

THE IMPACT OF COMMUNICATION CHANNEL ON SKILL ACQUISITION IN A DYNAMIC COLLABORATIVE TASK

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Abstract

Research on collaborative problem solving typically focuses on speech as the primary driver of team success. Yet, recent studies on joint action have identified additional, non-verbal mechanisms for coordination, such as entrainment, perception-action matching, and action-based communication. Perhaps even more surprising are studies using the complex dynamic Co-op Space Fortress task, which demonstrate that even in the absence of a communication channel, dyads can coordinate effectively through non-verbal mechanisms alone. More impressively, an ACT-R model constructed for this task successfully reproduced dyadic skill acquisition trajectory, suggesting that the same processes underlying individual skill acquisition can also describe how dyads become more skilled at coordinating. This possibility stems, in part, from the nature of Co-op Space Fortress. This task imposes high perceptual-motor demands on subjects while offering limited flexibility for changing the joint plan, aside from selecting teammate roles. Consequently, it has been argued that subjects acquire all necessary task knowledge during initial instruction and subsequently execute the only viable plan, while adopting the role they are more successful at. Automatic skill processes are then responsible for performance improvements. The current study aims to challenge the sufficiency of this account for Co-op Space Fortress by introducing explicit communication channel between participants. Using a between-subject design, we compared dyads without a communication channel to those allowed to communicate either verbally during game play (in-game verbal) or textually between games (in-pause textual). If explicit communication was not needed in this task, we expected that there would be no significant impact on skill acquisition rates and final scores between conditions. Our results demonstrated the opposite. Dyads with a communication channel significantly outperformed the no-communication group, improving their scores at a significantly faster rate. Furthermore, those with an in-game verbal communication channel showed a non-significant tendency for faster improvement than those with the in-pause textual channel. These findings suggest that initial task knowledge is often incomplete and that communication facilitates faster convergence on joint plans and effective real-time monitoring of partners. This study demonstrates that even in high-demand perceptual-motor tasks, explicit communication provides a critical advantage that exceeds the capabilities of individual learning mechanisms.

Keywords: *Collaborative skill acquisition, collaborative problem solving, coordination, communication channel, Co-op Space Fortress.*

1. Introduction

Collaboration is fundamental to human society, underpinning everything from physical labor and artistic improvisation to complex problem-solving (Graesser et al., 2018). Today, collaborative skills are recognized as crucial 21st-century competencies (Griffin & Care, 2015), a shift reflected in large-scale evaluations like those by PISA and the ATC21S project (OECD, 2017; Griffin & Care, 2015).

Research on joint action traditionally highlights speech as the primary driver of team success (Clark, 1996). In collaborative problem solving specifically, verbal communication allows teams to form shared beliefs, construct joint plans, make group decisions, and coordinate execution (Hesse, Care, Buder, Sassenberg, & Griffin, 2015). However, recent studies on joint action have shifted focus toward non-verbal coordination mechanisms, such as entrainment, perception-action matching, and action-based communication (Knoblich, Butterfill, & Sebanz, 2011; Sebanz & Knoblich, 2021).

The efficacy of non-verbal mechanisms is evident even in complex dynamic tasks like Co-op Space Fortress (Dimov, Anderson, Betts, & Bothell, 2019), a collaborative variant of classic skill-acquisition games (e.g., Mane & Donchin, 1989; Dimov, Anderson, & Betts, 2024). Recent work demonstrates that dyads can successfully master this task relying entirely on non-verbal coordination. Furthermore, an ACT-R model successfully reproduced this dyadic skill acquisition trajectory, implying that the same processes underlying individual learning can scale to explain how teams become more skilled (Dimov, Anderson, Betts, & Bothell, 2023).

This possibility stems partly from the nature of Co-op Space Fortress. The task imposes high perceptual-motor demands while offering limited flexibility for changing the joint plan, aside from selecting teammate roles. Consequently, it is hypothesized that teammates acquire all essential knowledge and plan during initial instruction, generate the only viable plan, and learn to adopt their optimal roles during its execution. Automatic skill processes are then responsible for performance improvements.

The current study challenges the assumption that explicit communication is unnecessary in Co-op Space Fortress. Using a between-subjects design, we compared a *no-communication* control group with dyads allowed to communicate either verbally during gameplay (*in-game verbal* condition) or textually between rounds (*in-pause textual* condition). If communication is truly superfluous for this task, introducing these channels should yield no significant impact on skill acquisition rates or final scores.

