# *If I Move, Do You Move?* Investigating the Role of Interpersonal Synchrony in Human-Robot Joint Painting

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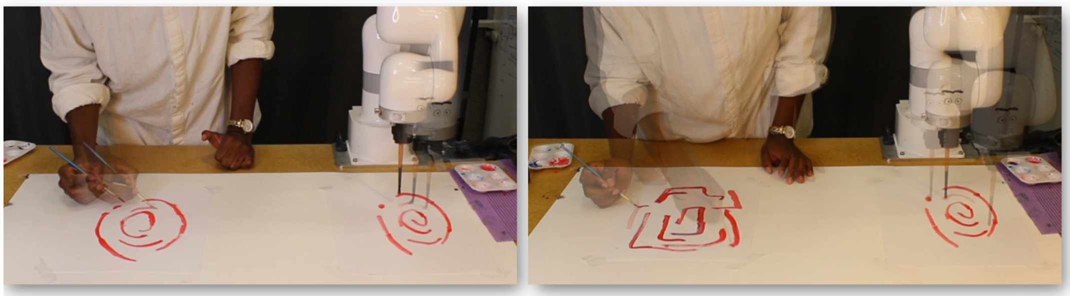

Fig. 1: Motion stills of two videos used in our user studies. The left image is from the synchronous condition (with both temporal alignment and spatial similarity); the right image is from an asynchronous condition that shows a lack of spatial similarity.

***Abstract*— Interpersonal synchrony (IS), the behavioral and physiological coordination across time and space, plays a crucial role in social interactions by fostering empathy, closeness, and prosocial behaviors. However, there is a need for more examination of human-robot interaction (HRI) research focused on interactions where the temporal alignment of body movements and the spatial coordination of the content produced by those movements is vital to the quality of the interaction, such as in joint visual art-making. In this work, we investigated the impact of IS on human raters' perceptions of a human-robot (HR) dyad engaged in a joint painting activity. We conducted two online studies (n = 70, total) in which participants watched 4 videos (1 repeated synchronous video and 3 asynchronous videos). We varied the degree of IS displayed by an HR dyad on two axes: (a) temporal alignment (e.g., speed of producing brush strokes) and (b) spatial similarity (i.e., similarity in the visual content produced). Our results indicate that some temporal and spatial dimensions of IS displayed by an HR dyad during joint painting have significant positive impacts on external observers' perceptions of the robot, including prosocial tendencies (i.e., empathy, synchrony, and closeness) and acceptance. These findings are significant for emergent research on collaborative robots.**

## I. Introduction

Every day, we coordinate our behaviors with those of other people. We may unconsciously match our speech patterns with our conversational partners to minimize misunderstandings [1] or mirror a friend's body posture during a difficult conversation, a cue that often signals empathy [2]. Interpersonal synchrony (IS) describes the time- or rhythm-based coordination of behavioral and physiological states between people or groups [3]–[6] over time and space [7], [8]. IS between humans has been found to promote prosocial behaviors, such as helping and sharing, and to encourage prosocial tendencies, such as empathy and social affiliation [9], [10]. Perceived synchrony also influences our beliefs about the prosociality of others. That is, when we see other people or groups that appear to be in sync, we make inferences about their social connection. For example, we may rate those who show synchronized movements as having higher levels of rapport [11], social affiliation [12], empathy [2], and entitativity (i.e., the perception of a group as a social unit) [11], [13].

Humans also attribute prosociality to non-humans that exhibit coordinated behaviors, such as robots [14]–[16]. Human-robot interaction (HRI) researchers have found that people experience a greater sense of closeness and affiliation with robots that mimic their movements [15]. Also, synchronized movement between humans and robots can improve the quality of their collaboration [17], especially during joint action tasks. Moreover, robots that can synchronize their movements can encourage the social development of children with autism [18], [19].

HRI researchers have focused on activities with observable temporal alignment of robot behavior, particularly body movements, with that of a human [14], [20], such as in pick-and-place tasks [21] and dance [17], [22]. They have

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also focused on spatial alignment of behavior in the context of robot mimicry of human behavior (e.g. [15]), a concept related to synchrony. Although previous work provides meaningful insight, there is still a dearth of work in HRI that operationalizes synchrony in interactions where *behavioral alignment over space* is more prominent than alignment over time, such as in visual art-making.

