



HAL
open science

Collaborative Creativity in Shared Diminished Reality

Loup Vuarnesson, Julien Laroche, Asaf Bachrach

► **To cite this version:**

Loup Vuarnesson, Julien Laroche, Asaf Bachrach. Collaborative Creativity in Shared Diminished Reality. 2025. hal-04954607

HAL Id: hal-04954607

<https://hal.science/hal-04954607v1>

Preprint submitted on 18 Feb 2025

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Collaborative Creativity in Shared Diminished Reality

Loup Vuarnesson

EnsadLab, Spatial Media, Ensad, PSL University, 31 rue d'Ulm Paris, France

Laboratory of Cognitive Neuroscience, Neuro-X Institute and Brain-Mind Institute, Ecole Polytechnique Fédérale de Lausanne (EPFL), Chemin des Mines 9, 1202, Geneva, Switzerland

Julien Laroche

EuroMov Digital Health in Motion, Univ. Montpellier, Montpellier, France

Fondazione Istituto Italiano di Tecnologia (IIT), Center for Translational Neurophysiology of Speech and Communication (CTNSC), Via Fossato di Mortara, 17/19 - 44121 - Ferrara, Italy

Asaf Bachrach

UMR 7023 CNRS and EUR ArTec Paris 8 university, Centre CNRS Pouchet 59 rue Pouchet 75017, Paris, France

Corresponding author: Julien laroche: lajulienroche@gmail.com

ABSTRACT

Purpose: This study explores collaborative creativity in Immersive Digitally Mediated Interactions (IDMI) using a novel virtual reality (VR) setup. The central question is how IDMI tools can promote collaborative creativity and to what extent they offer new avenues for creative agency. We introduce the YUMI model which proposes that shared control over a single avatar enhances creative interaction by blurring the self and other agency, and the prototype of an VR installation that holds the potential to investigate this hypothesis.

Methods: To provide a proof-of-concept of our model, we developed a Shared Diminished Reality (SDR) installation called "The Median," where two participants control a single avatar composed of three spheres. The avatar's movement is determined by the combined movements of the participants' heads and hands. Participants engage in unscripted movement improvisations while wearing VR headsets, with varying degrees of control over the avatar across trials. After the experiment, participants completed a questionnaire assessing different aspects of their experience and in particular their ability to distinguish their own contributions to the avatar's movement. Movement data was also collected and analyzed.

Results: Results showed a correlation between self-other agency confusion and an extended sense of self. Movement analysis indicated that participants with higher agency confusion exhibited less predictable head movements than their partner, and followed that partner's hand movement more.

Conclusion: This study supports the YUMI model, showing that blended agency enhances certain aspects of creative behavior. The Median setup is well suited to induce such states of confused agency, opening new avenues in VR research and design.

Keywords:

Shared Virtual Reality, Co-Creativity, Interpersonal Dynamics, Shared Agency

1. INTRODUCTION

1.1 The YUMI model: Co-creativity in IDMI

Digitally mediated interactions (DMI), mainly via smartphones and other haptic devices, are by now integral to our daily life, professionally, personally and in a variety of artistic activities. Immersive DMI (IDMI) such as the one offered by shared Virtual Reality (VR) platforms (e.g. Meta's metaverse) extends even further the role of technology in human interaction and brings with it both promises and challenges. However, IDMI has not yet become as omnipresent as it has been projected to. What is the potential of such technology for allowing and enhancing human interactions and collaborative work? And to what extent these tools-spaces offer novel avenues for creative agency, the ability to guide our behavior in novel ways and/or toward novel outcomes? More specifically, in what ways can they promote collaborative creativity?

To guide our research on creative interaction in IDMI, we offer a theoretical perspective that we name YUMI ('you'-'me'), and which draws from our own research in creative pedagogy (Laroche & Kaddouch, 2014, 2015), collective improvisation (Himberg et al 2018), DMI design (Vuarnesson et al., 2021), as well as our own experience in different improvisational practices. The central insight behind the YUMI model is that (co-)creativity is enhanced during interaction where the boundary between our own contribution and the contribution of others to a shared outcome is partially blurred (but does not dissolve). The blurring of causality is a feature of a system (like a group of agents) whose behavior is dominantly driven by the interaction between its components (such as the agents of that group). The more interactions dominate the group/system (that is, the more agents/components influence each other), the less agents' behavior are determined by their intrinsic properties (Stephen & Dixon, 2009). As such, a high degree of interdependence within the system facilitates its reorganization into novel states (Stephen et al., 2009). In other words, high interdependence fosters the exhibition of creative behaviors. From the point of view of the agent, the dynamics that link her behavior to those of others are experienced as heightened uncertainty regarding one's agency. This experience of uncertainty invites us to restructure our cognitive behaviors (Gabora, 2017) by helping us break away from our most spontaneous and habitual tendencies, thereby motivating the exploration of new behavioral possibilities (Laroche et al., 2024).

A variety of creative interactions seem to be conducive to such states of agential uncertainty, for example being in the 'zone' during a jazz improvisation (Sawyer, 2003), or when an unexpected sequence of actions is produced during a Contact Improvisation dance duet (Torrents et al., 2010; Kimmel et al., 2018). However, generating such states or manipulating them experimentally is not straightforward (Himberg et al 2018). VR tools can offer solutions to this problem. Since we can constrain the variables that constitute them to our liking, they can provide valid ecological environments that are yet simplified enough to allow for systematic empirical investigations. Moreover, the experimental control over the variables that constitute behaviors in the VR environment allows for the generation of relatively simple and reproducible occurrences of agency confusion. As such, VR appears as a well-suited tool to conduct research on YUMI. In turn, YUMI is particularly relevant to research and development in VR, and more specifically Shared VR. Agency confusion is often experienced in such contexts, due sometimes to the use of shared avatars, or to the shifts in perspectives and the visual-haptic mismatches of Shared VR.

To explore YUMI in VR, we designed and tested a specific instantiation of shared VR. This instantiation allows participants to experience, and researchers to experiment on, YUMI dynamics. As such, it holds the potential to study and eventually enhance collaborative creativity. This novel protocol finds roots in the literature on first person *co-embodiment* (see 1.2) but diverges from it by instantiating *second person co-embodiment* (see 1.3) which we deem more opportune to support *group movement improvisation* (see 1.4) that we consider as a privileged approach to the study of co-creativity. In the next sections and subsections, we briefly present these bits of literature, before we present the concept, design and implementation of our tool (2.1 - 2.3). Next, we present a protocol that uses this tool to provide a proof of concept along with performed analyses (2.4 - 2.7).

Then, we present the results of a user experience questionnaire (3.1) and offer analyses of the movement data this tool and protocol can generate (3.2). Finally, we discuss our observations in the context of shared VR and the YUMI model, as well as the potential future outcomes and applications of our methods and design (4-5).

1.2 First person co-embodiment

Most research on interaction between persons in virtual reality has focused on situations where two or more participants are embodied (within VR) as separate avatars (de La Rosa & Breidt 2018). On the other hand, over the past 5 years or so, a subfield of IDMI has started to explore more systematically virtual co-embodiment: VR setups where participants share (control over) the same avatar (Hagiwara et al., 2019; Fribourg et al., 2020, Manuri et al., 2024; Podkosova & Brument, 2024). Virtual co-embodiment pushes the limits of earlier IDMI research and design as it makes use of VR not in order to replicate analog interactions (e.g. how to make a virtual video chat more real-life like), but instead to create forms of interaction that are not possible, or at least are much less obvious, in ‘real’ life (such as sharing a control on one’s hand with another person). Research in or with co-embodied IDMI invents and implements the forms of interaction it intends to study and at the same time questions our commonsense notions of body ownership and individual agency (i.e., the control and authorship of the actions that body carries out). Virtual co-embodiment dialogues with earlier research and design installations in VR which manipulated point of view (e.g. seeing the interaction from the point of view of another (Petkova & Ehrsson, 2008; Slater et al., 2010) or offered new forms of interaction, where systems were partially fed with, and were reacting to, the user’s movement (*La Funambule Virtuelle*, Bret et al., 2015). Beyond VR research-design, virtual co-embodiment touches on a number of questions that have arisen in behavioral sciences, in particular in the “joint action” literature, regarding self vs. other agency and collective agency (Loehr, 2022).