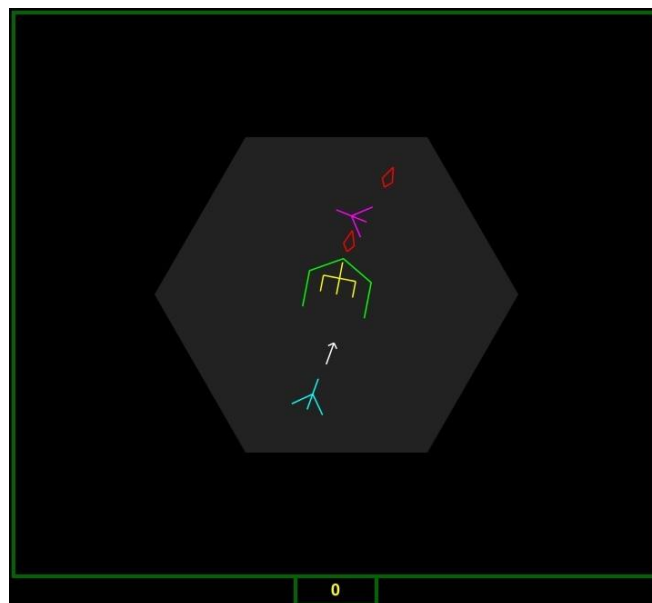
2. Methods

2.1. The task: Co-op Space Fortress

In Co-op Space Fortress, two players each control a spaceship with the shared goal of destroying a shielded fortress located in the center of a gray hexagon (Figure 1). Both players begin outside of this gray hexagon, as the fortress automatically targets the first ship that enters its perimeter and stays locked onto it until the ship exits. To successfully destroy the fortress, one player must act as bait and prompt the fortress to shoot. This action causes the fortress's shield to open up in the back, exposing a vulnerable region where it can be shot. The second player must then move in and shoot the fortress down while it remains vulnerable. Once the fortress is killed, both players must exit the hexagon so the fortress can reappear.

Team performance is tracked via a point system that ultimately translates into a payment bonus for the participants at the end of the experiment. Each time the team successfully kills the fortress, the players earn 100 points. However, players must carefully avoid getting hit by the fortress's shells or crashing into obstacles; if they do, they die and lose 100 points. Additionally, players must manage their ammunition efficiently and avoid wasting missiles, as every missile that fails to kill the fortress incurs a 10-point penalty.

Figure 1. A screenshot of Co-op Space Fortress during gameplay.



2.2. Participants

114 subjects (48 male; $M_{age} = 21$; $Min_{age} = 18$; $Max_{age} = 40$) from the Pittsburgh area, mostly students from Carnegie Mellon University and University of Pittsburgh, participated for Figure 1 money, which included a base payment (\$15) and a performance-contingent bonus payment. Pairs of participants were formed either randomly, restricted by participant availability, or by asking participants to bring another participant to play with. Informed consent approved by the University Institutional Review Board (IRB) of Carnegie Mellon University was obtained from each participant.

2.3. Procedure

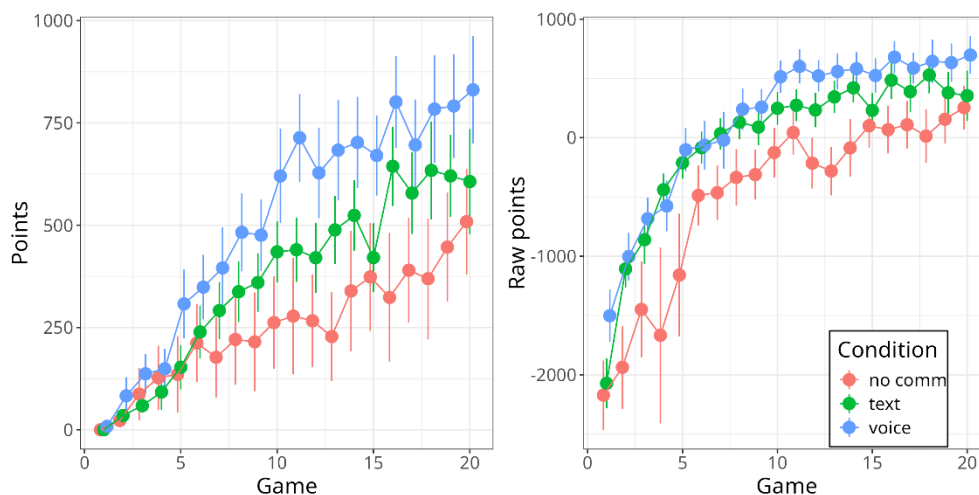
Participants were assigned to one of three conditions: *no-communication*, *in-game verbal*, or *in-pause textual*. Data for the *no-communication* baseline condition was collected first ($n = 28$). The two communication conditions were subsequently run in parallel: an *in-game verbal* condition ($n = 46$) where dyads could speak to each other through a verbal channel during active gameplay, and an *in-pause textual* condition ($n = 40$) where participants communicated via a text chat interface exclusively during the pauses between games.

