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Incidental Coupling of Perceptual-Motor Behaviors Associated with Solution Insight during Physical Collaborative Problem-Solving

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Abstract

Solving problems with others not only reduces the time required to complete a challenge but may also enable the discovery of novel strategies that qualitatively change how a problem is approached. At the dyadic level, the laboratory-based 'shepherding task' demonstrated that, when tasked to contain evasive agents to a centralized location, some participants discover a non-obvious but optimal strategy to solve the task. This paper quantified the interactions between participants engaged in the task using Multidimensional Cross-Recurrence Quantification Analysis (MdCRQA), applied to each participant's gaze and hand movements. The results demonstrated that strategy discoverers exhibited greater amounts of incidental coupling than non-discoverers prior to discovery. Once discovered, the strategy reduced the strength of coupling between participants, indicating that the strategy also reduced coordination demands. Future work will investigate whether differences in problem-solving can be attributable to differences in the perceptual features participants use which scaffold the discovery of task-optimal solutions.

Keywords: interpersonal coordination; joint action; collaborative problem-solving; perceptual-motor behaviors; virtual reality

Introduction

Working with others not only reduces the amount of time or effort needed to complete a task but can also enable the discovery and exploitation of unique strategies. A simple example is the formation of a bucket brigade to efficiently transport objects – the formation of which necessitates the coordination of actions with others. However, variation in group composition and skill results in variation in the level of performance teams can reach. This paper reports results pertaining to the interpersonal dynamics which differentiate expertise in two-person groups to discover and exploit strategies that effectively solve a collaborative problem-solving task referred to as the 'human shepherding task' (Nalepka et al., 2017).

The human shepherding task requires dyads, holding motion controllers, to work together to corral and contain a set of evasive objects (target agents) towards a central red containment area for a prespecified period (see Figure 1). The target agents exhibit random, Brownian motion, but will flee from the participants if their controllers come near them. Early in the experiment, participants utilize a strategy referred to as *Search & Recover* (S&R) (Figure 1, middle). S&R involves both participants dividing the game space in half, and each participant pursues the target on their respective side that is farthest from the containment goal. In the original experiment (Nalepka et al., 2015, 2017), this strategy is effective if the number of target agents is low (three or five), but it becomes a challenge to solve the task using the S&R strategy when the number of targets is high (i.e., seven).

In the most difficult condition, many dyads who continue to utilize the S&R strategy are more likely to fail at meeting the task completion criteria. For those who succeeded, some discovered a novel and nonobvious solution to solve the task. Instead of each participant pursuing individual target agents to corral towards the goal, some participants learn that when all targets are near the goal, a more effective strategy is to make rhythmic, oscillatory motions around the entire herd to collectively corral and contain them within the containment region. This strategy, referred to as coupled oscillatory containment (COC) (see Figure 1, right), once discovered, resulted in near-ceiling levels of performance. When participants implement COC, participants will either mirror the actions of their partner (in-phase) or oscillate in opposite directions (anti-phase). The observation of both in-phase and anti-phase behavior, and their relative likelihood, is consistent with previous literature regarding the emergent

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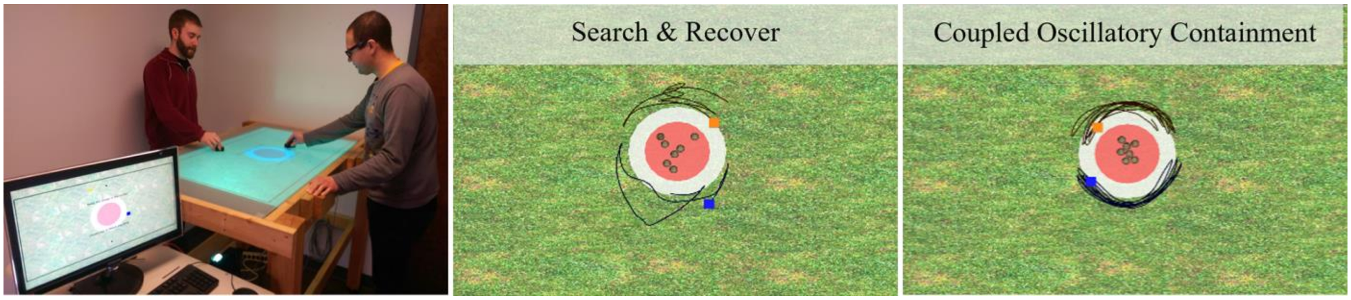