Abraham and colleagues [23], [24] showed that IS is important in joint painting by humans, a task in which they argue that *spatial* alignment of behaviors is more dominant than temporal alignment. They showed that some observers' beliefs about the social connection of a human dyad were influenced by their *perceptions of the dyad's synchrony*. Synchronization between the dyad led to an observer's enhanced *perceptions* of friendliness, *empathy*, *closeness* and similarity between the human dyad. In the context of psychotherapy, movement and psychological synchronization between a client and therapist can improve their alliance [5], [25]. The findings of Abraham et al. suggest that a dyad's synchronized behaviors during collaborative art-making are associated with enhanced perceptions of prosociality. They hypothesized that their findings indicated that synchronized behavior during visual art-making could enhance prosocial perceptions *experienced by* the dyad, which could improve their therapeutic alliance and lead to favorable therapeutic outcomes. Recent work in HRI has contributed robots that can collaboratively paint with humans [26], [27] as well as intelligent agents for therapeutic art-making activities to promote human mental well-being [28], [29].

Inspired by the findings of Abraham and colleagues, we examined whether an observer's perceptions of synchrony between a human-robot (HR) dyad doing a joint painting activity were indicative of their social connection. We aimed to provide an empirical basis for emergent HRI research that focuses on robots for collaborative and therapeutic visual art-making. We examined the impact of perceptions of interpersonal synchrony on similar prosocial measures as Abraham and colleagues, including perceived *empathy* and *closeness*. We investigated whether the *perceived synchrony* of an HR dyad is associated with *user acceptance* [30] of these robots for joint visual art-making. We conducted two online studies (n = 70, total) in which participants watched four videos. In the videos, we varied the degree of IS within an HR dyad based on (a) temporal alignment (e.g., the speed of brush strokes created by the human and robot) or (b) spatial similarity (e.g., the similarity of the visual content produced). Our findings suggest that both *temporal* and *spatial dimensions* of IS displayed by an HR dyad doing joint painting impact an observer's *perceptions* of the dyad's prosociality. Furthermore, we provide evidence that a robot synchronizing its behavior when collaboratively creating visual art with a human results in favorable perceptions from a human observer and enhances the likelihood that a human would accept a robot for the purpose of therapeutic art-making.

## II. Related Work

This section summarizes relevant research contributions across multiple domains, including developmental, social, and behavioral psychology and HRI. We aim to provide a foundational understanding of the role of IS in HR art-making.

### A. Synchrony in Human Interactions

Synchrony is an important phenomenon in human interactions [31]. IS is a special case of *interpersonal coordination* [4], which refers to the 'degree to which the behaviors in an interaction are non-random, patterned, or synchronized' [4]. Interpersonal coordination can be further distilled into two categories: behavior matching and IS. Behavior matching describes behavioral mirroring or mimicry. IS (also referred to as 'movement synchrony' [3] or 'interactional synchrony' [32]') can be further divided into three categories: 1) interactions with similar rhythms, 2) simultaneous body movements, and 3) smooth meshing of behaviors [3]. Perceived synchrony is important and is often indicative of the interpersonal synchrony experienced by the pair [3], [11]. Bernieri and colleauges [3] showed that untrained observers rated synchronized dyads as having greater rapport, a finding that was consistent with the rapport ratings experienced within the dyad. Similarly, Lakens and colleagues [13] showed that observers view synchronized movement as indicative of increased entitativity.

Dyadic synchrony [33], the concept of IS between children and their caregivers, is vital to child development [34], [35]. Dyadic painting, or joint painting, draws on the concept of dyadic synchrony between infants and their caregivers and theories of attachment [33]. It is an important collaborative art-making activity used in arts psychotherapy [5], [36] that is used to inform how collaborative art-making can simultaneously inform practitioners about and shape interpersonal dynamics within a dyad. During joint painting activities, child-caregiver dyads create art together while observed by a visual art therapist [37], [38]. Recent work by Abraham and colleagues built on the role of dyadic painting by examining the impact of coordination during joint painting. Their work demonstrated that some groups, such as children [24] and visual art therapists [23], viewed the synchrony displayed by human dyads during joint art-making as indicative of improved social connection on several measures, including perceptions of friendliness, empathy, similarity, closeness, and supportiveness [23], [24].