1.3 Second person co-embodiment and co-creativity

Existing research into virtual co-embodiment offers new insights into agency and body ownership, and exciting perspectives into ways in which IDMI can be used, such as in teaching new sensorimotor patterns to a novice (Pinkl & Cohen, 2023). Paradoxically, despite the fact that virtual co-embodiment builds upon novel technologies that allow unprecedented behaviors and experiences, the question of creative agency, and more specifically its potential for fostering collaborative creativity, has not been addressed. We note two features of this approach that hinder potential research into these issues. The first is the use of ‘first person’ avatars that frames the participant’s experience and the researcher’s focus on the individual level of action, and the associated issue of body ownership. The second issue, which derives from the attempt to create or manipulate a sense of body ownership, is the use of highly scripted and goal-oriented tasks, which leaves very little room for creative behavior and its study.

In this paper, we report on a research-design project that expands on the virtual co-embodiment literature to address the question of collaborative creativity during unscripted interactions. The novel approach we propose shifts from the use of ‘first person’ realistic avatars to ‘second person’ avatars that embody the *product* of the interaction as a fictional partner (i.e., the perceptible avatar combines information from the different partners). Unlike the existing literature, the avatar is not designed to resemble, or to extend, the participant’s body; rather, it materializes the relationality that emerges between human partner’s behaviors in a new form (see Vuarnesson et al., 2021; Laroche et al., 2021). The shift to second person avatars allows for the implementation of open-ended, improvisational tasks that are better suited for the exploration and the observation of creative agency in collaborative contexts.

1.4 Collective movement improvisation as an epistemological lens into creativity

Improvisational tasks are ideal to study group creativity. In particular, the design and protocol presented here are inspired by group movement improvisation (GMI). GMI is a prime case of co-creativity (Himberg et al 2018...). It provides the perfect context to fulfill our objectives: (i) it focuses participants on the agency they share over their movement interaction (ii) it makes the product and process of creativity coincide in time, enabling the study of the creative outcome and movement interaction over the same timeline and (iii) as movements externalize this creative process, it can be captured and quantified. Combining GMI and second person co-embodiment has a number of relevant advantages for the exploration of co-creativity in IDMI: (i) Using a movement task to study (and enhance) co-creativity makes direct use of a principal feature of IDMI technology: capturing and visually rendering body movement. (ii) The absence of a clear task and hence any form of optimization strategies favors more open-ended exploration of the relational movement space the setup offers. (iii) IDMI allows us to invisibilize the ‘bodies’ of both dancers. Because participants don’t have any other confirmation of their (or their partner’s) presence in the shared VR apart from the effects of their movement on the second-person avatar, understanding and controlling its movement is a condition for them to "exist", thus it motivates them to engage in the interaction with the avatar. (iv) Since this approach eschews the first-person avatar perspective, it avoids the potential ‘competition’ over control and instead favors the feeling of co-action or collaboration. (v) The open-endedness of the task (no pre-prescribed goal) focuses the attention of the participants on the quality and unfolding of the interaction itself rather than on the task to complete. This provides for more informative first-person reports.

2. METHODS

2.1 SDR principles

The VR approach we have previously named Shared Diminished Reality (SDR, Laroche et al. 2021; Vuarnesson et al. 2021) provides a remedy for the complexity inherent in naturalistic group movement improvisation and in interaction more generally. Instead of trying to mimic the ‘real’ world (Virtual Reality) or to add digital content to the actual visual scene (Augmented Reality) we argued that the reduced nature of the digital rendition (Diminished Reality) can have an advantage for first and third person research as it allows us to discard dimensions of the actual situation that could interfere with the research question (for example, gender or body features of the co-actor, or irrelevant features of the physical environment). In our Shared Diminished reality set up, the movement information of both partners is reduced to a minimal form, which further focuses the partners on their interaction and eases the tracking and the analysis of their creative behaviors. As such, this allows ecological validity to coexist with strong experimental control. In our past work (Laroche et al. 2021; Vuarnesson et al. 2021), we presented a specific SDR installation, ArTiculations, that allows for two persons to dance freely with each other in a rarefied environment (a very large open space with clear blue sky) where each participant is represented as an ensemble of three spheres (corresponding to the head and two hands). We showed that, in this installation, removing the visual feedback of each participant’s own body (but not the feedback they received of their partner’s body) increased the coordination of their movement with the (avatar of) the other, as well as their feeling of being ‘close’ to the other. (Laroche et al. 2021). In other words, the absence of perception of one’s virtual body does not impede coordinated interaction and feelings of relationality with a dance partner but in fact enhances them.

2.2 The Median

In line with the YUMI hypothesis, we developed a new dyadic VR protocol, ‘the median’. In this protocol, as in other existing virtual co-embodiment protocols, participants do not receive direct visual feedback of their own motion, nor that of the partner. Instead, participants interact with an avatar that combines their own movement information with that of their partner. Participants can thus recognize that their own movement contributes to the movement of the avatar, but because they cannot disentangle it from their partner’s, they can neither fully appreciate the extent of that contribution, nor can they fully predict the effects their ongoing motion will have on

the avatar. As such, the median provides us with the opportunity of a co-creative task that allows us to blur participants' feelings of self and other agency. The YUMI model predicts that this entanglement results in increased creative potentials.

This protocol builds on the principles of SDR and second-person co-embodiment (see 1.3). It consists of a co-embodied avatar constituted by three spheres situated in the VR space in front of the participant, as if it was a dance partner. The spheres' motion is generated by the combination of the participants' movement, captured by three body sensors that track their hands positions and head positions (six points in total). Two small spheres are animated respectively by the participants' mirror hands (left hand of dancer 1 and right hand of dancer 2, and vice-versa), while the third sphere is medium-sized and its position is always at the barycenter of the participants' six tracked points. The median dancer thus moves in synchrony with the two dancers, as they both feed the system with their respective movements. The algorithm governing the movement of the median dancer is set as a real-time blend of our participants' sensors positions. At its balance state, each participant shares an equal amount of control over the median dancer's resulting movement (this movement is influenced at 50% by the first participant, and 50% by the second). Yet it is possible to blur even more the boundaries between self and other agency by temporarily shifting the amount of control each participant exerts over the shared avatar. The resulting object appears as a highly engaging interactive object. Never being exactly one, nor the other, the median dancer fluctuates in a continuum, mixing familiarity and unknown. Entirely generated by the participants' movement, the median dancer is therefore a co-animated minimalistic avatar that blends the agency of 2 interacting persons. The goal is therefore to retain only part of the attunement between participants actions and the tangible traces they leave, but at the same time to conjure uncharted patterns of behaviors and experience by blurring this attunement thanks to the blending of the action of the partner.

Importantly, this novel protocol differs from those employed in the canonical virtual co-embodiment literature in a number of ways. First, the shared avatar is not materialized or spatialized as a plausible homologue or extension of the participant's body but rather as a partner situated at a distance. Compared to more canonical forms of virtual co-embodiment, this shifts the focus of inquiry from body ownership effects (and the risk of the participants experiencing a body semantic violation; see Padrao et al., 2016) to the relation between self and other agency and the conditions for the emergence of co-agency (Felnhofer et al 2024). Second, we do not prescribe particular actions to the participants but rather let them freely improvise and explore what the set-up affords. The absence of a prescribed goal (either shared or individual) prevents participants from having a sense of competition (about the control over the avatar or the task at all). Rather, it focuses them on their experience of the process of interaction, and on their collaborative generation of novel movement sequences or combinations. Moreover, it brings forth a creative product (the improvised performance materialized by the Median) that coincides in time with the processes of creation (the co-movement of the partner) that can be captured and analyzed. The Median set-up thus grants both the user and the experimenter access to the dynamics of real time interactive creativity. As such, it is particularly well suited for the exploration of the YUMI model of creative interactions.

