Solving Signaling Ambiguity Through Cooperation

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Abstract—**Resolving overloading in communication requires attention to context. Previous research has found that the mutual assumption of cooperation during communication can act as a powerful constraint, allowing successful resolution under ambiguity. In this study, we investigate two specific types of cooperative context used in a communicative task which arise from different sources: beliefs and actions. In belief-driven communication, signals are interpreted in context of what else a speaker could have said about the world. Here communicators assume that the speaker aims to change the listener's beliefs by providing the most straightforward signal. In action-driven communication, signals are considered in terms of what a speaker can reasonably ask others to do in the physical world. Through a communication game, we tested how listeners would interpret an ambiguous signal using belief-driven or action-driven strategies. We find that while no one strategy is dominant overall, individuals are highly consistent in which strategy they employ when forced to decide. In a follow-up which accounts for a potential bias, we find that an action-driven strategy begins to dominate, while all other behavioral patterns remain the same.**

I. Introduction

Everyday communication can be incredibly overloaded: a single word often has many meanings. Despite this, even a sparse, ambiguous signal can be enough to communicate successfully [17] which stems from sensitivity to the context in which exchanges are framed [21]. Cooperation has been viewed as a key aspect of communication [24], providing another form of context to constrain ambiguity. We focus on understanding communication under this cooperative frame; moreover, we make the distinction between two types of rational cooperative logic: speech acts and joint planning. Speech acts involve reasoning about signals as a cooperative way to change the *beliefs* of others. Joint planning involves assuming cooperators will choose *actions* that are jointly efficient and fair. These discrete but complementary views offer distinct mechanisms to constrain how signals can be sent and interpreted to resolve ambiguity. While both cooperative aspects of communication have previously been explored, they have been typically viewed separately and from different contexts. In the present study we incorporate them in the same behavioral task to explore whether humans can flexibly employ these two cooperative heuristics for disambiguation with a focus on what individuals do when these two heuristics come into conflict.

A. Context of Beliefs: Cooperative Speech Acts

The first type of cooperative logic employed is speech acts. Speech acts fall under the umbrella of language pragmatics, which focuses specifically on the context sensitive interpretation of utterances. Under Grice's cooperative framework, communication is treated as a truthful, relevant, and straightforward exchange [11]. To determine what signal is straightforward and efficient, communicators must engage in social reasoning about their partners – this requires considering the context of all available, but not chosen, options.

To solve uncertainty in communication, Grice's maxims must be combined with the insight that exchanges center around the *use* of language. This ties signals to communicative goals, making their utilities easier to define [1, 9]. Under this formulation, communication is a type of rational action: a speech act [2, 5, 11]. When viewed as such, signals have the communicative goal of conveying information about a referent or state of the world to a listener given the decision context [27]. A rational, utility driven signaler chooses a signal by evaluating all possible things she could say and picking a good option. Having a communicative goal provides the mechanism for that evaluation of what is good: a signal's value comes from how it is expected to change the listener's beliefs to reflect the intended referent. In turn, under these same assumptions, the listener can use these cooperative constraints to infer the intended pragmatic meaning of the signal.

Referential language games provide a controlled environment well suited for studying pragmatic communication in adults [16, 31]. In these games, a set of items with features (e.g. shape, color) act as context, and a listener aims to understand which referent a speaker is indicating from a potentially ambiguous signal [8, 4, 18].

B. Context of Actions: Cooperative Joint Planning

The second type of cooperation we focus on is the context joint planning provides in a shared task. Much of communication occurs face-to-face where perceptual cues in the environment provide important context for framing an exchange. From this perspective, communication is a social tool which can enable individuals to coordinate and get things done together more effectively [3, 23, 28]. Again, communication is framed in terms of use, but this time studied using commonsense knowledge outside of language. This knowledge lies in considering consequences in the physical world through action planning and in others' mental world which provide the beliefs and desires to create a plan.

We motivate our emphasis on joint action context by examining how even young children who do not yet have the capacity for fully-developed language can intelligently and flexibly reason using sparse communication. Young children are sensitive to minimal communicative cues (e.g. joint attention) used to establish strong joint goals in the context of cooperation [10, 20, 29, 32]. Moreover, early use of limited communication demonstrates an insistence on fairness in children not seen in chimpanzees when splitting rewards [13, 30] and successful usage of sparse, overloaded protesting (e.g. "Hey!") to resolve violations of fairness [6].