### B. Dimensions of Synchrony

The notion of IS having different dimensions is not novel. However, the focus on IS manifesting during interactions where non-temporal or non-rhythmic elements (e.g., moving arms at the same time or marching at the same rate) are dominant is less explored in HRI [14]. Da Silva and colleagues [7] outlined a taxonomy for categorizing IS along six dimensions, including periodicity, spatial similarity, directionality (e.g. in-phase or anti-phase), leader-follower lag, and observability. Rasenberg and colleagues [8] categorized

IS along similar dimensions [8], including time, sequence, meaning, form, and modality. In our work, we summarized some of these dimensions into two broad categories. The first category involves the temporal and rhythmic qualities of IS; this includes *periodicity*, *directionality*, *leader-follower lag*, *time*, and *sequence*. The second category involves spatial qualities of IS; this includes *spatial similarity*. Depending on the *modality* (e.g. gestures), both the *modality* and *form* may occupy the spatial domain. Abraham et al. investigated the impact of synchrony on an external observer watching a joint painting activity [23]. During their coordinated condition, the human dyad started and ended painting at similar times. Although the dyad's behaviors were not always temporally similar, their behaviors were often spatially similar (i.e., the dyad's arm movements were similar when producing figures that were similar and there was similarity in color choices). In these examples, we observe that some of the temporal and spatial dimensions of IS are interrelated [8]. Nevertheless, by manipulating one dimension – that is, increasing or decreasing it relative to the other – we can operationalize them separately [8]. In our study, we isolated the temporal and spatial dimensions of IS to examine their *individual* roles on the prosocial and user acceptance measures of an external observer watching a HR dyad participate joint painting. To this end, we drew on previous taxonomies [7], [8] and findings [23], [24], to define each of the dimensions of IS broadly along two categories: Temporal Alignment and Spatial Similarity (Subsection III-B).

### C. Synchrony in Human-Robot Interaction

Synchrony, and interpersonal coordination more broadly, have been explored in HRI [14]. Because previous studies in psychology have focused on interactions in which the temporal dimensions of IS were integral to the quality of the interaction, HRI research related to or centered on IS has also focused on interactions with discernible temporal qualities. According to Stoeva and colleagues [14], HRI research related to IS can be broadly classified as movement-based and conversation-based synchrony, and studies primarily focused on the impact of synchrony on human social perceptions (e.g. [15], [16]).

Movement-based scenarios in HRI research have focused on synchrony and behavioral matching, which includes mimicry (i.e., imitation of another person's nonverbal behaviors, such as facial expressions) and mirroring (i.e., imitation of body movements). Some previous work includes collaborative tasks, such as joint action (e.g. pick-and-place [21]); creative tasks, such as robots used to encourage children to participate in movement by synchronizing with background music [22]; and coordinated dance between humans and robots [17]. It has also centered on therapeutic tasks in which robots have been developed to display synchrony to sustain engagement, especially when supporting the social development of children with autism [18], [19]. Conversation-based scenarios focused on the impact of synchrony and mirroring exhibited in nonverbal and verbal behaviors of robot conversation partners [39], [40].

HRI research has explored the ramifications of the temporal and spatial dimensions of coordination and synchrony. In HRI research, studies that focused on spatial coordination – often mimicry, which is the spatial and temporal alignment of body movements – did not center the content produced beyond the body movements themselves (e.g. [15]–[17]). Studies that did focus on the coordination of the content produced, for example in music (e.g. [18]) centered on the temporal structure, or rhythm, of the music.

To our knowledge, there is no HRI research that has focused on interactions where coordination occurs in both the temporal alignment of body movements and the spatial coordination of the content produced, such as in joint visual art-making. We drew on findings by Abraham and colleagues [23], [24] to examine the prosocial consequences of synchrony in HR joint painting. We hope that this work can provide an empirical basis for research that aims to use robots for collaborative and therapeutic tasks (e.g., visual art-making [26]–[29]).