As a proof-of-concept, we present results from an experiment we ran with 46 participants regarding their reported experience on a user questionnaire, and more focused analyses regarding their feeling of self-other agency distinction in relation with kinematic analyses of their movement.

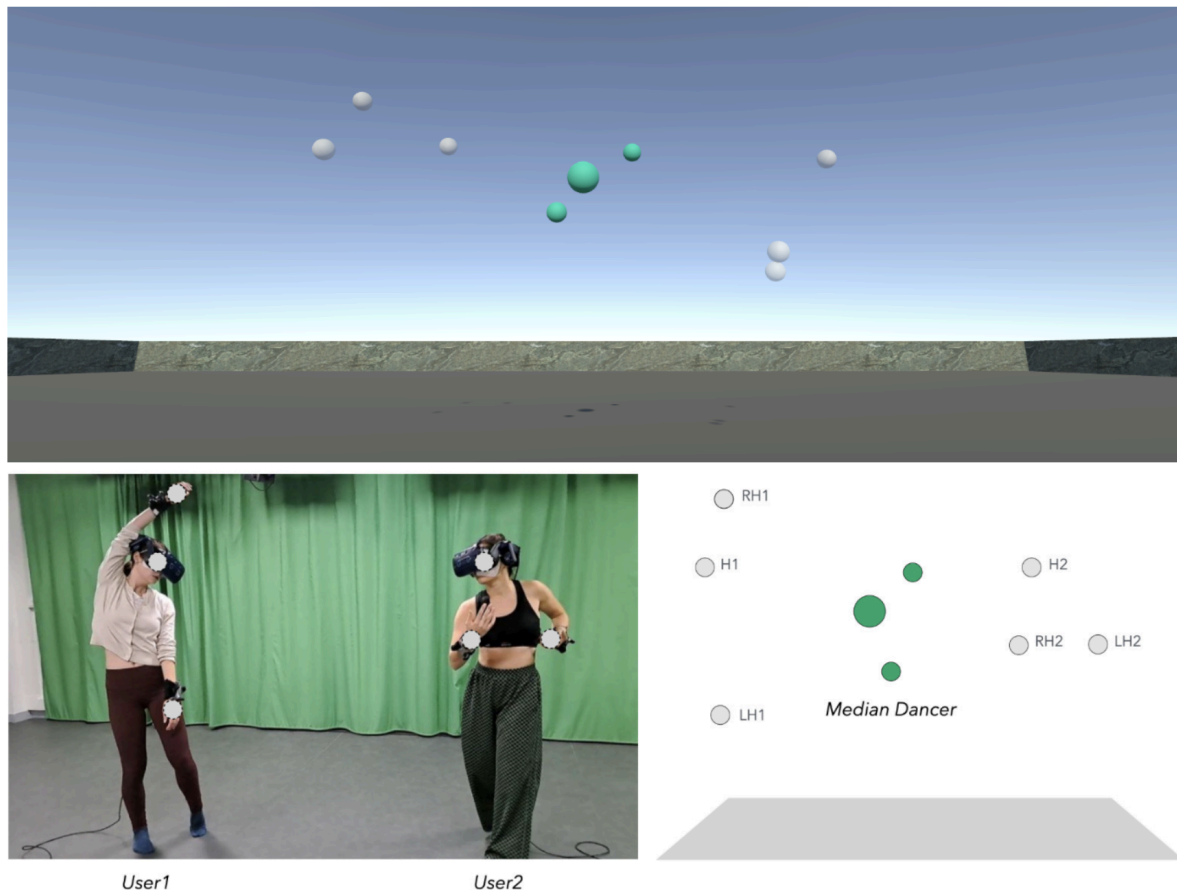


Figure 1. Illustration of the Median principles. Top) A view of the 3D environment with two participants (white spheres) and the median dancer in the middle (green spheres). Bottom Left) Two participants, each of them being tracked by three sensors (head and hands). Bottom Right) Schematic view of the median dancer, computed from the six tracked points.

2.3 Implementation

Our system runs on two separate computers, synchronized to each other thanks to an in-house networking program. They both run a VR environment via Unity3D, into which are fed the participant's movements. We use two virtual reality headsets (HTC Vive Pro 2) which are connected to the computers via a 5 meters long cable. Each VR headset is associated with two movement sensors that are placed on the wrists of the participants. All the tracking is done via an outside-in system, with 4 HTC Vive lighthouses displaced into the corners of the room to avoid occlusion between our participants.

Each participant's movement is directly sent from one computer to another at 60 frames per second, and each computer uses both movement time series to compute the resulting movement of the median avatar. The median avatar is constituted of a central sphere (a), and two small spheres (b and c). Their movements are fed in real time with the 3D position of our user's six points: their heads (u_1 and u_2), their left hands (v_1 and v_2), and their right hands (w_1 and w_2). One of the features of our program is that each user can have a different amount of influence than their partner over the median avatar's movement. To allow this, the median avatar's algorithm takes into account a weight factor (p_1 and p_2), to give more control to one or the other. Finally, and to make sure that the median avatar remains always centered between our two users, we move the median avatar with a compensation vector (V_c). The median dancer is animated as follows:

$$a = ((u_1 + v_1 + w_1) * p_1 + (u_2 + v_2 + w_2) * p_2) / (3 * p_1 + 3 * p_2) + V_c$$

$$b = (v_1 * p_1 + w_2 * p_2) + V_c$$

$$c = (w1 * p1 + v2 * p2) + Vc$$

$$Vc = - (u1 * (p1 - 1) + u2 * (p2 - 1)) / 2$$

This algorithm enables us to explore different conditions:

- In the case of a 100/0 condition, 100% of the control will be given to participant 1. The spheres of the median dancer will therefore only respond to the movements of this participant.
- In the case of a 33/66 condition, two-thirds of the control will be given to participant 2, meaning they will have twice the impact on the movement of the median dancer compared to their partner.

2.4 Protocol

The experiment took place at the CNRS Pouchet center in Paris, France. It lasted one week in December 2022. We tested 23 dyads, all having an experience with dance and improvisation. We chose to test the setup first with experienced movers as we consider them as experts in relational movement and we were interested in collecting expert first person reports.

After a phase of relaxation and introduction of the experiment, the two participants were placed into two respective zones, equipped with a VR headset and immersed in our minimalist visual paradigm. In the spirit of SDR, they were surrounded by a large arena, topped by an infinite blue sky. Participants were located into two separate physical spaces but shared the same virtual space, allowing them to move freely without the risks of hitting each other. In front of them they could see their median avatar, which first was set to move synchronously with their movements (100% control).

The experimenters explained to the participants how the movement of the avatar was generated, and that they were co-controlling it together with the other participant. The participants were then introduced to the 0% setting (full control of the avatar by the partner) and the 50% setting (shared, equal control). The experiment itself was composed of 10 short (1 min and 30 seconds) episodes of improvisations with the avatar. In each episode we independently varied the degree of influence each participant exerted over the avatar, helping us to further increase the sense of agency confusion. During these experiments, the participants' movement was recorded using the VR body sensors. After the 10 sequences were completed, the participants took off the headsets and filled an online questionnaire regarding their experience and were proposed a post-experience debrief during which they could freely describe their experience and interact with the experimenters.

2.5 Questionnaire

A post-experiment questionnaire to probe participants' experience was built using the same method as in our previous SDR experiments (Vuarneesson et al., 2021; Laroche et al., 2021). We used experiential reports from participants of pilot experiments that helped us parametrize the current protocol. The formulation of the questions was based on their own vocabulary and through the selection of the most distinctive traits of experience they shared with us. Participants reported their agreement to the questions (see supplementary materials) on a Likert scale between 0 and 6 (from total disagreement to total agreement with the propositions).

2.6 Population

A total of 23 dyads (46 participants) were recruited for the study. However, 2 participants did not complete the questionnaires and were excluded from the analysis, along with one dyad due to technical issues, resulting in a final sample of 21 dyads (42 participants; mean age = 41.8 ± 13.4 years; 33 women, 8 men, 1 non-binary).