These cooperative properties of commitment and fairness can be realized through utility-driven joint planning: cooperators act under a rational plan that apportions fair costs and rewards to all parties given a joint goal. Even toddlers understand the cooperative logic of ambiguous requests from a joint utility perspective [12]. When a speaker makes an ambiguous request in the presence of two equivalent items equidistant from the toddler, but near and far relative to the speaker, children are able to use cooperative logic to reason over the *joint* utility dynamics of the environment in the context of the speaker's capabilities. These studies support how communication should be taken in context of committing to achieve a shared goal fairly and respectfully.

II. Experiment 1

A. Methods

This task combined feature overloading enriched by a spatial scene, which included abilities to disambiguate signals both using the belief-driven context of words and the action-driven context of utility dynamics. In a grid-world environment, participants played a referential communication game where they were told the goal was to cooperate with their partner to reach a target item in the fewest steps. During the game, the participant always played the role of a receiver who could observe the entire environment but did not know which item was the intended target. Participants were told they were working with a cooperative, intelligent signaler who had a full view of the grid and knew the target; however, in reality, signals were pre-programmed. The signaler's decision depended on the condition and consisted of either an ambiguous signal – consistent with multiple potential items in the trial – or walking to an item when that item was closer to the signaler than the receiver.

B. Participants

Sixty-six undergraduate students in the Department of Communication at University of California, Los Angeles (UCLA) participated in this online study for class credit. We analyzed the data of 51 participants after excluding six participants for not finishing the experimental trials, three participants for failing the comprehension quiz more than twice, and seven participants for self-reporting not being serious in the experiment (one participant among them also did not finish the experimental trials). The experiment was performed in accordance with guidelines and regulations approved by the UCLA institutional review board IRB#19-001990.

C. Stimuli and Task

Participants were able to access the experiment on their personal computer or laptop. On each trial, a 9 by 10 grid layout was presented to participants. Each grid square was 50 px $\times$ 50 px and, three items were placed in the grid. Each item had two features of color (orange, purple, or green) and shape (triangle, circle, or square) for a total of nine distinct items. An icon representing the participant was located at grid location (4, 6) while their partner was located at (4, 0). Both agents traveled along the grid taking steps in the four cardinal directions, so Manhattan distance was used to describe how far each item was from an agent.

1) Design: The experiment followed a within-subject design with four conditions: Pragmatic, Utility, Conflict, and Signaler-walk (see Fig. 1). Participants played a total of 80 randomly ordered trials (20 per condition). The main dependent variable was the strategy the participant employed to solve each condition, reflected by the item they chose as the target. The receiver's decision time from when they received a signal to when they selected an item was recorded. In addition, participants rated their own confidence after each decision.

The Pragmatic condition coincided with the example from Frank and Goodman [8], but was spread spatially in a visual display. Two items had one unique feature and one feature shared with a third item (see Figure 1). The signal was a shared feature, consistent with two items. Utility dynamics were fixed so they could not influence the receiver's decision. Specifically, relevant items were equidistant from the receiver and all items were jointly efficient for the receiver (closer to receiver than signaler). Receivers could select an item that was irrational: inconsistent with the signal, literal: consistent but could be indicated with a more straightforward signal, or pragmatic: consistent and most straightforward because both features were overloaded.

The Utility condition forced participants to make a purely utility-based decision with two identical items (and one irrelevant distinct one). The observed signal was one feature of the identical items, which made the context of language pragmatics unable to help with disambiguation. This setup reflected the dynamic in Grosse et al. [12], but with a stronger individual utility component. One of the identical items was closer than the other to the receiver, making it individually efficient to reach. However, the individually efficient item was also closer to the signaler than to the receiver, making it jointly inefficient. Thus, receivers could select an item that was irrational: the non-identical inconsistent one; individual: individually efficient but jointly inefficient; or joint: jointly efficient but individually inefficient.