Figure 1: Original task environment and observed behaviors from Nalepka et al; (2015, 2017). Participants used handheld controllers (left) to move their player (the blue or orange square; middle, right) to corral and contain a set of evasive agents (the spheres) to the red containment circle by using repulsive forces caused by players being near the agents. Participants would subdivide the task space in half and pursue the agents farthest from the goal (termed *Search & Recover* [S&R]). Some dyads learned that a more effective strategy is to make oscillatory movements around the entire herd to keep the agents contained (termed *Coupled Oscillatory Containment* [COC]). See text for more details. Adapted from Nalepka et al., (2021).

stable patterns of rhythmic coordination more generally (Haken et al., 1985; Kelso, 1995; Schmidt et al., 1990; Schmidt & Richardson, 2008).

In the original experiment, when participants were debriefed and questioned how they come to learn the COC strategy, anecdotally many participants utilize language to suggest that they experienced a moment of cognitive insight – an *Aha!* Moment. Specifically, participants will describe that they would suddenly see that the COC strategy was the preferred solution to the shepherding task.

Current Study

The discovery of the COC strategy to effectively contain the target agents was not observed by all participants. The current study sought to determine whether its discovery can be predicted by how participants interacted during the experiment. Previous research in social interaction has documented how interpersonal coupling, as well as strong forms of coupling such as behavioral synchronization, is associated with problem-solving ability (Miles et al., 2017; Valdesolo et al., 2010). This present experiment utilized Multi-dimensional Cross-Recurrence Quantification Analysis (MdCRQA) to measure the interactivity between participants – specifically of their perceptual-motor states. MdCRQA is a multidimensional extension of univariate CRQA, which is an analysis technique that describes the interactions between coupled dynamical systems via various quantifiable measures derived from recurrence plots (RPs), which is a two-dimensional pictorial representation of the time-lagged *recurrences* between the two systems. This analysis quantifies properties of unknown, complex dynamical systems with how such systems behave when they revisit states (Marwan et al., 2007).

Method

Participants

Sixty participants, recruited as dyads, took part in the experiment. Participants received course credit for participating in the experiment. The average age of the sample was 19.07 years (*SD* = 3.68), with ages ranging from 17 to 45 years. Thirty-nine of the participants self-identified as female, 19 as male, and two as gender non-binary or undisclosed. Sixteen of the dyads consisted of participants of the same self-identifying gender. For two of the dyads, participants had previously encountered their partner prior to taking part in the experiment. The remaining participants had never met their partner prior to the experiment. All but one participant reported to be right-hand dominant.

Materials and Task

The shepherding task was implemented in the Unity game engine (ver. 2018.4.23f, Unity Technologies, San Francisco, USA) as an immersive virtual reality (VR) experience (Figure 2). The task environment and game logic mirrored the implementation from previous work (Nalepka et al., 2019).

Participants were situated on each long side of a table measuring 2.2 m (L) x 1.2 m (W) x 0.81 m (H). Each participant was equipped with an HTC Vive VR headset (Vive DevKit 2, HTC) with integrated eye tracking (Tobii AB). The participants were embodied as either a male-presenting or female-presenting avatar. The avatars were created using Adobe Fuse CC (Beta Version 2014.3.14) (Caruana et al., 2021). The avatars head and eye movements were controlled by the data sent by the participant's VR headset. An inverse kinematics calculator (FinalIK, RootMotion Inc.) was used to approximate the movement of the avatar's torso and hips from the displacements of the head position. Additionally, participants held a custom-made paddle with their right hand, which was fitted with a Vive Tracker (HTC). Participant head, eyes and hand movements were transmitted at 90 Hz across a local network to the other participant using Mirror Networking API (https://mirror-networking.com/).