To isolate the targeted communication channels and prevent unintended non-verbal signaling, each participant was seated in a separate room. The experimental session consisted of four sequential phases: (1) a demographic questionnaire, (2) game instructions, (3) twenty 3-minute rounds of Co-op Space Fortress, and (4) a concluding feedback questionnaire. Both dyad members were required to complete each phase before the team could advance to the next. A one-minute break was provided halfway through the gaming session, immediately after the tenth round. In total, the experimental procedure took each participant between 1 h 15 min and 1 h 20 min to complete.

3. Results

Team success was evaluated using two metrics: *points* and *raw points* (Figure 2). Points represent the in-game score visible to players, which is floored at zero. Because players respond to this visible metric, they may adopt riskier behaviors (e.g., crashing without penalty) when they cannot earn positive points. Conversely, *raw points* provide a more objective measure of performance. By capturing negative scores, *raw points* are sensitive to subtle performance improvements early in the learning process before players are skilled enough to achieve positive scores.

Figure 2. Dyadic skill acquisition curves over the course of 20 3-minute games per condition. (A) Points per game (mean and CI). (B) Raw points per game (mean and CI).

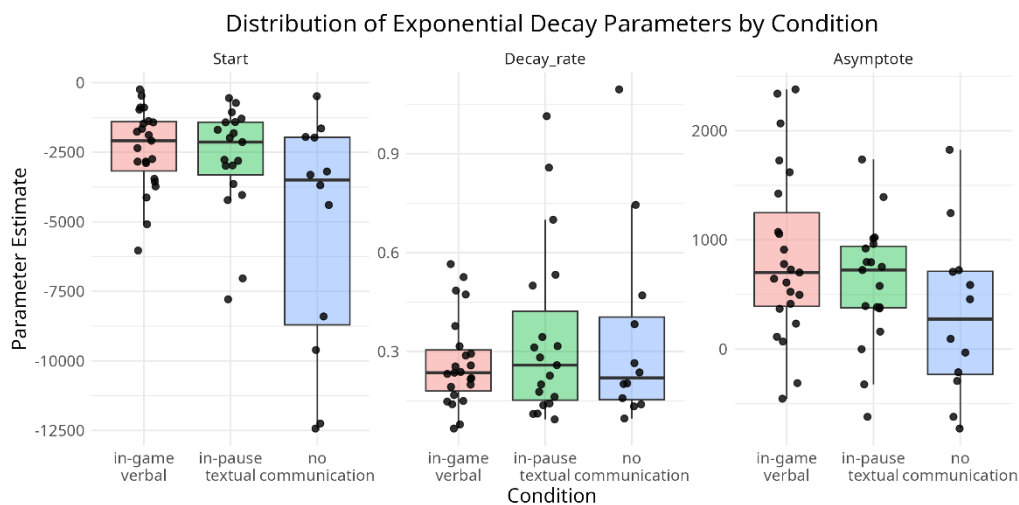


In Game 1, only dyads in the *in-game verbal* condition had the opportunity to communicate, while the *in-pause textual* and *no-communication* groups did not. No team in any condition was skilled enough to score positively during this initial round ($M_{verbal} = 8.26$, $M_{textual} = 0$, $M_{no\ communication} = 0$). However, a Kruskal-Wallis test revealed a significant difference in Game 1 raw points across conditions ($p = .026$). A pairwise Wilcoxon test indicated that the *in-game verbal* dyads scored significantly higher than both the *in-pause textual* ($p = .041$) and *no-communication* ($p = .041$) dyads. By Game 2, both communication groups had interacted. Performance differences remained significant (Kruskal-Wallis: $p = .031$). At this stage, dyads in the *no-communication* condition scored significantly lower than *in-game verbal* ($p = .043$) and *in-pause textual* ($p = .043$) dyads.