The Conflict condition was designed to force participants to choose between a joint utility and pragmatic strategy. It was identical to the Pragmatic condition in terms of item feature structure and signal. Also, the two consistent items

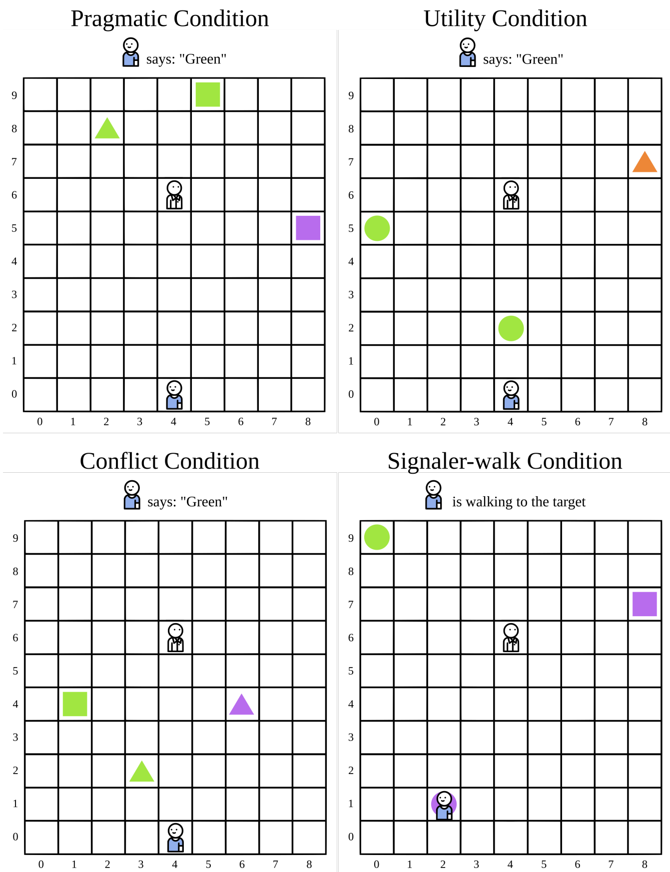

Fig. 1: **Example trials**: Pragmatic: green square is pragmatic; green triangle is literal. Utility: green circle at (4,2) is closer by individual utility; green circle at (0,5) is jointly efficient for the receiver. Conflict: green triangle is pragmatic; green square is jointly efficient for the receiver.

were equidistant from the receiver. However, instead of all items being jointly efficient for the receiver, the pragmatic item was jointly efficient for the signaler. Receivers could still select an irrational item, but now had two previous heuristics in conflict and could select either a pragmatic interpretation inconsistent with joint utility (pragmatic) or a joint utility interpretation that was not pragmatically efficient (joint).

Finally, in the Signaler-walk condition, the signaler walked to an item, and participants did not make a decision. In all cases, the item walked to was jointly efficient for the signaler. This established that the signaler was rational and cooperative.

Items and signals were counterbalanced to account for preference of feature or feature value. In addition, items were separated by a minimum distance of two grid units to reduce potential perceptual chunking. Items always were always at least two grid units farther from one agent than the other in order to ensure clear joint utility judgments. Finally, item locations within a condition were sampled randomly without replacement, subject to the utility constraints defined by the condition and aforementioned restrictions.

2) Procedure: Participants entered the experiment by opening the link to the experiment on their own device. They started with an instruction tutorial which established the rules and cooperative context of the task, and then completed a comprehension quiz that tested them on the goal and set-up of the experiment. Participants completed eight practice trials to familiarize them with the task.

In each trial, the signaler made the first decision: she either walked to an item herself or sent a signal to the participant describing a single item feature (e.g. "circle"). If the signaler signaled, the participant then had a chance to walk to the item they believed was the target by clicking on it. Before they made a decision, hovering the cursor over any item in the grid displayed the distance of each agent from the target: the cost of traveling there. If the signaler moved to the target herself, participants observed the signaler walking to the item. The trial ended when either agent reached an item. Then, a review box would pop up, showing who took how many steps to reach which item. Participants were asked to rate their confidence in their selection from one (least confident) to five (most confident). Participants then proceeded to the next trial. After all experimental trials, participants took an exit survey which included a self-report on how serious they were throughout the experiment, strategies they used, and performance of their partner.