The virtual environment consisted of a grass field (measuring 1 × 1 m), seven target agents (TAs), and a herding agent (HA) for each participant. A fence surrounded the grass field to prevent the TAs from escaping. The TAs were depicted as white spheres (diameter = 2.5 cm) which, when left unperturbed, exhibited Brownian motion. The HA for each participant was either a blue or orange colored cube (edge length = 2.5 cm) and were used by the participant to interact with the TAs. When a participant's HA was within 12 cm of a TA, the Brownian force acting upon the TA was changed to a repulsive force directed away from the participant's HA (Nalepka et al., 2019). This was the only method by which the participants could interact with the TAs.

Before each trial, each participant moved their HA to a start location on their respective side to jointly initiate a trial. Once started, the TAs appeared in a red circle (diameter = 20 cm) in the center of the grass field and began to disperse in different directions (see Figure 2 for their initial configuration). The participant's task was to use their HA to keep all seven TAs within this red circle. The experiment consisted of one-minute trials in which participants jointly corralled the TAs towards the red circle. Successful trials were those in which all TAs were inside the red circle for at least 60% of the one-minute period. At the end of each trial, each participant received visual feedback regarding their performance. The feedback was the percentage of time that all TAs were contained in the red circle and whether the trial was successful or not. Participants were also informed of how many more trials they needed to finish the experiment.

The positions of the TAs, HAs, and a Boolean indicating if all TAs were contained was recorded at a 90 Hz sampling rate. Participants' head and hand position and orientation, as well as their eye gaze direction and position (i.e., where the gaze vector intersects with the task environment) was also recorded at 90 Hz.

Procedure

Following informed consent and completion of a form requesting demographic information, participants stood on either side of the long edge of the table and placed the VR headset on their head. The experimenter assisted each participant in adjusting the lens separation of the headset so that it closely aligned to the participant's interpupil distance to maximize gaze detection. This was done using a visual aid provided by Tobii Pro's SDK which represented the quality of gaze detection using colored circles (whereby green would indicate suitable gaze detection). Following this, participants completed a five-point calibration, where the calibration stimuli were represented as expanding red circles placed 50 cm from the participant. To verify the calibration, participants were asked to gaze at the TAs which were placed at their initial starting positions at the center of the task environment. Participants were asked to gaze at a TA named by the experimenter, and if their gaze did not intersect on or near the object, the eye calibration procedure was redone.

Figure 2: The virtual environment. Participants embodied a virtual humanoid avatar whose head and eye movements were driven by the participants. Participants controlled one of two cubes using their right hand which represented their player in the shepherding task. The avatars' right arms were not visible to not occlude the task environment.

Following eye calibration, participants were given their controller, which they held in their right hand, and were told to keep the controller on the table. Participants were then told the goal of the task – to work alongside their partner to keep the TAs contained within the red circle for at least 60% of the trial. The experiment ended once dyads either met the success criteria on eight separate instances, if 45 minutes have elapsed while completing the task, or if the scheduled end time for the session has passed (sessions were scheduled for one hour). Participants were also told that they had to complete the task without verbal communication.

To initiate each trial in the experiment, both participants placed their respective HA on the starting location in front of them. When both participants had done so, the TAs would appear, indicating the trial has started. Participants were informed that the trial had ended once they received visual feedback about their performance following the trial's one-minute duration.

Data Preprocessing

Behavior Classification. Behavioral classification was done using the method employed by Nalepka et al. (2019). For each participant, the two-dimensional (the transverse plane) hand position data was low-passed filtered at 10 Hz using a 4^{th} order Butterworth filter. Then, an angular timeseries was constructed with reference to the center of the red containment location. Following detrending and z-score normalization, Welsh's power spectral density estimates (using MATLAB's *pwelch* function) were conducted to determine the peak oscillatory frequency of the angular timeseries between 0 and 2 Hz. Windows of 512 samples were used, with 50% overlap. A participant was considered to use oscillatory behaviors if the peak frequency of the angular timeseries was greater than 0.5 Hz; otherwise, the participant was coded as using the S&R strategy. If both participants exhibited a peak frequency > 0.5, the trial was coded as a *COC Trial*. If this was true for only one participant, the trial was coded as an *Oscillatory-S&R* trial.

