friend Claire just got a new apartment in a nice area of town. You're good roommates: you both do your dishes, keep things tidy, and take turns taking out the trash and recycling.

One day, however, while Claire is away, you run into your landlord, who gives you some surprising news: the town's recycling services are temporarily suspended. You're pretty forgetful though, so it slips your mind when Claire gets home later**; thus, she doesn't know that there's nowhere to empty the bin**.

A few days go by, and your recycling bin starts to overflow. It's your turn to empty the bin, but unfortunately, there's nowhere to drop it off.

While she's washing the dishes, Claire looks over at the recycling bin and shakes her head. She says, "The bin is sure getting full."

Prompt for Experiment 2:

Do you think she is making a request?

(13)

Speaker Aware

After several weeks of looking for work, you finally find a job at a local cafe. You quickly learn the basics: taking orders from customers, how to prepare different drinks, and even which items are the most popular.

Customers especially love the chocolate croissants, but the baker stops making new ones by noon, so these are often in short supply.

One afternoon, a familiar-looking customer enters the store. Just as he approaches the counter, you **both** hear a shout from the back room: “Hey, we’re out of chocolate croissants!” **The customer looks disappointed when he hears this.** You exchange pleasantries. He looks up at the menu and his eyes alight on the pastry section.

He says, “My favorite thing to get here is usually a chocolate croissant.”

Speaker Unaware

After several weeks of looking for work, you finally find a job at a local cafe. You quickly learn the basics: taking orders from customers, how to prepare different drinks, and even which items are the most popular.

Customers especially love the chocolate croissants, but the baker stops making new ones by noon, so these are often in short supply. One afternoon, the cafe runs out especially early, and you hear a shout from the back room: “Hey, we’re out of chocolate croissants!”

Soon after, a familiar-looking customer enters the store, **unaware that you’ve just run out of the most popular item**. You exchange pleasantries. He looks up at the menu and his eyes alight on the pastry section.

He says, “My favorite thing to get here is usually a chocolate croissant.”

Prompt for Experiment 2:

Do you think he is making a request?

(14)

Speaker Aware

In college, you decide to take a particularly challenging mathematics course. Many of the other students struggle with the homework, but you find that you can usually get it, as long as you work hard at it.

Harold, one of the other students, consistently struggles with understanding the concepts. You feel bad, so you often help him with his homework in the morning before class.

One night, though, you are completely lost. None of the concepts make sense, and you don't manage to answer a single homework problem. You text a couple of your friends, including Harold, that you are having a really hard time and won't be able to complete the work.

The next day, Harold approaches you before class. **He knows that you weren't able to finish the homework.** He pulls out a piece of paper with some half-hearted scribbles on it, but it's clear he didn't get very far.

He says, "I couldn't get any of the answers on the homework last night."

Speaker Unaware

In college, you decide to take a particularly challenging mathematics course. Many of the other students struggle with the homework, but you find that you can usually get it, as long as you work hard at it.

Harold, one of the other students, consistently struggles with understanding the concepts. You feel bad, so you often help him with his homework in the morning before class.

One night, though, you are completely lost. None of the concepts make sense, and you don't manage to answer a single homework problem.

The next day, Harold approaches you before class. **He doesn't know that you struggled with the homework, assuming that, as usual, you completed all of it.** He pulls out a piece of paper with some half-hearted scribbles on it, but it's clear he didn't get very far.

He says, "I couldn't get any of the answers on the homework last night."

Prompt for Experiment 2:

Do you think he is making a request?

(15)

Speaker Aware

Your spouse, Terry, has been very busy recently with extra long days at work, coming home late in the evening.

As a consequence, laundry has started to pile up, which Terry doesn't really have the time to do. One evening, after Terry has returned home, you decide it's time to make a dent in some of the laundry. But when you try to turn on the washing machine, you realize that it is broken. With Terry watching, you make an appointment for someone to come fix the machine.

Terry knows that you made an appointment to fix the broken washing machine, and seems satisfied. The laundry hamper is growing ominously large at this point.

Seeing it, Terry says, "Those clothes really need to be washed soon."

Speaker Unaware

Your spouse, Terry, has been very busy recently with extra long days at work, coming home late in the evening.

As a consequence, laundry has started to pile up, which Terry doesn't really have the time to do. One day, while Terry is at work, you decide it's time to make a dent in some of the laundry. But when you try to turn on the washing machine, you realize that it is broken. You make an appointment for someone to come fix the machine.

Soon after, Terry returns home exhausted, **and also not yet realizing that the washing machine is broken**. The laundry hamper is growing ominously large at this point.

Seeing it, Terry says, "Those clothes really need to be washed soon."

Prompt for Experiment 2:

Do you think Terry is making a request?

(16)

Speaker Aware

You and your friend Paul are moving into a new apartment. There's a ton of stuff to unload: pots and pans, furniture, miscellaneous belongings, and more. Most of it is light, but some of the furniture is quite heavy. For the heavy stuff, you agree to help each other out.

At one point, while Paul is helping you carry your mattress into your bedroom, you suddenly feel a jolt of sharp pain in your back. You inadvertently gasp and clutch your back. Once you

recover, you decide you should take it easy the rest of the day and not pick up any more heavy furniture. **Knowing you are hurt,** Paul finishes pushing the mattress into the room.

The two of you go back outside, and see Paul's gargantuan desk sitting in the driveway. Paul looks at the desk doubtfully.

He says, "This desk is really heavy…"

Speaker Unaware

You and your friend Paul are moving into a new apartment. There's a ton of stuff to unload: pots and pans, furniture, miscellaneous belongings, and more. Most of it is light, but some of the furniture is quite heavy. For the heavy stuff, you agree to help each other out.