D. Results

We analyzed the strategy, response time, and confidence rating on each trial. Across all conditions, only 17 trials had irrational responses (Pragmatic: 9, Utility: 3, Conflict: 5), thus we restricted our analyses to focus on the major strategies employed – for the Pragmatic condition, pragmatic/literal; for the Utility condition, joint/individual; and for the Conflict condition, joint/pragmatic.

1) Strategy Preferences: Population versus Individual: First, we tested whether any clear strategy preferences emerged across the population. For each condition, we calculated the proportion of selecting one strategy for each subject and used a two tailed t-test under the hypothesis $H_0 : \mu = .5$, which tested for a strategy preference across the sampled individuals. In the Pragmatic condition, there was a significant preference for pragmatic signal interpretations ($\overline{x}_{prag} = .698$, $p < .001$). In the Utility condition, there was no preference for one type of utility reasoning over the other ($\overline{x}_{ju} = .559$, $p = .331$). Similarly, there was no dominant strategy in the Conflict condition ($\overline{x}_{ju} = .569$, $p = .234$).

While results from the Conflict condition did not indicate a dominant strategy, a strong pattern emerged at the individual level: people were highly *internally* consistent in choosing a strategy (see Figure 2). We focused on the Conflict condition to explore this idea. We tested whether an *individual* employed a dominant strategy, adjusting for multiple comparisons using the Benjamini-Hochberg criteria (BHC). In 39 out of 51 cases (76.5%), participants adopted a dominant strategy ($p_{adj} < .05$).

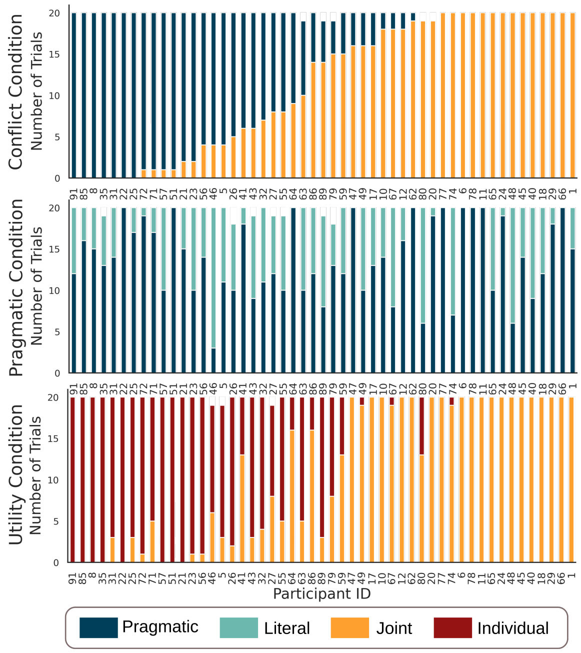

Fig. 2: Strategy breakdown: high consistency in joint utility reasoning within individuals across conditions.

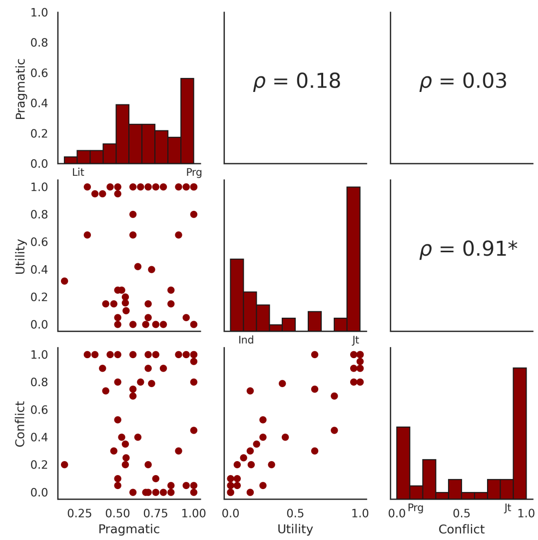

Fig. 3: Strategy correlations across conditions. Correlation coefficients (upper triangle), corresponding to the individual responses (lower triangle). Histogram describing distribution of strategy preference (on diagonal). Data concentrated at the extremes of the histogram indicate the strong, divergent preferences seen in the Utility and Conflict conditions.