MdCRQA Preprocessing. For MdCRQA, each participant's two-dimensional hand and gaze position data (along the transverse plane) was submitted for analysis, resulting in a four-dimensional timeseries for each participant. No preprocessing was applied to the hand data. For the gaze data, missing values were replaced with the nearest valid datum.

Measures

The following measures were computed for all trials.

Task Performance. Task performance was assessed using the trial's *containment time* – the duration (s) all target agents were contained within the red containment location, with a maximum value of 60 s.

Interpersonal Coupling Dynamics. Interpersonal coupling was quantified using multidimensional cross-recurrence quantification analysis (MdCRQA) (Wallot, 2019). MdCRQA is a nonlinear correlational analysis technique which quantifies the dynamics of coupling behavior between two dynamical systems (e.g., two people). MdCRQA is a multidimensional extension of CRQA (Marwan et al., 2007). The benefit of recurrence-based techniques is that few assumptions are made regarding the inputted data (e.g., the analysis can handle nonlinear data, data containing outliers, nonstationary signals) (Wallot, 2019).

Measures from MdCRQA can provide a description of the number of shared states between two systems (referred to as %REC, see below) as well as the coupling's strength (referred to as MaxL). MdCRQA computes these measures from the patterning of two-dimensional recurrence plots (RPs) (see Figure 3). RPs provide a visualization of the co-occurrences of two different timeseries (in the case of a cross-RP) at any two timepoints. Co-occurrences (i.e., recurrences) along the main diagonal of the RP represent co-occurrences at the same timepoint, while recurrences away from the main diagonal refer to time-delayed visitations by the second multivariate timeseries following the first (the order determined by whether recurrences appear above or below the main diagonal). Due to inherent stochasticity embedded in measured data, states are considered recurrent if they fall within a distance threshold parameter, which is a free parameter. The RP is a binary matrix consisting of 1s (recurrent/similar state) and 0s (dissimilar state).

MdCRQA was performed using code provided by Wallot (2019) using MATLAB (R2020a, MathWorks Inc.). Each participant's four-dimensional timeseries consisted of their hand and gaze position (each being two-dimensional along the transverse plane). Each dimension was z-scored normalized before being submitted to MdCRQA. A co-occurrence was computed (i.e., given a value of 1) if the distance matrix was within 0.5 standard deviations from the mean distance between the two timeseries – otherwise the value for that timepoint was set to 0.

The following measures were computed from the constructed RPs:

Incidental coupling (%REC) is computed as the percentage of possible timepoints from the RP where a co-occurrence was detected (i.e., computed by summing all co-occurrences divided by the total possible number).

Coupling strength (MaxL) is computed as the longest diagonal line length from the recurrence plot (i.e., the maximum number of diagonally co-occurring timepoints without interruption). A diagonal line on an RP indicates time periods where both timeseries followed similar trajectories.

Previous research demonstrated that MaxL provides an estimate of the coupling strength between two interacting dynamical systems (Richardson et al., 2007), while %REC is sensitive to the amount of random variation in the timeseries (and thus is why it is referred to as *incidental* coupling).

Social Impression. In addition to the task performance measures, participants completed a set of six questions following the experiment rating their impression of their partner. A composite score was constructed by taking the average response to all questions (rated on a scale from 1 [Not at all] to 9 [Very]). The questions were the following: *How much do you like the other participant? How similar to you is the other participant? How close do you feel to the other participant? How connected do you feel to the other participant? How willing would you be to work with the other participant on a group task? How willing would you be to make friends with the other participant?*

Analysis

For all analyses, linear mixed-effects (multilevel) models were constructed, whereby each trial (689 total observations) was nested under their respective dyad. The models were fitted following the recommendations by Barr et al. (2013) and Meteyard and Davies (2020). First, the maximal random-effects structure was identified for each model by first including all random intercepts and random slopes (including interactions), and then removing model parameters iteratively until the model could reach convergence. Covariances between the random effects were not estimated. Once the random-effect portion of the model was defined, the fixed-effects were added and assessed whether they significantly improved the fit of the model using likelihood-ratio (LR) test. Finally, once the final model was determined, the model was refit using restricted maximum likelihood (REML) so that Kenward-Roger estimates of degrees of freedom for the fixed effects could be calculated (Kenward & Roger, 1997). All pairwise comparisons following significant effects were adjusted using the Bonferroni correction. All models were constructed using the Stata/MP software (ver. 17; StataCorp).