## III. Method

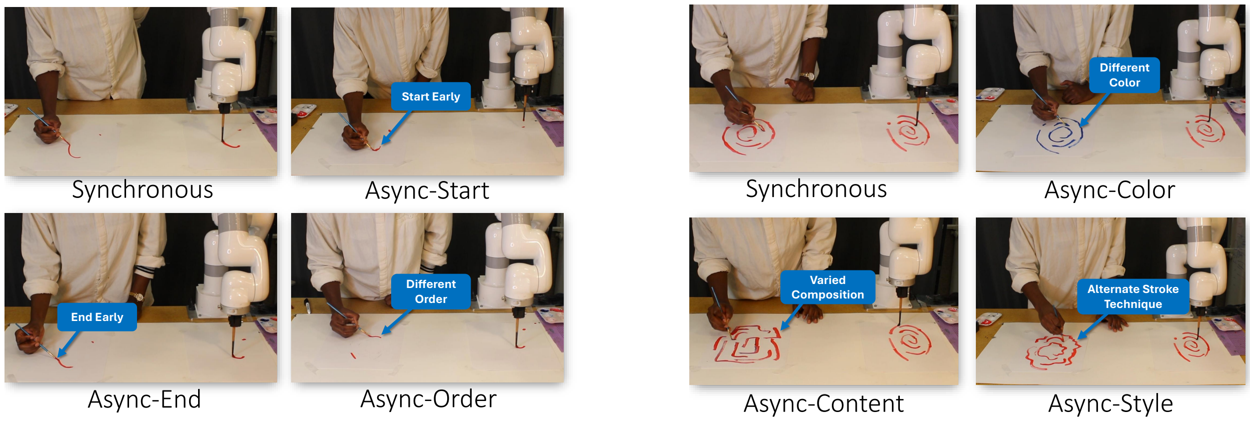
The objective of our research was to investigate the impacts of the **temporal** and **spatial** dimensions of IS displayed by an HR dyad engaged in a joint painting activity. We examine this impact on measures related to *prosocial tendencies* and *user acceptance of the robot*. To do this, we conducted two online studies. In these studies, the participants viewed 4 videos (Section III-B) of an HR dyad in which we varied the degree of IS on two dimensions: *temporal alignment* (Study 1) and *spatial similarity* (Study 2). Both studies were conducted using common measures, procedures, and analyses, detailed below. They were both approved by our institutional review board.

### A. Study Procedure

Participants first completed a consent form and answered demographic questions. We then administered the brief version of the Interpersonal Reactivity Index (IRI) [41], which measures dispositional empathy on four subscales: perspective-taking (PT), empathic concern (EC), personal distress (PD), and fantasy (FS) (for further details on subscales, see [42], [43]). This measure is used exclusively for correlational analyses [42], [43]. To gain insight into our participants' preferences for technology, participants completed the Affinity for Technology Interaction (ATI) questionnaire [44], a 9-item questionnaire scored from 1 to 6 (highest affinity). The participants watched the 4 videos in randomized order. After each video, the participants answered an attention check question ('What happened in the video?') and the randomly ordered study measures (Subsection III-C). Each study took an average of 25 minutes and the participants were paid $5.

### B. Study Conditions

Here, we describe the *experimental stimuli* (i.e., videos) used in each Study 1 and Study 2. Each study consisted of four conditions: a synchronous condition (used in both studies) and three asynchronous conditions.




(a) (b)

Fig. 2: Stills from: (a) **Study 1** (*Temporal Dimensions*). In Async-Start, the human started each stroke before the robot but ends at the same time; in Async-End, the human started each stroke at the same time, but ended each stroke before the robot; and in Async-Order, in which the human created the same painting as the robot, but in a different stroke order. (b) **Study 2** (*Spatial Dimensions*). In Async-Color, the human painted an image using a different color than the robot; in Async-Content, the human created content with a dissimilar visual appearance from the content produced by the robot; and in Async-Style, the human performed a different stroke technique from that of the robot.

*1) Temporal Alignment:* In Study 1, we investigated the role of temporal dimensions of IS. In the synchronous condition, there was minimal temporal lag between the human and the robot, similar stroke order, and similar visual content produced (Subsection II-B). We used an *ablation technique* to form the 3 temporally asynchronous conditions: Async-Start, Async-End, and Async-Order (Fig. 2b). An ablation refers to the removal of one component of an AI system [45]. In our case, this was the removal of a single temporal dimension from the synchronous condition. The descriptions of these conditions can be seen in Fig. 2a.