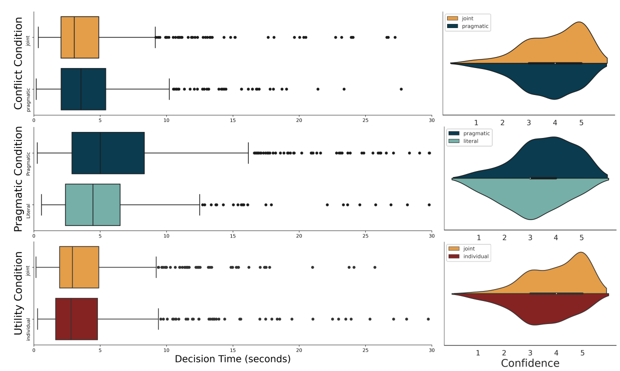

Fig. 4: Left: Boxplot of decision times Trials > 30 seconds ($n_{pragmatic} = 17$, $n_{utility} = 7$, $n_{conflict} = 9$) are included in analyses but not shown here for legibility. Right: Self-rated confidence, split by strategy.

Moreover, we investigated whether participants' strategies correlated between conditions. Pairwise correlation analyses indicated a strong positive relationship between an individual's strategy in the Utility and Conflict conditions (Spearman's ρ = .91, $p < .001$). That is, individuals who chose a joint utility strategy in the Utility condition were also likely to choose a joint utility strategy when pragmatic reasoning and utility reasoning were in conflict. This effect was not observed for the Pragmatic and Conflict (ρ = .03, $p = .852$) or Pragmatic and Utility conditions (ρ = .18, $p = .211$).

2) Strategy Difficulty: Decision Time and Confidence: In this task, we examined decision time, which can act as a rough proxy for the cognitive difficulty involved in employing that strategy [26]. We relied on non-parametric testing, which is robust to outliers and skew inherent in decision time data. In the Pragmatic condition, we found participants to take more time when employing pragmatic reasoning than literal reasoning ($\tilde{x}_{prag}$ = 5.23 sec, $\tilde{x}_{lit}$ = 4.58 sec, Mann-Whitney-Wilcoxon test (MWW); 95% CI of median difference: [.201, 1.103], $p < .001$). In the Utility condition, participants took similar time to respond when employing either strategy ($\tilde{x}_{ju}$ = 2.93 sec, $\tilde{x}_{iu}$ = 2.83 sec, MWW; 95% CI: [-0.094, .389], $p = 0.115$). Finally, in the Conflict condition, participants spent longer to make a decision when employing pragmatics as opposed to joint utility reasoning ($\tilde{x}_{prag}$ = 3.61 sec, $\tilde{x}_{ju}$ = 3.07 sec, MWW; 95% CI: [.003, .561], $p = 0.024$).

We also examined self-reported confidence as a function of decision. Participants were significantly more confident when choosing pragmatic items than literal ones ($\overline{x}_{prag} = 3.60$, $\overline{x}_{lit} = 3.05$, $p < .001$ under Welch's t-test) as well as when choosing items that maximized joint utility than individual utility ($\overline{x}_{ju} = 4.06$, $\overline{x}_{iu} = 3.44$, $p < .001$). Finally, in the Conflict condition, participants were significantly more confident when choosing the joint utility items than pragmatic ones ($\overline{x}_{ju} = 3.99$, $\overline{x}_{prag} = 3.67$, $p < .001$).

E. Debriefing Data: Collaboration Between Partners

While participants were told they were playing with a cooperative and intelligent partner, without live interaction and role reversal in the game, there was no way to regulate one's partner. As a result, one potential concern was what participants would not feel that their partner was collaborative or that they may lack the motivation to be collaborative themselves. However, qualitative examination of post-experiment debriefing data suggests participants did engage collaboratively with their partner.

When asked to rate their partner's performance in the experiment on a scale of 1 (lowest) to 5 (highest), participants tended to rate their partners favorably or above average ($\overline{x} = 3.79$). Examining participants' written reflections, 36 of the 51 participants (70.58%) indicated that their strategy involved reasoning about their partner collaboratively, beyond just the literal signal that was sent. Self-reported strategies included references to joint utility by considering relative distances between their partner and the targets, as well as references to pragmatics by considering what signals their partner did not choose to send in addition to the one that was sent. Finally, when given a chance to report any issues or confusion with the experiment, only 2 of the 51 participants (3.92%) expressed any doubt over the helpfulness of their partner.