Results

Twenty-four dyads (80%) completed the shepherding task successfully on eight instances. For the six unsuccessful dyads, three never completed the task successfully, two dyads had one successful trial, and one dyad had two successful trials. For those who were successful, dyads completed an average of 19.38 trials (SD = 8.92, ranging from 10 to 37 trials).

When considering all dyads, nine dyads (30%) discovered the COC strategy reported in previous research (Nalepka et

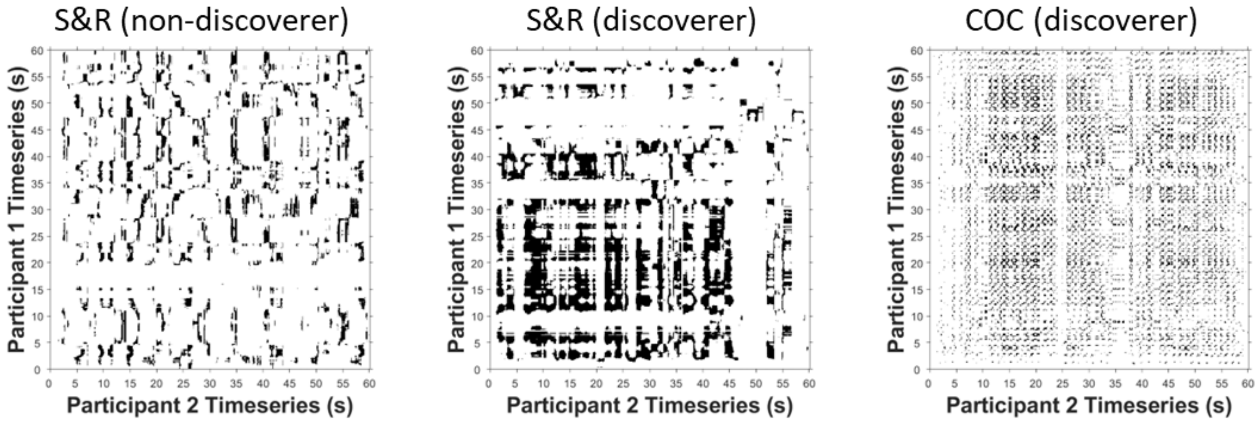

Figure 3: Three examples of recurrence plots (RPs) from the Multidimensional Cross-Recurrence Quantification Analysis (MdCRQA). Black regions indicate timepoints where both participants exhibited a similar perceptual-motor state. Non-discoverers (left) exhibited fewer shared perceptual-motor states compared to Oscillatory-discoverers (middle). Once the Oscillatory-S&R or COC strategy was discovered (right), the length of time participants maintained perceptual-motor coupling decreased. See text for more details.

al., 2015, 2017). For an additional three dyads (10%), one participant in the dyad discovered and utilized oscillatory movements as a containment strategy, while the other participant exhibited S&R behavior. This strategy asymmetry was also observed by three (33%) of the COC-discovering dyads prior to COC discovery. In all instances, the participant exhibiting oscillatory behaviors was the same. This asymmetric strategy will be referred to as *Oscillatory-S&R*.

The strategy dyads adopted when completing the shepherding task (*Strategy:* S&R, Oscillatory-S&R, COC) had a significant effect on task performance, $F(2, 160.24) = 10.79$, $p < .0001$. Consistent with previous research (Nalepka et al., 2015, 2017), dyads utilizing the COC strategy exhibited greater performance compared to when the S&R strategy was used (average marginal effect [AME] = 13.43 s, $SE = 3.18$, $95\%CI = [7.00, 19.86]$), $t(136.7) = 4.13$, $p < .0001$. A similar result was found when only one participant in the dyad utilized oscillatory behaviors as a containment strategy (AME = 11.51 s, $SE = 3.90$, $95\%CI = [3.81, 19.20]$), $t(173.1) = 2.95$, $p = .011$. No difference was found in task performance between Oscillatory-S&R and COC trials, $t(225.8) = 0.43$, $p > .99$, indicating that only one participant is required to discover oscillatory behaviors as an effective strategy. These results follow fitting a model consisting of the following fixed effects: *Trial Success* (Yes, No) and *Strategy*, and a random effect of *Trial Success*.