*2) Spatial Similarity:* In Study 2, we investigated the role of spatial dimensions of IS. We used the aforementioned ablation technique to form the 3 spatially asynchronous conditions: Async-Color, Async-Content, and Async-Style (Fig. 2b). Similarly to [23], we varied the color, content similarity, and stroke technique of the synchronous condition to form the spatially asynchronous conditions. In all conditions, the same number of brush strokes and stroke order was used between the human and the robot; thus, the temporal dimensions were kept constant. The descriptions of these conditions can be seen in Fig. 2b.

## C. Measures

The dependent variables are related to prosocial tendencies, robot acceptance, and perceived synchrony. Aside from the Inclusion of Other in the Self (IOS) scale, we modified some wording in existing scales to focus on the perceptions of an observer. We excluded items from the questionnaire that were not relevant to our research questions [46] (Appendices , B).

(1) Perceived Empathy: We used the Perceived Empathy of Technology Scale (PETS scale) [47], used to measure how empathic users perceive an interactive system to be. We used a subset of the original questionnaire.

(2) Human-Robot Collaboration and Acceptance: We used a subset of questions from the Human-Robot Collaboration and Acceptance Model (HRCAM) [48]. Each of these items was altered to evaluate whether the human would accept the robot in the video for use in a joint painting activity. We used items related to perceived ease-of-use, behavioral intention (i.e., the willingness to use the robot for the given task), perceived enjoyment of using the robot, and perceived physical safety of working alongside the robot. All of these factors impact the acceptance of robotic systems [49].

(3) Perceived Synchrony: We used a four-item questionnaire introduced by Abraham and colleagues [23] that measures perceived interpersonal synchrony between a dyad participating in a joint painting activity.

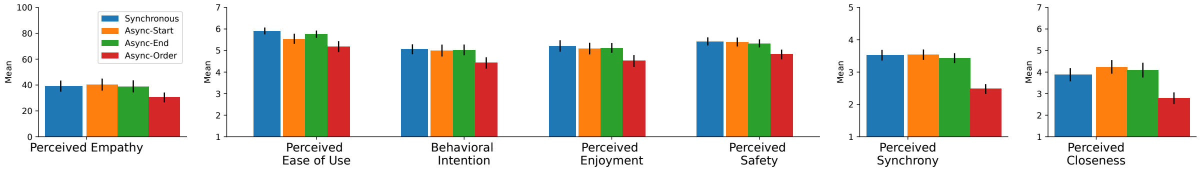
(4) Perceived Closeness: The Inclusion of Other in the Self (IOS) Scale [50], [51] is a single item used to measure the perceived closeness/connectedness that respondents feel with another person/group. We used a version tailored to HRI [52].

## D. Participants

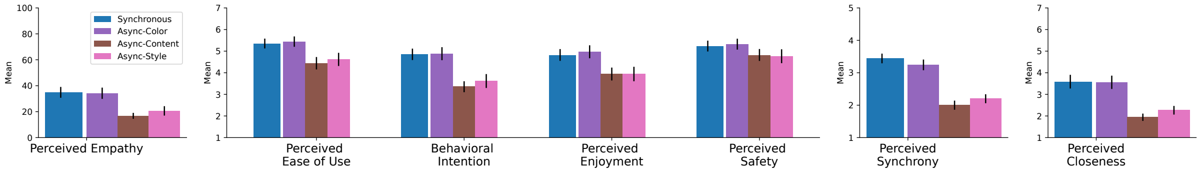
For Study 1, we recruited 36 participants. However, after data screening and exclusion (Subsection III-E), we retained data from only 33 participants (19 women, 14 men). The participants were between the ages of 19 and 66 ($\bar{x} = 31.97$, $sd = 10.19$) and had a moderate affinity for technology ($\bar{x} = 3.80$ and $sd = 0.71$). For study 2, we recruited 34 participants (22 women, 11 men, 1 genderqueer). The participants were between the ages of 22 and 68 years ($\bar{x} = 36.88$ and $sd = 12.42$) and had a moderate affinity for technology ($\bar{x} = 4.03$ and $sd = 0.90$). All participants were recruited from the Prolific crowdsourcing platform.