F. Discussion

At first glance, overall results on strategy preference may appear inconclusive. A preference for pragmatic reasoning in the Pragmatic condition supports previous empirical findings in referential language games [8, 18], replicating this phenomena in our visual task. On average, people took longer to make a pragmatic decision than a literal one, which is highly consistent with the computational models of pragmatics. In order to come up with a pragmatic interpretation of a signal, a listener must first reason over literal interpretations [9]. At the same time, people were more confident about pragmatic selections than literal ones. In contrast, we found no general strategy preferences in either the Utility or Conflict conditions. However, when we consider the Conflict condition at the individual level, we see that people are exceptionally strategic in their decisions. There may not be one dominant "average" strategy, instead results suggest groups of highly consistent decision-makers who have overwhelming preferences for *different* strategies. Some individuals interpreted signals in a belief-driven manner: reasoning based on the speaker's intention to be straightforward. Other individuals interpreted signals in an action-driven manner: interpreting signals in a way that led to jointly efficient actions.

Moreover, examining individual preferences across all conditions, an interesting pattern emerges. While people were generally capable of adopting a pragmatic approach — shown in the Pragmatic condition — their individual preference for pragmatics was not indicative of their dominant strategy in the Conflict condition. In contrast, individual preference for a joint utility approach in the Utility condition was highly correlated with the individual's preference for joint utility in the Conflict condition. This suggests that while only a subset of individuals used a joint utility based strategy, it was an incredibly powerful heuristic that could generalize across contexts for those people, a phenomenon not observed for pragmatic reasoning.

In the Utility condition, we found participants to be more confident about their decision when they chose a jointly efficient item; however, we were surprised by the prevalence of individual utility reasoning given previous work on joint efficiency in cooperative tasks [12, 25]. One explanation is that being cooperative requires effort. It is more intuitive to reason from an egocentric perspective [7], and participants who have the capacity to plan jointly may not have had high enough motivation in the task to engage it. Empirical work points to the idea that when interpreting referring expressions, individuals weigh both egocentric and joint perspectives depending on context [15], leading to a division of labor in communication. One factor that could contribute to this division is an estimation of the degree of effort one's partner is exerting [14]. The debriefing data supports that participants likely believed their partners to be at least somewhat collaborative and the majority of self-reported strategies indicated reasoning about one's partner cooperatively. However, as there was no true interaction between participants, this still may not have been enough motivation to choose jointly efficient actions.

On the other hand, in the Conflict condition participants were in fact faster at making joint utility based decisions than pragmatic ones. At the same time, confidence ratings were higher on trials where people employed joint utility. These results suggest that joint utility reasoning may be an easier means to solve this task than pragmatics, even though we found no population preference in the Conflict Condition.

III. EXPERIMENT 2

Results from Experiment 1 indicated that when joint utility and pragmatics were in conflict, people were split between the two strategies despite being faster and more confident about joint utility reasoning. For this reason, we hypothesized that the inclusion of the non-conflict conditions could be explicitly cuing people to consider a strategy that they might not have naturally used otherwise, introducing additional bias. In order to test this, we removed these two conditions and just focused on cases where subjects were forced to make a conflicting choice. We also kept the signaler-walk condition to demonstrate that the signaler could act cooperatively. Other than this change, the stimuli, task, and game play were all the same as in Experiment 1. As a result, participants saw 20 trials of each of the two remaining conditions for a total of 40 trials.

Fifty undergraduate students in the Department of Communication at University of California, Los Angeles (UCLA) participated in this online study for class credit. We analyzed the data of 40 participants after excluding three participants for failing the comprehension quiz more than twice, and seven participants for self-reporting not being serious in the experiment.

A. Results

We performed the same analyses as in Experiment 1 with particular emphasis on the overall strategy and individual strategy preferences. Across all conditions, four trials had irrational responses. Unlike in Experiment 1, a two-tailed t-test of subject strategies indicated a dominant strategy in the Conflict condition ($\overline{x}_{ju} = .623$, $p = .0397$). Additionally, as before, individuals still tended to be consistent in choosing their strategy (see Figure 5). In this case, 26 out of 40

(65%) participants adopt a dominant strategy after adjusting for multiple comparisons using BHC ($p_{adj} < .05$).