Like the research findings of Abney et al. (2015) and Wallot et al. (2016), succeeding in the shepherding task was associated with less coupling of perceptual-motor states between participants than during failed attempts (AME = -2.84 %REC, $SE = 0.28$, $95\%CI = [-3.39, -2.29]$), $t(29.4) = -10.0$, $p < .0001$. Similarly, the strength of this coupling was also less during successful trials (AME = -4.63 $\sqrt{\text{MaxL}}$, $SE = 0.27$, $95\%CI = [-5.16, -4.10]$), $t(28.9) = -16.86$, $p < .0001$. Additionally, the strategy dyads used influenced the strength of the coupling between perceptual-motor behaviors, $F(2, 12.01) = 4.96$, $p = .03$. Specifically, dyads implementing the COC strategy exhibited weaker coupling as compared to when dyads implemented the S&R strategy (AME = -2.03 $\sqrt{\text{MaxL}}$, $SE = 0.63$, $95\%CI = [-3.27, -0.80]$), $t(251.8) = -3.16$, $p = .005$ (all other comparisons $p \geq .82$). The strategy dyads used did not have an effect on the number of perceptual-motor states that were shared (%REC), $F(2, 12.26) = 0.41$, $p = .68$. The %REC and $\sqrt{\text{MaxL}}$ models contained the following fixed effects: *Trial Success* and *Strategy*, and random effects for *Trial Success* and *Strategy* – Oscillatory-S&R. MaxL was transformed by computing the square root due to skewness in the data. The models also controlled for potential confounding effects that may influence the amount of observed behavioral recurrences. Specifically, the models included 1) the mean proportion of gaze data that was valid and (*%Gaze Validity*) 2) the total distance participants' hands traversed during the trial (averaged across participants, *Hand Travel*).

Were there particular interactions between participants that differentiated whether they would discover that performing oscillatory behaviors was an effective strategy to contain the fleeing agents? To investigate this question, additional models predicting state coupling (%REC) and coupling strength (MaxL) were constructed. The models included the following trials: for dyads where at least one participant discovered the oscillatory movement strategy, S&R trials were included which occurred *prior* to the first observation of oscillatory behavior. For dyads where oscillatory behavior was never observed (non-discoverers), all trials were included. The models contained the following fixed effects: *Trial Success* and *Discovered Oscillations* (Yes, No). Additionally, the model predicting %REC also contained *Trial Success* as a random effect. Additionally, to control for confounding effects that may impact the recurrence results, *%Gaze Validity* and *Hand Travel* were also included as fixed effects for the model predicting %REC (their inclusion in the MaxL model did not improve model fit, $\chi^2(2) = 4.79$, $p = .09$).

As before, successful trials were associated with fewer instances of shared perceptual-motor states between participants (AME = -2.95 %REC, $SE = 0.25$, $95\%CI$ = [-

3.48, -2.42]), $t(22.2) = -11.61$, $p < .0001$, as well as weaker coupling strength (AME = -4.63 $\sqrt{\text{MaxL}}$, *SE* = 0.25, *95% CI* = -5.12, -4.14], $t(20.2) = -18.23$, $p < .0001$. Additionally, dyads who go on to discover oscillatory behaviors exhibited more coupled perceptual-motor states when performing the S&R strategy compared to non-discovering dyads (AME = 1.01 %REC, *SE* = 0.37, *95%CI* = [0.26, 1.75]), $t(31.2) = 2.76$, $p = .01$. However, there was no difference in the strength of the coupling between participants (AME = 0.14 $\sqrt{\text{MaxL}}$, *SE* = 0.47, *95%CI* = [-0.78, 1.06]), $t(31.1) = 0.30$, $p = .78$. Additionally, there was no difference in task performance between Oscillatory-discovering and non-discovering dyads, $t(32.0) = -0.24$, $p = .81$.