Among the participants, 11 were professional dancers, 25 regularly practiced dance without being professionals, and 6 reported limited dance experience, such as having taken a few lessons or only dancing at parties. 30 participants reported practicing dance for more than five hours per week. Regarding virtual reality (VR) experience, 18 participants were using VR for the first time, 22 had limited prior experience, and 2 were regular VR users. None of the participants knew their partner before the study.

2.7 Analysis

2.7.1 Post-experience questionnaires

First, we analyzed the post-experience questionnaire by reporting and describing the distribution of responses for each item. To organize the presentation of the results, we grouped the items in 5 categories: adhesion, quality of interaction, creativity, co-embodiment and co-agency. We illustrate the description of the results with quotes of the participants reporting their felt experience at the end debrief.

Then, we focused on participants' reports on one specific item: the responses to the question "*Throughout the episodes, I couldn't distinguish my own contribution to the movement of the spheres from that of my partner*"). This item is crucial for the YUMI model because it probes participants' reaction to our attempt to induce agency confusion (i.e., the blurring of the limits between self and other agency). Plus, as we show below, the distribution of responses to this item was relatively wide, indicating that the protocol had a differential impact on participants. We are therefore interested in understanding experiential and behavioral correlates to states of (self and other) agency confusion. First, we computed Spearman correlation between agency confusion and responses to the other items in the questionnaire. Then, we explored the association of agency confusion with movement patterns, both at the individual and the relational level.

2.7.2 Movement analyses

Movement analyses were performed separately for head and hands movement, as these effectors are often moved very differently (e.g., in terms of velocity, amplitude and periodicity) and fulfill different roles in nonverbal communication and coordination (Laroche et al., 2021, 2022). Moreover, head and hands served different roles in the animation of the Median (i.e., as explained above, two spheres were moved by the two hands, and one was moved by a combination of the hands and the head). To conduct our movement pattern analyses, we focused on velocity time series (i.e., how participants change the velocity of their movement across time). To extract velocity time series, we took the 3D positional time series recorded with the Unity motion tracking system and our custom scripts, interpolated these time series at 20 Hz, and lowpass filtered them with a two-pass, second-order Butterworth filter with the cutoff frequency set to 5 Hz, to eliminate noisy jitter. The derivatives of the resulting positional time series allowed us to obtain 3D velocity time series.

Movement analyses were then performed in two ways, to gauge leader-follower dynamics and movement predictability.

Leader-follower dynamics are a core feature of interpersonal movement coordination and illustrate the directionality of information exchange in an interconnected system of multiple agents (Calabrese et al., 2021). To gauge leader-follower dynamics, we performed windowed cross-correlation analysis (WCC, Boker & Rotondo, 2002) between partners' velocity time series, by taking, for each partner, the norm of their velocity time series. We slid windows of 2 seconds across the whole time series, and computed cross-correlation at lags ranging from -2 and +2 seconds, with a 75% overlap between successive windows. We then calculated a leader-follower balance index by (i) identifying peak correlation values at both positive and negative lags, which respectively indicate the extent to which participants tended to follow *versus* lead their partner at a preferred lag (ii) subtracting the peak value found at negative lags (leading) from the value found at positive lags (following); positive results indicate that a participant followed more than they led their partner, and, consequently, that the partner led the participant more than followed them.

We are also interested in movement predictability because it indicates a lack of creative exploration from participants. To approach it, we performed Principal Component Analysis (PCA) on 3D velocity time series (Hilt et al., 2019). The amount of variance explained by the first component (henceforth called PCA1) tells us how simple it is to project tridimensional movement patterns onto one unique dimension, providing us with a proxy of the simplicity and predictability of movement patterns.

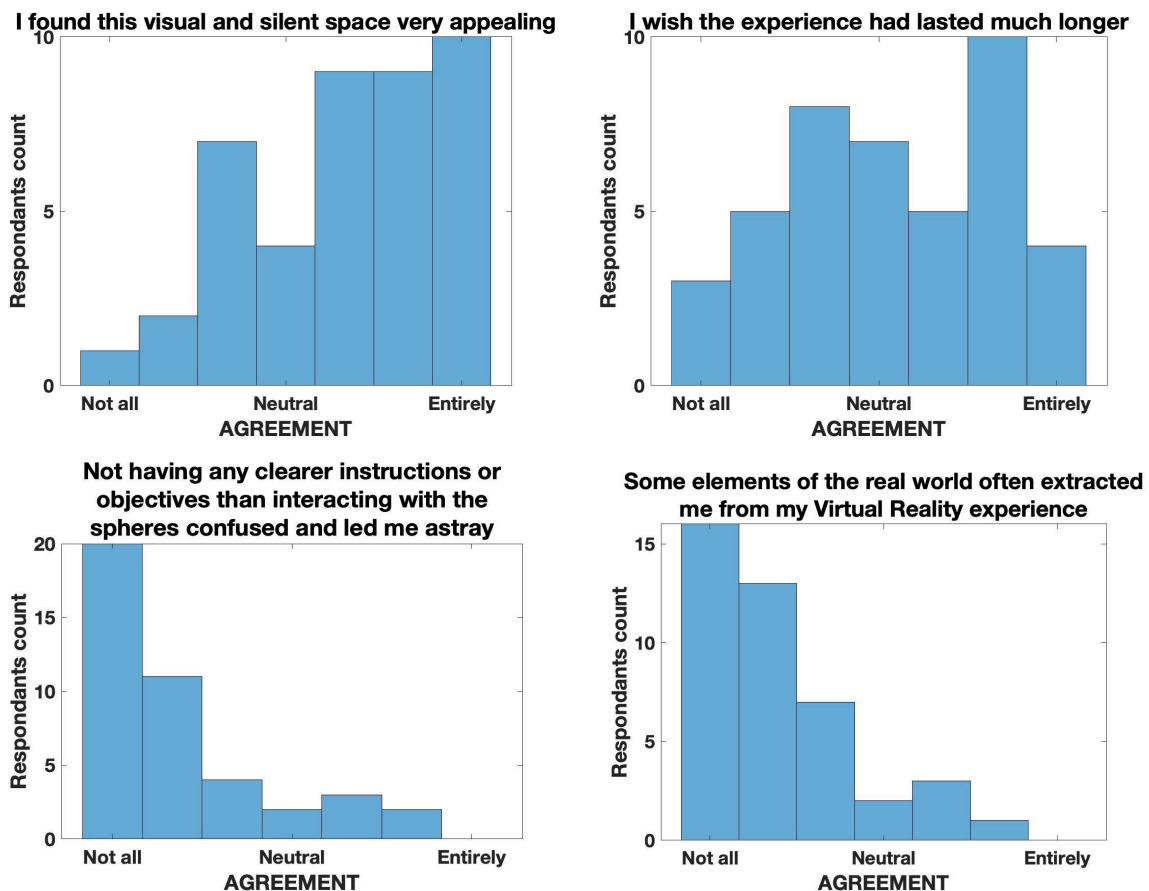
PCA and WCC were performed for each trial. Results obtained for the 10 trials were first averaged for each participant. However, during joint action, movement dynamics of individuals are codependent, in a co-creative task like ours, where participants directly interact with the perceived product of their interaction, individual movement dynamics become deeply entangled. As such, the sense of self-other agency confusion that can result is always contingent on the movement dynamics of the coupled partner. For this reason, we computed relational variants of the preceding indices - in other words, the within-dyad differences in terms of self-other agency confusion and movement predictability (leader-follower balance intrinsically constitute a relational variable). We then computed the correlation between the resulting relational variables.

3. RESULTS

3.1 Questionnaire results

3.1.1 Adhesion

Six questions addressed different aspects of the individual experience of the VR installation (figure 2).