Furthermore, we replicated the decision time and confidence patterns seen in Experiment 1. Participants spent longer to make a decision when employing pragmatics as opposed to joint utility reasoning ($\tilde{x}_{prag}$ = 4.20 sec, $\tilde{x}_{ju}$ = 3.58 sec, MWW; 95% CI of median difference [.069, .857], $p < .001$). Additionally, they were more confident when choosing the joint utility items than when choosing the pragmatic ones ($\overline{x}_{ju} = 4.03$, $\overline{x}_{prag} = 3.70$, $p < .001$ under Welch's t-test).

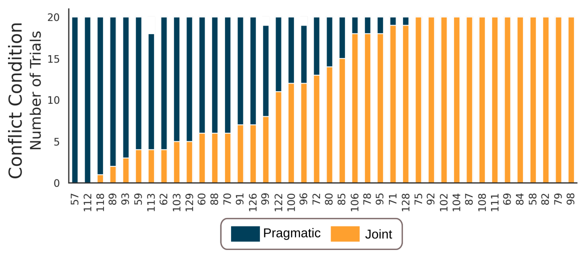

Fig. 5: **Strategy**: individuals are highly internally consistent and have an overall preference for joint utility.

Finally, participant ratings of their partner and the interactivity of the task in Experiment 2 matched that of Experiment 1. When asked to rate their partner's performance in the experiment on a scale of 1 (lowest) to 5 (highest), participants tended to rate their partners favorably ($\overline{x} = 4.10$). Thirty of the 40 participants (75.00%) indicated that their strategy involved reasoning about their partner collaboratively, with similar strategies to those reported in Experiment 1. No participants reported doubt over their partner's cooperation.

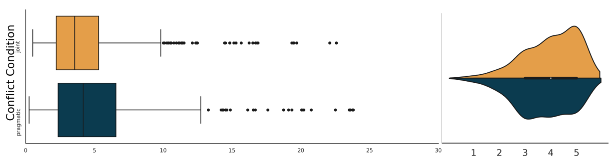

Fig. 6: Left: Boxplot of decision times Trials > 30 seconds ($n = 9$) are included in analyses but not shown here for legibility. Right: Self-rated confidence, split by strategy.

B. Discussion

These results do indicate a preference for adopting a joint utility strategy, helping confirm the suspicion that the other additional conditions were prompting subjects to consider a strategy that they may not have naturally adopted on their own. Moreover, all other results in this follow-up remain consistent with the original experiment. Around two-thirds of individuals are highly individually consistent in their strategy, and participants who adopted a joint utility strategy were both highly confident and faster to make their decisions. Additionally, self-reported strategies again affirm that the majority of participants believe their partner to be at least somewhat collaborative, and engage in decision-making centered around this belief. This consistency between experiments serves to further validate the pattern of results found.

IV. Conclusion

When individuals were forced to choose between action-driven or belief-driven strategies in Experiment 1, they were highly internally consistent. However, counter to our initial expectations that joint utility would be widely adopted, there was no overall preference for joint utility reasoning. This was surprising since confidence and decision time results indicated joint utility reasoning was easier than pragmatics in the Conflict condition. In Experiment 2, we followed up on this idea, hypothesizing that the explicit inclusion of the Pragmatic condition acted as a cue to highlight feature pragmatics as an important heuristic. We demonstrated that after removing this potential bias, joint utility began to dominate as a strategy.

Another potential explanation for less joint utility reasoning which leaves room for interesting potential future work is the lack of interaction between partners in the task. Although framed as cooperative, the signaler's responses were pre-programmed. A version of this task where the role of communicator and listener are not fixed which could lead to much stronger preferences for fairness and cooperation. Additionally, future research could aim to create a more interactive version of this experiment, bringing subjects in to work together in person or in real-time online in order to further encourage collaboration.

While these experiments have shown how individuals act when forced to choose between action and belief driven strategies, future research should address how these heuristics interact with each other, which has been demonstrated to be a theoretically promising approach to communication [22]. In fact, context — and the constraints it provides — likely *accumulates* evidence to resolve ambiguity in linguistic communication [19]. Integration of many simpler contextual heuristics may be a key to fast, flexible, and sparse signaling.

Acknowledgments

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