At one point, while Paul is still outside and you are carrying your mattress into your room, you suddenly feel a jolt of sharp pain in your back. You inadvertently gasp and clutch your back. Once you recover, you decide you should take it easy the rest of the day and not pick up any more heavy furniture. **Paul, however, didn't see what happened, so he doesn't know that you are hurt.**

When you go back outside, you see that Paul is still out front, looking at his gargantuan desk.

He says, "This desk is really heavy…"

Prompt for Experiment 2:

Do you think he is making a request?

Supplementary Analysis 1: Short Story Task results

Experiment 1:

SST responses were coded according to the rubric provided by Dodell-Feder et al (2013), yielding three scores for each participant: Explicit mental state reasoning, Reading comprehension, and Spontaneous mental state inference. Inter-rater reliability was highest for Explicit mental state reasoning (Cohen's kappa=.77, r=.9), followed by Reading comprehension (Cohen's kappa=.68, r=.86). Disagreement on both these measures was addressed by taking the mean of the scores given by each coder. Agreement was quite low for Spontaneous mental state inference (Cohen's kappa=.07, r=.18), necessitating a third coder to act as tiebreaker: for all items on which the first two coders disagreed, the third coder's independent coding was taken as the final measure.

Explicit mental state inference was correlated with Reading comprehension (r=.43, $p=7.69*10^{-8}$) but only weakly related to Spontaneous mental state inference (r=.14, p=.1). Reading comprehension did not correlate significantly with Spontaneous mental state inference (r=.12, p=.16).

Finally, age did not correlate with Explicit mental state reasoning (r=.08, p=.4) or Spontaneous mental state inference (r=-.004, p=.97), but did correlate with Reading comprehension (r=.16, p=.05). Gender did not predict explicit mental state inference [F(1, 140)=.7, p=.4], Reading comprehension [F(1, 140)=2, p=.16], or Spontaneous mental state inference [F(1, 140)=.05, p=.8].

Experiment 2:

As in Experiment 1, SST responses were coded according to the rubric provided by Dodell-Feder et al (2013). Inter-rater reliability was highest for Reading comprehension (Cohen's kappa=.75,

r=.89), closely followed by Explicit mental state reasoning (Cohen's kappa=.73, r=.9). For both of these measures, we addressed disagreement by taking the mean of the scores given by each coder. There was more disagreement on the binary Spontaneous mental state inference measure (Cohen's kappa=.56, r=.56); as in Experiment 1, we addressed disagreement by bringing in a third coder to act as tie-breaker.

Explicit mental state reasoning was strongly correlated with Reading comprehension (r=.62, p=$1*10^{-8}$), and weakly correlated with Spontaneous mental state inference (r=.28, p=.02). There was no significant correlation between Reading comprehension and Spontaneous mental state inference (r=.18, p=.13).

We also asked about how these individual difference scores correlated with demographic variables such as age and gender. Age did not significantly correlate with Explicit mental state reasoning (r=.01, p=.9) or Reading comprehension (r=.2, p=.12), or Spontaneous mental state inference (r=-.05, p=.7). Finally, gender did not explain variability in Explicit mental state reasoning [F(2, 66) = 2.1, p=.13], Reading comprehension [F(2, 66)=.63, p=.5], or Spontaneous mental state inference [F(2, 66)=1.4, p=.3].

Figure captions

Figure 1: Adopting a speaker's perspective to infer their pragmatic intent likely involves multiple component processes. Comprehenders must ***sample*** *information about their perspective,* ***maintain*** *that information with minimal decay, then* ***deploy*** *it to adjudicate between competing interpretations of the same utterance.*

Figure 1: Participants in both groups showed an effect of Awareness (Experiment 1). However, the effect was larger in the Knowledge group, when participants only had to sample and maintain this information and answer whether the speaker was aware or unaware of the obstacle. The effect was smaller in the Inference group, where participants had to not only sample and maintain but also deploy implicit information about speaker knowledge to infer whether the speaker was making a request.

Figure 2: Density plot of individual differences in Explicit mental state reasoning across the two experimental groups (Experiment 1). Each point represents a trial, and is colored by whether that response was congruent or incongruent with the speaker's knowledge states. Mentalizing differences predicted congruent responses in the Knowledge group, when participants only had to sample and maintain information about implicit knowledge states, but not in the Inference group, when they also had to deploy that information for pragmatic inference.

Figure 3: Participants showed an effect of Awareness on pragmatic interpretation when knowledge was Explicit or Implicit (Experiment 2). However, the effect of speaker knowledge

increased on Explicit trials—i.e., when participants only had to deploy this information. Dotted line represents chance performance (50%).

Figure 4: Density plot of participants' Explicit mental state reasoning scores, filled by whether a given response was congruent or incongruent with a speaker's knowledge states (Experiment 1). For Explicit trials (when participants only had to deploy speaker knowledge information), better mentalizers were more likely to make congruent responses (p=.003); for Implicit trials (when participants had to sample, maintain, and deploy speaker knowledge information), the effect was qualitatively similar but only marginally significant (p=.12).

Figure 5: Density plot of individual differences in mentalizing, with each trial colored by whether the response was congruent or incongruent with a speaker's knowledge states. Explicit trials include those from Experiment 2 (Trott & Bergen, 2018), Experiment 1b (current work), and Experiment 2-Explicit (current work); implicit trials include those from Experiment 3 (Trott & Bergen, 2018), Experiment 1a (current work), and Experiment 1-Implicit (current work).