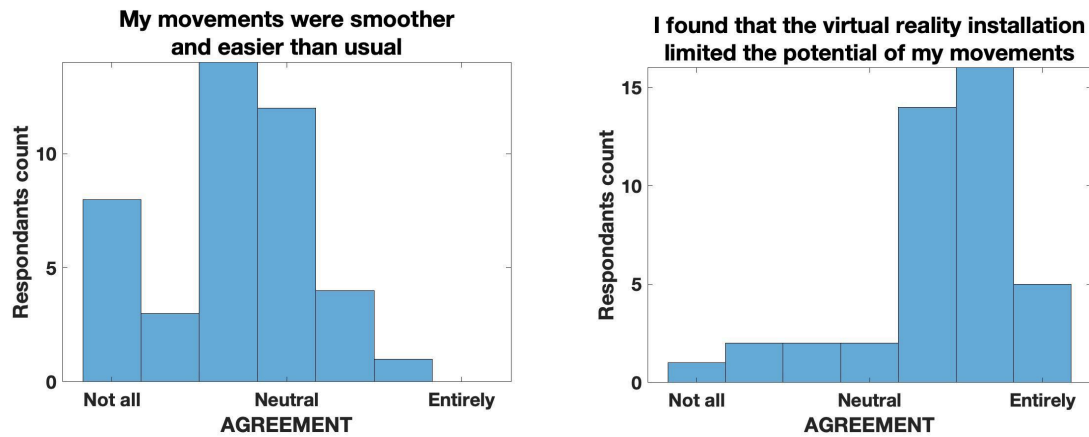


Figure 2. Responses to items related to the 'Adhesion' category.

The aesthetics of the VR environment was well appreciated and felt appealing to 66% of the participants. The majority of participants wished for the experience to last longer (19 vs 16). The wide distribution of opinions on this item indicates that the experiment duration was close to a limit.

A vast majority (35) of participants did not feel that the lack of specific instructions or the open-ended nature of the activity negatively impacted their experience indicating that the installation is well suited to generate spontaneous, improvised interactions. Similarly, a vast majority of participants (38) didn't feel distracted by external elements, a signature of their immersion in the VR environment and the task.

To support these results, we can cite some words from our participants, gathered during our post-experiential interviews:

D1 (Dyad 1): "I never felt it boring, we were quite connected."

D7: "It was very playful but also frustrating, sometimes it responded well but sometimes not at all."

D12: "I never got bored."

D15: "I think it also pushes you into a kind of movement that's not really your own. [...] And a rhythm that we don't usually go to. [...] I really often found it playful."

D10: "It's super soothing. It's so cool."

Most participants didn't find that the installation made their movement more fluid, and most agreed with the statement that the setup actually limited their capacity of movement. These results are not surprising considering the technical constraints (equipment, reduced space and precautions to avoid collision when blind to the real environment).

D14: "Super frustrated not to have feet of feet or a sensor of feet [...] not having feet is a bit scary and so all the focus we have visually is this suggestion of heads and arms [...] It still affects the movement."

D2: "There you can only really move your arms and upper body. You can't really get down on the floor and do rolls."

D1: "I've tried to do things where sometimes you don't move, sometimes you move, sometimes you go fast, sometimes you don't go fast. There isn't a huge choice either. [...] because you're already limited in space."

D21: “I think that the representation in three balls also encourages us to a certain type of dance, a certain type of movement. Because we don't get visual feedback from other parts of the body. So that's it, I think it concentrates us in certain movements.”

They were rather conscious of the system's limitations, which they reported several times

D10: “It wasn't easy to move your head with the weight of the headset.”

D13: “And then there's the cable. [...] It forces you to stay in the plane a bit.”

These limitations made them sometimes more receptive to external stimuli such as the sound made by them or their partners.

D18: “There's something about the sound. Me, it's my feet that I can feel moving around on the floor even though I can't see them. So, there's something very strange going on in my brain.”

D7: “Sometimes, when it was a bit less clear or precise [...] I realized that I was compensating with sound. I could hear when you moved.”

3.1.2 Quality of interaction

Three questions targeted specifically the quality of the interaction with a partner within the setup (figure 3).

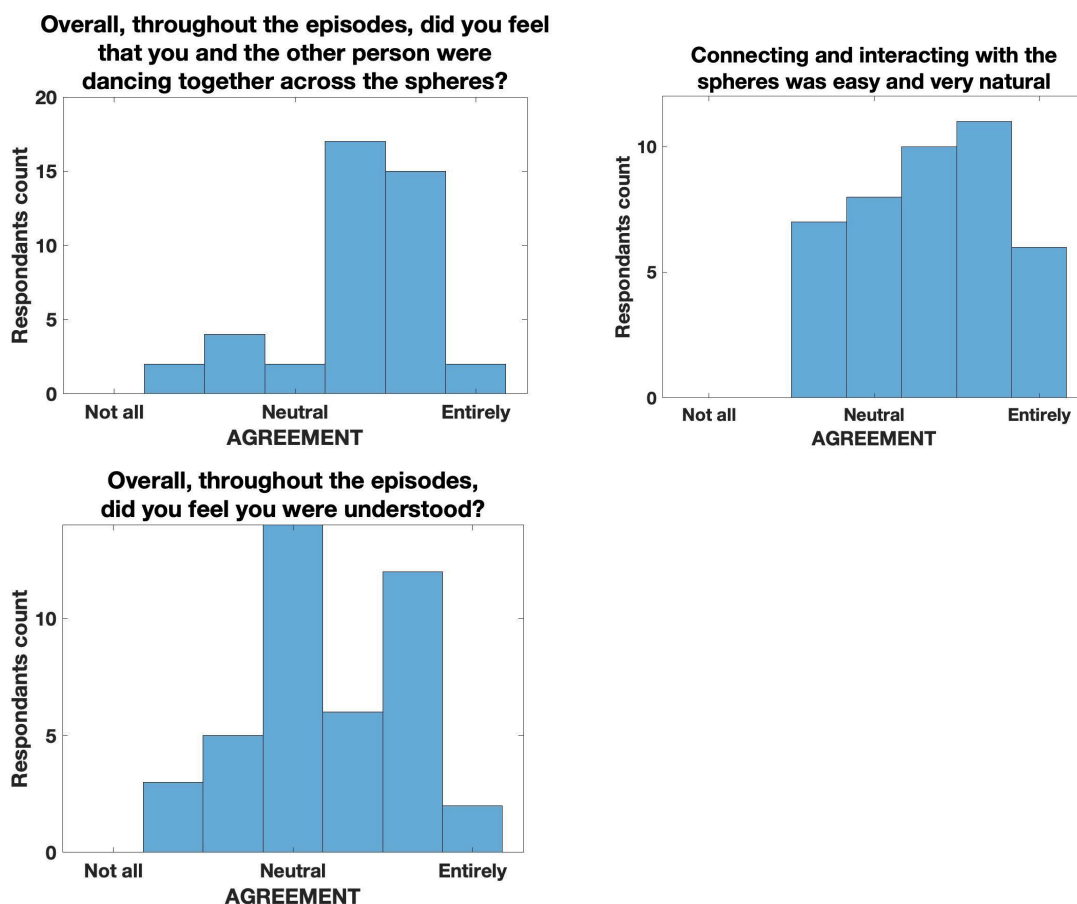


Figure 3. Responses to items related to the ‘Quality of interaction’ category.

The vast majority had a feeling that they and their partner were dancing together and that the connection with the partner through the spheres was easy to establish.

This was reflected in the interviews:

D3: “You find the connection, the moment, you stop concentrating”

D20: “I found it moving at times, when you reached a state of plenitude. When I was leading, it was more restful but more boring.”

D15: “When I saw this result and even in my experience, I had the impression that we were in symbiosis and that I knew you.”

D20: “I had the impression that we were in sync. In any case, the balls were in sync with me. I found it hard to see how much you actually had to do with it.”

A slight majority of participants felt understood, but a larger number of participants responded neutrally to the item, which might indicate the question was abstract and hard to address (indeed, a few participants named this question as confusing).

Below we report some of the words said by our participants after the experience:

D20: “I don't know if it was the balls leading and us following, or if it was me leading, the balls following and you following where there was a resonance. You know what I mean?”

D5: “I wish I would have a way to know that it was really me and him, and we succeeded to dance better together and I felt connected to a person, rather than a reflection of myself.”