## E. Analysis, Data Screening and Exclusion

The amount of time taken to view the four videos and answer the study questions (captured by the Qualtrics survey




(a)




(b)

Fig. 3: Mean values with standard error bars for the conditions in (a) **Study 1** (*Temporal Dimensions*) and (b) **Study 2** (*Spatial Dimensions*). The **asynchronous** conditions with diagonal shading have *significant mean differences* ($p < 0.01$) from the **synchronous condition**.

platform) was used, in conjunction with the attention check questions, as grounds for exclusion. In Study 1, we excluded three participants who took more than one hour to complete the study. Of the remaining 33 participants, two individuals' PETS scores were dropped from our analysis because they missed a question. Thus, 31 participants were included for all dependent variables. The 34 participants in Study 2 completed all the survey questions in a reasonable time and therefore were retained for analysis. No participants in either study were excluded due solely to their attention check responses, which were all considered satisfactory by the research team.

Significance was tested with Restrictive Maximum Likelihood (REML) with our participants as random effects. The fixed effects were the study conditions and known participant traits, which were treated as observed covariates, including gender, age, ATI and IRI scores. We then performed Tukey's Honest Significant Difference (HSD) post hoc tests at $\alpha = 0.050$. Furthermore, we analyzed the correlations between the personality variables of the participants and the dependent variables. Finally, we confirmed that Cronbach's $\alpha$ values were above $0.7$ (all were above $0.8$) for the validated questionnaires for which we changed the language.

## IV. Results

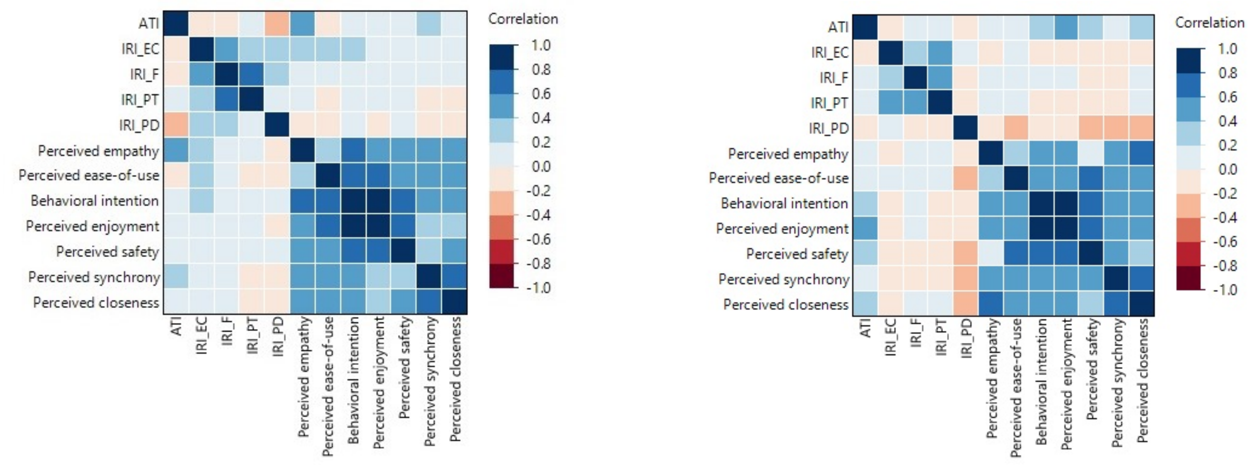
As this was an ablation study, rather than a full factorial, we only report significant differences between our synchronous and asynchronous conditions. Some inferences about the relative importance of each dimension of synchrony are feasible, but a goal of this study was to first identify which of the six dimensions of IS merit closer attention in the future. For all seven dependent variables (Subsection III-C), our fixed effect model indicated that the means of the asynchronous conditions were significantly different from the synchronous condition ($p < 0.01$), (Figs. 3a and 3b). Next, we computed a Tukey HSD post hoc test at $\alpha = 0.05$, which we report below.

*1) Study 1:* We found a *significant difference* between the *means* of the **synchronous condition** and the **asynchronous condition, Async-Order** for all 7 study measures (Fig. 3a). We found that there were no significant differences between the means of the synchronous condition and the asynchronous conditions Async-Start and Async-End for all 7 of the study measures.