To assess longer-term trends, we averaged dyad scores over three-game blocks for the middle (Games 10–12) and end (Games 18–20) of the experiment. Mid-game performance differed significantly across conditions ($p = .003$). Both communication groups significantly outperformed the no-communication baseline (*in-game verbal*: $p = .003$; *in-pause textual*: $p = .034$), with the verbal condition showing a non-significant tendency to score higher than the textual condition ($p = .158$). By the end of the study, the overall difference between conditions was only marginally significant ($p = .076$). A pairwise Wilcoxon test confirmed that the *in-game verbal* condition still scored marginally significantly higher than the *no-communication* condition ($p = .071$).

Finally, we modeled dyadic learning trajectories by fitting exponential decay curves to the raw points for each dyad, starting from Game 2. Raw points were used because their trajectories adhered to the shape required for an exponential fit, unlike the zero-truncated point curves. We fitted an equation with three parameters: starting score (S_{Start}), decay rate, and asymptotic score ($S_{\text{Asymptote}}$). Although visual trends (Figure 3) suggested higher starting and asymptotic scores for the two communication conditions, a Kruskal-Wallis test indicated that none of these parameters were statistically different across the groups ($p_{\text{Start}} = .32$, $p_{\text{Decay_rate}} = .54$, $p_{\text{Asymptote}} = .53$).

Figure 3. Exponential decay curve parameter distributions.



4. Discussion

This study investigated how the presence and modality of a communication channel impact skill acquisition in a dynamic collaborative task previously shown to be learnable without explicit communication. Our findings confirm that communication channels facilitate learning, with different modalities offering distinct advantages.

4.1. Does speech help when learning to collaborate

In The beneficial impact of speech is evident across several contrasts. In Game 1, dyads using *in-game verbal* communication significantly outperformed other groups that had not yet communicated. This suggests that even when players are struggling with basic controls and cannot fully focus on high-level planning, real-time communication provides an immediate advantage. By Game 2 – following one communication pause – the *in-pause textual* condition caught up with the *in-game verbal* group, with both significantly outperforming the *no-communication* baseline.

This performance gap persisted into the middle of the experiment. However, toward the end, only the verbal condition maintained a statistically higher score than the baseline. Ultimately, these results indicate that any communication yields a higher dyadic skill acquisition rate than none, with *in-game verbal* communication proving more beneficial than *in-pause textual*.

4.2. Why does communication help?

Research on collaborative problem solving suggests that communication aids in understanding the task, forming shared plans, coordinating their execution, and monitoring their execution progress (Hesse et al., 2015). Although the ACT-R model for this task assumed task understanding and planning were completed prior to gameplay, the superiority of the two communication conditions suggests this assumption is incomplete. Players likely do not acquire all necessary knowledge from the instructions alone; instead,

they dynamically fill knowledge gaps and share newly discovered causal knowledge through communication. Moreover, they might also share both high-level joint plans and low-level individual strategies (e.g., specific ship controls), accelerating individual skill acquisition and preventing misaligned plans. The tendency for the *in-game verbal* condition to outperform the *in-pause textual* condition late in the experiment, albeit not significant, likely stems from the real-time capabilities of coordinating plan execution and monitoring progress, but also of managing the interpersonal relations and social obligations essential for team cohesion (Petukhova & Bunt, 2020).

4.3. Shortcomings

These results should be interpreted cautiously due to the relatively small sample size, which resulted in marginally significant contrasts and non-significant differences in model fit parameters. Future research must replicate these findings with larger cohorts to ensure robustness. Additionally, our design perfectly confounded two factors: communication time (in-game vs. in-pause) and communication channel (verbal vs. textual). While texting during gameplay would cause excessive interference, future studies should introduce an in-pause verbal condition to disentangle these variables. Furthermore, the *in-pause textual* condition lacked pre-game communication, effectively rendering its Game 1 identical to the baseline no communication. Finally, Co-op Space Fortress is a highly specific task that can be mastered without communication, inherently limiting the marginal potential for communication-driven improvement. However, this exact middle ground characteristic makes the game an excellent environment for studying the precise benefits of communication

Acknowledgments

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