3.1.3 Creativity

Two questions addressed the questions of curiosity and creativity (figure 4).

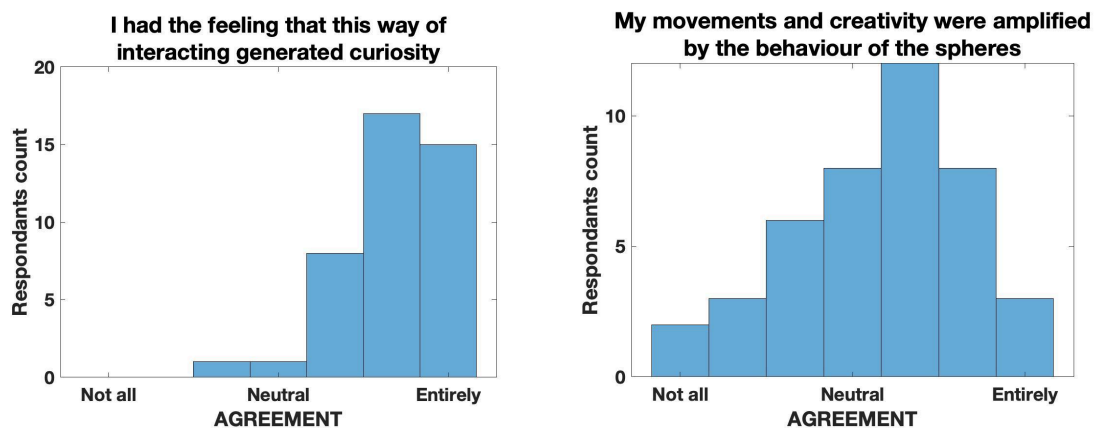


Figure 4. Responses to items related to the ‘Creativity’ category.

The vast majority of participants reported that the set-up generated curiosity. Along the same lines, more than half the participants reported that their creativity was amplified by the setup. We note however that the responses to this question showed a larger variance compared with the one addressing curiosity. We will come back to this issue later.

D12: “I was trying to guess the movement of these golems”

D13: “I tested a lot of things, I never followed the balls, I always tried to change their behavior.”

D12: “I'd try to copy the movement I was doing at the same time, it was difficult. I'd try lots of things to see what I could really control.”

3.1.4 Co-embodiment

Our setup implements the concept of second person co-embodiment. 4 questions addressed different dimensions of this experience (figure 5).

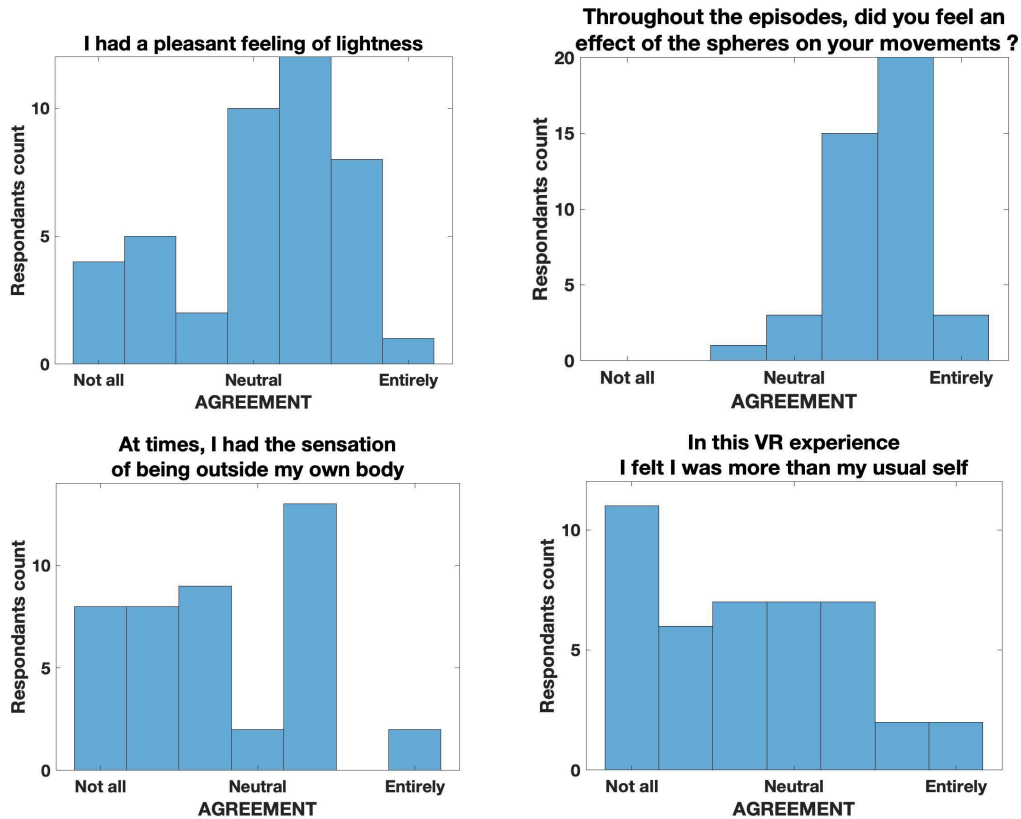


Figure 5. Responses to items related to the ‘Co-embodiment’ category.

Participants often reported a pleasant feeling of lightness, which indicates that the VR system had an important impact on their kinesthetic awareness. This sensation is similar to the ones reported in our previous study on SDR (Vuarnesson et al, 2021) where participants embodied a set of three spheres in a first person point-of-view. We can speculate that, again, by giving agency over an avatar that appears light and which is not constrained by real-world physics, mechanisms such as the Proteus Effect are triggered (Yee and Bailenson (2007), inducing a feeling of lightness.

The majority of participants did not have an experience of feeling out of their body, which can indicate that they did not feel embodied in the 2nd person avatar in the same way as in the case of first-person avatars (Kim et al 2020, Döllinger et al 20203, Cui & Mousas 2022)). However, almost all participants felt that the movement of the spheres were having an effect on their movement.

D11: “When I saw that it was moving, I said to myself we'll follow it. I tended to follow when the green spheres were moving without me. I tended to follow what they were doing.”

D9: “All the time I was influenced, but was I influenced by the spheres, by my impact on the spheres? It was very difficult to separate the two.”

We take the experience of being affected by the second person avatar and feeling a sense of lightness, both reported by a majority of participants, while not having a sense of being outside one’s body as indications of co-embodiment. We will return to this in the intermediary discussion. Finally, the sense of feeling more than oneself, often reported in group flow states (Schroeder et al 2019, Salmela 2021) and collective improvisation (Saint-Germier et al., 2024), was highly variable across participants. We will return to this issue later.

3.1.5 Co-agency

Second person co-embodiment and the YUMI model make reference to different experiences of agency. Three questions addressed this aspect of the experiment (figure 6).