*2) Study 2:* We found a *significant difference* between the *means* of the **synchronous condition** and the **asynchronous conditions Async-Content** and **Async-Style** for all study measures, except Perceived (physical) Safety (Fig. 3b). We found that there were no significant differences between the means of the synchronous condition and the asynchronous condition Async-Color for any of the 7 study measures. Figure 3b shows these mean values with standard error bars reported on the scales used.

We computed Spearman correlations between the personality variables of the participants (Interpersonal Reactivity Index and Affinity for Technology Interaction) for both studies. The correlations can be seen in Figs. 4a and 4b. We report significant correlations between personality variables and all 7 dependent variables at $p < 0.05$. There were several **significant** correlations between both IRI and ATI measures and the dependent variables, some of which we summarize below. In both studies, there were positive correlations between technology affinity (ATI) and perceived empathy; positive correlations between technology affinity and behavioral intention, perceived enjoyment, and perceived safety; and negative correlations between personal distress (IRI-PD) and perceived ease-of-use, perceived enjoyment, and perceived closeness. However, while there was a positive correlation between empathic concern (IRI-EC) and perceived empathy in Study 1, there was a negative correlation between those variables in Study 2.

We also computed Spearman correlations between perceived synchrony and the remaining 6 dependent variables. We found that perceived synchrony was positively correlated with all 6 dependent variables at $p < 0.0001$ for both studies.



(a) (b)

Fig. 4: Pairwise Correlations between Personality Variables, Interpersonal Reactivity Index (IRI) and Affinity for Technology Interaction (ATI) and dependent variables for (a) Study 1 - Temporal Dimensions. (b) Study 2 - Spatial Dimensions.

## V. Discussion

Our findings show that **perceived synchrony** in the behaviors of a human-robot dyad during a joint art-making activity has a **positive** impact on perceptions of the dyad's social connection and user acceptance of the robot. We summarize the implications of these contributions to HRI research.

### A. Impact on Prosocial Measures

In previous HRI work by Choi and colleagues [15], they found that during a dance activity, spatial coordination (in this case, mimicry) of a robot's body movements with that of its human partner increases the partner's feelings of closeness to the robot. We found that spatial coordination beyond body movement has an impact on the perceived closeness of an HR dyad. The synchronization of the spatial qualities of the visual content has consequences on an observer's perceptions; that is, the lack of some spatial dimensions of synchrony are associated with a decreased perceived closeness. Although our study did not explore these impacts on the connection experienced within the dyad, previous findings suggest that the perceptions of an untrained observer are correlated with the experiences within the dyad [3], [11]. Combined, this suggests the importance of spatial coordination of visual content in collaborative HR tasks where relational closeness is vital, such as therapeutic art-making [24], [33].

Furthermore, we explored the impact of synchrony on human rater's perceptions of the empathy of the robot within the HR dyad. We discovered that the temporal condition Async-Order and the spatial conditions Async-Content and Async-Style were associated with lower perceived empathy ratings. These findings are similar to those concerning synchrony in human-human joint painting [23], [24]. The impact of spatial conditions are similar to previous findings on object recognition [53], which showed that human vision uses shape-based features more than color/texture features.

However, our results have a key difference from prior findings. In Abraham et al. [23], they found that non-visual art therapist adults did not give higher empathy to a human-human dyad that coordinated their movements and content during a similar joint painting activity. In our study, participants – none of whom were visual art therapists – did rate the robot as more empathic. This difference may be due to the phrasing of the questions. In the study by Abraham and colleagues [23], participants were asked if each person in the dyad seemed more empathic. In our study, participants were only asked whether the robot seemed more empathic [47]. While these findings are still significant, more work is needed to ascertain whether non-expert adult observers would also view the human as more empathic.

Furthermore, although our synchronous condition was associated with higher perceived empathy ratings than asynchronous conditions in both our studies, we note that all perceived empathy scores are not remarkably high. Previous research in HRI suggests the importance of both verbal and nonverbal factors, such as facial expressions, to induce discernible empathic behaviors in robots [54]. Because our videos did not have any audio or any visible facial features/expressions, this may have affected human raters' perceptions of empathy displayed by the robot in the HR dyad.