Collectively, the interpretation of these results is that what may differentiate dyads who discover oscillatory behaviors from non-discoverers may be due to incidental moments resulting in the coupling of perceptual-motor behaviors, as opposed to differences in the amount of explicit interpersonal coupling (as would be indicated by MaxL). Although a baseline measure of social affiliation was not captured prior to participants completing the shepherding task, the post-experiment measure of participants' impressions of their partner did not show an effect whether participants discovered oscillatory movements (AME = 0.24, *SE* = .51, *95%CI* = [-0.77, 1.25]), $t(16.0) = 0.46$, $p = .65$. There was an effect of familiarity of one's partner prior to the experiment on their social impression following the experiment (AME = 1.69, *SE* = .77, *95%CI* = [0.17, 3.21]), $t(23.2) = 2.13$, $p = .044$. However, of the four participants (2 dyads) who have previously interacted with their partner, only one participant discovered oscillatory movements as an effective containment strategy. The model predicting social impressions included observations at the participant level, which were nested within the dyad. The model contained the following fixed effects: *Discovered Oscillations* (Yes, No) and *Familiarity* (Yes, No), and a random effect of *Discovered Oscillations* at the dyad level.

Discussion

The experiment sought to determine whether the discovery of oscillatory behaviors as a containment solution in the shepherding task can be predicted by specific interactions between participants and their partner. The results demonstrate that oscillatory-discovers can be differentiated from non-discovers by an increase in the amount of shared perceptual-motor states (as measured using %REC) when completing the task using the S&R strategy. However, the strength of perceptual-motor coupling (as measured using MaxL) did not differentiate discoverers from non-discovers, suggesting that Oscillatory-discovererers were incidentally coupled to their partner. Future analyses will determine how the observed interpersonal coupling relates to chance-level interactions using surrogate data. This involves randomly selecting participants to construct new, unobserved dyads.

In the human social interaction literature, there has been a historical bias in attributing increases in coordination, or synchronization of behavioral or physiological states, to beneficial outcomes (Mayo & Gordon, 2020). However, as highlighted by recent research, the utility of behavioral synchronization in goal-directed joint action is task-specific and may result in worse performance (Abney et al., 2015; Wallot et al., 2016). Here, the discovery of the COC strategy not only resulted in better task performance, but its use also reduced the synchronization of perceptual-motor states between participants, as indexed by MaxL. Although consistent oscillatory movement is more physically effortful, it may result in lesser attentional demands compared to chaining together discrete motions consistent with S&R behavior (Nalepka et al., 2019).

The incidental coupling of perceptual-motor states is hypothesized to be driven by the interactions between participants and the task environment. Previous work using agent-based models demonstrated that COC-like behavior can emerge from agents implementing S&R behavior (Nalepka et al., 2021) when using an agent selection heuristic that incorporates an agent's position as well as their velocity. Similarly, recent research using supervised machine learning and explainable-AI to elucidate the perceptual features novices and human experts use during the shepherding task found that experts incorporate direction of heading information when making pursuit decision, while novices relied heavily on positional information alone (Auletta et al., 2023).

Inspired by these findings, future analyses will evaluate whether Oscillatory-discovers incorporated, or learned to incorporate, a richer set of perceptual features when making their decisions as to which agent to pursue during the task. If so, then the resulting interactions between participants and the task environment may generate information that scaffold the emergence of oscillatory movements as an effective containment strategy. The feeling of insight some participants experience (Nalepka et al., 2017) may therefore be due to the realization that they can exploit these oscillatory movements explicitly as a task strategy (Nalepka et al., 2021). Although this assumes non-discoverers perceive a different set of features that prevent these emergent dynamics from forming, it is also plausible that similar dynamics also emerge for non-discoverers, but these participants fail to perceive and exploit this dynamic explicitly.

Finally, previous research has developed a dynamical model that accounts for the transitions between S&R and COC strategies (Nalepka et al., 2019). This model has been employed for human-machine interaction (Nalepka et al., 2019), skill training (Rigoli et al., 2022), and to constrain the development of agents trained using deep reinforcement learning (Patil et al., 2021). Future research can adapt these same models to provide accommodation for individual differences in decision-making in social settings, affording an opportunity for artificial agents to play the role as teachers, coaches, or facilitators to encourage the development of effective or desired patterns of social behavior.

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