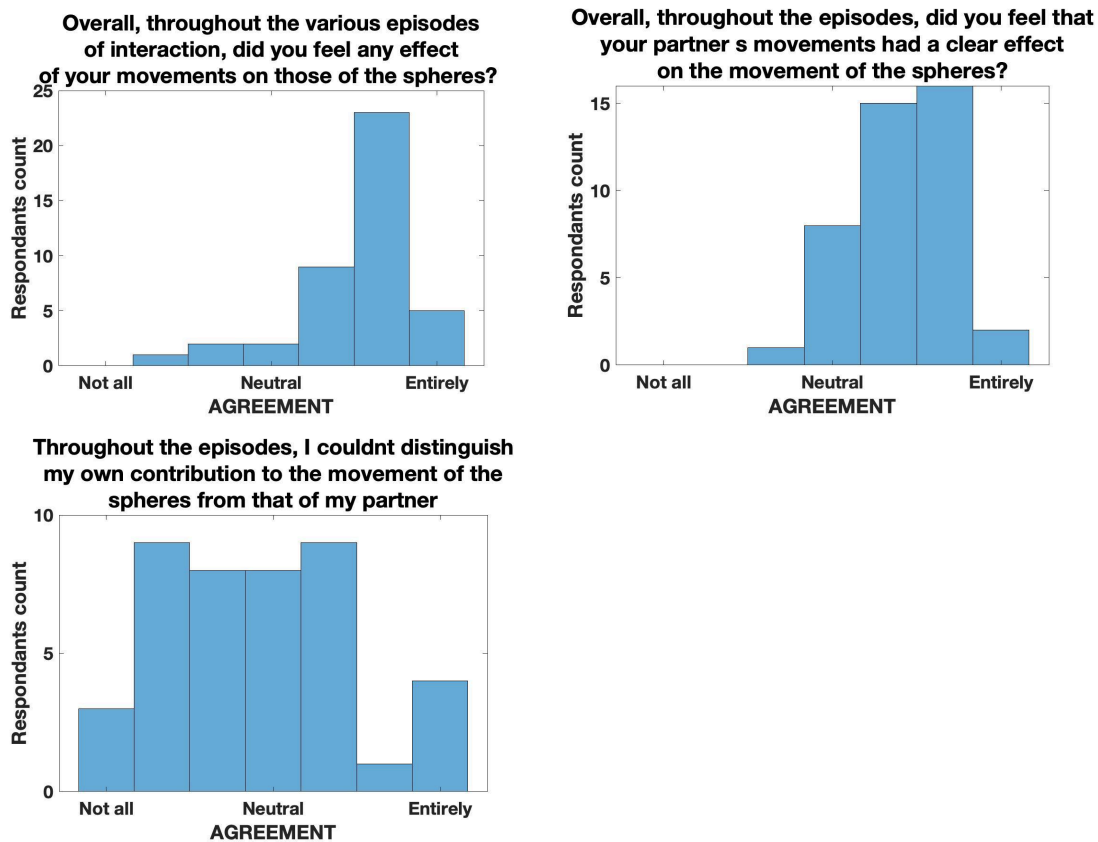


Figure 6. Responses to items related to the ‘Co-agency’ category.

Despite the sharing of control, the vast majority of participants clearly felt the effects they exerted on the spheres (self-agency). To almost comparable extent, they could feel the effects their partner had on the same spheres (other-agency).

D10: “There was always a moment of listening at the beginning to see how well it was responding.”

D4: “There have been times when we've played off each other. I mean, there were times when one would dance and the other would stop, and we did that at one point. I'd dance and then I'd stop and you'd dance and it became a sort of dialogue. So we stopped dancing together, but we were still dancing together. In other words, you danced, I watched what you did and then I responded.”

D7: “When I had less control, I changed my gestures or let her do.”

D19: “You asked « were you influenced by the spheres », and it depends because it was a choice, sometimes I would say I’m just going to dance, I don’t care, sometimes I will really focus, and I’ll dance according to that”

The YUMI model proposes that (co-)creativity is enhanced when self and other agency are blurred. Indeed, a significant number of participants reported being confused regarding their own contribution to the movement of the spheres and that of their partner. However, as with the question of creativity, and feeling more than oneself, the variability across participants was rather large.

D5: “For me also when I felt connected, understood and seen, then I was immediately aware that the balls move the way I wanted them to move.

It's like this loop that I'm supposed to be connected to, but I am basically connected to myself. If the balls are moving the way I expect them to move, the way I want them to move so then I am connected more. But it's supposed to be with him. So who am I connected to here basically?”

D3: “Sometimes I confused what was the mix and what was the other.”

D21: “Sometimes I'd say to myself, am I dancing with myself or with someone else?”

D14: “Rather than free improvisation, I found myself trying to understand how the interaction worked.”

D2: “I had the impression that all I could see was my movement, not his. And then I realized that I could see this when I stopped moving.”

3.2 Intermediary discussion of questionnaire results

Overall, participants’ responses regarding the installation were very positive. Most enjoyed the design of the environment, the unconstrained nature of the task itself was not an issue and a slight majority even wished the protocol could be longer. Perhaps having less episodes of interaction but longer ones could increase the percentage of participants who would wish to stay longer in the VR environment. This positive experience is remarkable given the reported limiting nature of the setup on movement (in particular for dancers). We also note that the installation fostered the intended collective improvisation activity. Participants felt connected to their partners and had the experience of dancing together despite the absence of direct visual cues. Indeed, as one would expect in a rewarding collective dance improvisation activity, the participants felt enhanced curiosity and (for most) creativity. It is noteworthy that dancers would feel that their movement creativity is enhanced despite the felt (real) limitations imposed by the setup. Indeed, we found a significant mild negative correlation between dance experience (hours of dance practice a week) and the experience of creativity.

Co-embodiment in VR has been studied only with first person avatars. We found that participants reported certain experiences that can be the reflection of co-embodiment with a second person avatar. In particular a sense of presence in their body (for most), having a sense of being larger than in real life and (as a consequence of the sensation of being larger or because of the form of the avatar) feeling lighter. We propose that having the sense of being affected by the spheres is also an index of co-embodiment. Finally, both self-agency and other agency were clearly experienced by the vast majority of participants which clearly indicates that our setup of second-person co-embodiment was successful in conserving one’s own sense of agency while sensing the agency of the partner without the two being in competition. As far as the YUMI model, a majority of the participants felt mildly or highly confused as to their relative contribution to the movement of the spheres (without eliminating their sense of self-agency). We take this confusion to be an indicator of the creativity inducing blurring of agency described in the YUMI model.

Despite the blending of control across the two partners the responses to the question regarding agency confusion were highly variable. A slight majority of participants (20) felt they were able to parse the two sources of control. Yet, a significant number of participants (14) did feel confused about the agential origin of the spheres animation and couldn't properly distinguish their own contribution on the spheres' animation from their partner's. In a sense, this achieves one goal of the set-up, which is to induce a sense of diffused agency. Because the responses to this question are more widely distributed than all other questions, especially those linked to agency, and because this question touches directly on the YUMI construct, we now explore this question more thoroughly, by looking at the association between the experience of agential confusion and other experiential and behavioral variables.

3.3 Self-other agency confusion: correlation with other questions

We first turn to look at the correlation between the degree of self-other agency blurring (confusion) and participants' responses to other questions. The experience of self-other agency confusion was significantly correlated with two other items in the questionnaire. First, a significant correlation was observed with the item "During this experience in VR, I was feeling that I was more than my habitual self" ($r = .57$, $p = 0.00008$), meaning that the more participants experienced self-other agency confusion, the more they felt more than themselves. Second, a significant correlation was observed with the item "Not having any clearer instructions or objectives than interacting with the spheres confused and led me astray": ($r = .47$, $p = .0017$), meaning that the more participants were confused regarding agency, the more they felt distraught by the lack a clear goal.

As we discussed above, we take the experience of being more than oneself as a proxy of the second person co-embodiment effect the protocol is set to induce. From this perspective the correlation between the degree of self-other agency confusion and the sense of being more than oneself makes sense to the extent that both tap into the second person co-embodiment construct. It suggests that agency is tightly linked to our embodied sense of self and furthermore that joint agency or collective agency is intracorporeal.

The second significant correlation, with the sense of feeling lost in the absence of clear instructions or a goal, tells a different story. It is possible that for certain persons feeling confused about their effect on the spheres was associated with a more general (and negatively appraised) sense of confusion or 'being lost' generated by the open-ended improvisation task. It is important to note that the 'more than myself' and 'lost without a goal' responses did not exhibit a meaningful correlation ($r = .21$, $p = .18$). This suggests that the question about confusion might still need to be refined in future research so to distinguish participants for which this confusion was a source of difficulty and participants for which it was empowering.

3.4 Self-other agency confusion: correlation with movement variables

We turn to look at how participants with differential experiences in terms of self-other agency confusion moved individually and collectively. Collectively, we look at leader-follower balance indices. Individually, we look at movement predictability, indexed by PCA1. As explained above in the method section, for both indices, we compute correlations between within-dyad differences in terms of self-other agency confusion and within-dyad differences of the movement variables.