### B. Impacts on Robot Acceptance Measures

We uncovered that both the temporal and spatial dimensions of synchrony positively impact observers' acceptance of robots. Our participants viewed the robot in the synchronous condition as easier to use, more enjoyable, and safer for physical interaction, and they were more willing to use this robot for joint painting in the future. These insights can be gleaned from the mean robot acceptance ratings, which were greater than half of the total value for both studies (see the synchronous condition in Figs. 3a and 3b). While a temporally asynchronous condition (Async-Order) does have an impact on perceived safety, some spatially asynchronous conditions (Async-Content and Async-Style) do not, despite impacting all other measures. Previous HRI findings related to perceived physical safety emphasize the predictability of a robot's motion [55]. Our results confirm this by suggesting that the temporal dimension of synchrony, specifically asynchronous stroke order execution, negatively impacts the perceived safety of the robot; the moderate positive correlation between perceived synchrony and perceived safety ratings supports this finding.

### C. Limitations and Future Work

There are three main limitations to this study. First, doing an ablation does not enable us to draw conclusions about the interactions between specific temporal and spatial dimensions. As mentioned, a goal of this study was to first identify which of the six dimensions of IS deserves closer attention. Future research should examine such interactions between the dimensions of synchrony this study has identified as priorities. Second, we conducted two studies investigating the impact of spatial and temporal dimensions of IS on an observer's perceptions of an HR dyad during a joint painting activity. During these studies, we treated the various dimensions (described in Section III-B) as discrete variables. In [8], it was noted that these dimensions are interrelated. Nevertheless, this may be acceptable as natural visual art-making does not enable such fine-tuned control of each temporal and spatial dimension. This was seen in studies by Abraham et al. [23], [24] in which natural art-making did not control for the spatial and temporal qualities individually, but recognized that they were interrelated within visual art-making. However, we observed a significant negative impact of excluding some temporal and spatial dimensions of IS in our dependent variables. Finally, although previous work suggests that the prosocial consequences of an external observer were correlated with those experienced within the dyad [3], [11], we recognize that the perceptions of the participants may be different in person. As such, we plan to move towards in-person experiences in the future. The breadth of this study allows future work to focus more on specific dimensions of synchrony. Aside from reducing the number of permutations to test, this also relieves some of the implementation and human artist training required to consistently display the same synchrony stimuli.

## VI. Conclusion

In conclusion, we investigated the role of IS in human-robot collaborative art making by conducting two online studies. Observers rated perceptions of empathy, closeness, robot acceptance, and synchrony of HR dyads painting from videos with varying degrees of temporal and spatial aspects of synchrony. We found that some dimensions (both temporal and spatial) of synchrony had significant consequences on perceived robot prosociality and robot acceptance measures.

## Appendix

### A. Perceived Empathy of Technology Scale

The subscales were Emotional Responsiveness (ER) and Understanding and Trust (UT) [47]. We altered each item's language to refer to perceived interaction (e.g., original ER4 read 'The system sympathized with me'). We omitted items ER-6 from the PETS-ER subscale and UT-2 and UT-3 from the PETS-UT subscale because they were deemed more appropriate for an in-person experience. We averaged each subscale and used the weights presented in the paper to compute the final score. Total scores were between 0 and 100.

(ER-1) The robot seemed to consider the human's mental state.
(ER-2) The robot seemed emotionally intelligent.
(ER-3) The robot seemed to express emotions.
(ER-4) The robot seemed to sympathize with the human.
(ER-5) The robot seemed to show interest in the human.
(UT-1) The robot seemed to understand the human's goals.
(UT-4) The robot seemed to understand the human's intentions.

### B. Human-Robot Collaboration Acceptance Model

This questionnaire was adapted from Brohl et al. [48]. The items were on a scale of 1 (strongly disagree) to 7 (strongly agree) (corresponding to the total scores per item). Items 1-4 correspond to perceived ease-of-use, behavioral intention, perceived enjoyment, and perceived physical safety, respectively.

1) The interaction with the robot seemed easy.
2) If I could choose whether the robot supports me, I would appreciate working with the robot.
3) I would find using the robot to be enjoyable.
4) I would feel safe while using the robot.

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