3.4.1 Leader-Follower dynamics

We performed windowed cross-correlation analysis between the velocity time series of the coupled partners in each dyad to evaluate the extent to which they tended to synchronize with each other, and whether one tended to lead or follow the other (see figure 6).

For head movement, CC peaked at lag-zero, indicating a slight tendency for coupled partners to move their head in synchrony. For hand movement, CC peaked at a lag of 450ms, indicating that participants had a slight tendency to follow or lead the velocity variation of their partner with a short delay.

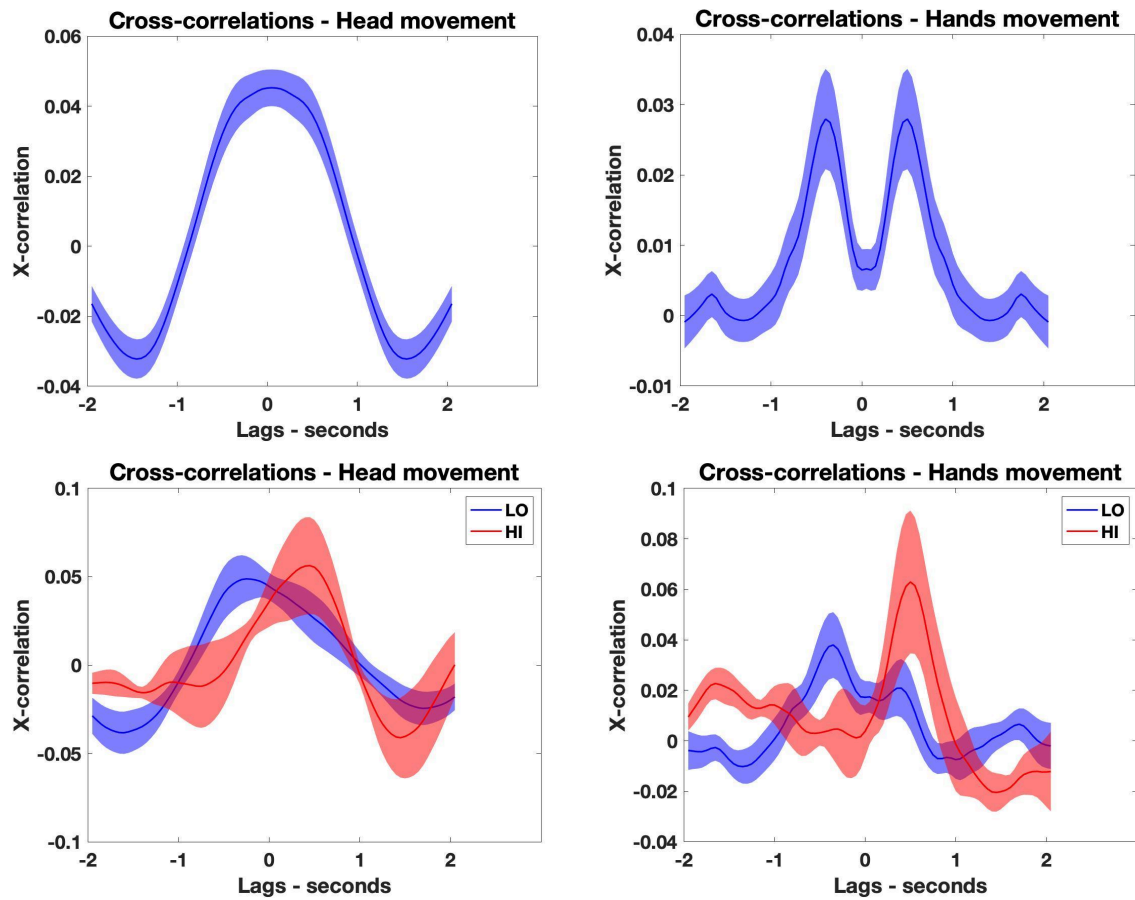


Figure 7. Representations of the cross-correlation functions between coupled partners head and hands movement. Upper left) cross correlation between head movement: the graph illustrates the tendency of coupled partners to display peak correlations around lag-0, which corresponds to real-time synchrony of velocity displacements. Upper right) cross correlation between hands movement: the graph illustrates the tendency of coupled partners to exhibit leader-follower dynamics in which movements are more likely followed at a lag of 450ms. To graphically illustrate the different facets of the presented results, we constituted 2 sub-groups of participants according to their self-reported experience of self-other agency confusion: HI and LO. LO refers to the 12 participants that reported not being or being very poorly confused in terms of self-other agency (i.e., they responded 0 or 1 to the related item). HI refers to the 5 participants who felt rather highly confused (i.e., they responded 5 or 6 to the related item). Bottom left) cross correlation between head movement for HI and LO participants. Patterns of synchrony shifted only slightly depending on participants' agency confusion, but followership did not correlate with intra-dyad differences in terms of agency confusion. Bottom right) cross correlation between head movement for HI and LO participants. Patterns of synchrony clearly shifted toward followership for HI participants, meaning that those who were most confused in terms of agency tended to follow their coupled partners with their hand movements more.

The difference in the form of dyadic coupling between the head and the hands is important to highlight before we explore other results. With respect to the movements of the hands we find a leader-follower pattern that is often observed in contexts of mutual creative movement (Hartmann et al., 2023; Whitehead et al., 2024) or joint goal-directed action (even when there are no designated roles; Konvalinka et al., 2010; Calabrese et al., 2021). It can be associated with a more general turn-taking coordination pattern one also finds in conversations (Hale et

al., 2020), games (Kalaydjian et al., 2022) and other social encounters (Lombardi et al., 2020). The head movement analysis reveals a different organization, one of (a tendency towards) synchrony. The spontaneous emergence of movement synchrony has been studied extensively (Ayache et al., 2021). However, as discussed above, in many natural collaborative settings, pure gesture synchrony is replaced by other coordination patterns (such as leading-following). However, it has been observed in conversation studies that speaker-listener dyads do synchronize their postural sway (Shockley et al., 2003). This has been extended to other social or collaborative settings such as music playing (Chang et al., 2019) and movement improvisation tasks such as the Mirror Game (Gueugnon et al., 2016). Sway synchrony has been associated with interpersonal rapport (Ishigaki et al., 2017) and joint emotional expression (Chang et al., 2019). While head movement in our set up is not strictly speaking a measure of postural sway, we propose that while hand movement indexes collaborative gestural meaning making, head movement indexes interpersonal rapport or attunement. We will interpret the results to be discussed below with this functional differentiation of the two movement loci.

Spearman correlation revealed a significant association between within-dyad differences in terms of self-other agency confusion and their leader-follower balance for hand movements ($r = .34$, $p = .03$), but not for head movement ($r = .05$, $p = .74$). In other words, the more participants felt greater self-other agency confusion than their partner, the more they were following rather than leading the partner's hand movement (see figure 6).

3.4.2 Movement predictability

PCA1 explained on average 54.5 (+- 4.9) % of the variance of head movements, and 34.8 (+- 4.0) % of the variance of hands movements. Within-dyad differences in terms of self-other agency were significantly correlated with within-dyad PCA1 differences for head movement ($r = -.55$, $p = .0003$), but not for hands movement ($r = -.06$, $p = .72$). In other words, participants who were more confused than their coupled partner in terms of self-other agency moved with less predictability than their partner.

As leader-follower balance for hand movements and relative head movement predictability were both associated with self-other agency confusion, we performed correlation between these two variables and found a significant association ($r = -.48$; $p = .0007$), meaning that the less predictable participant's head movement relatively to the partner's, the more that participant was following the partner's hands movements.

4. FINAL DISCUSSION

In this paper we addressed collective creativity in shared virtual reality and introduced the YUMI model, which posits that creativity is enhanced when the boundaries between individual contributions to a shared outcome are blurred. We explored this concept through a novel VR setup called 'the Median,' where two participants control a single avatar, thus creating a shared embodied experience. Results indicate that participants experienced a sense of connection and creativity, and that the blurring of self-other agency was correlated to a sense of an extended self on the one hand, and to less predictable head movements and a tendency to follow one's partner hands movement on the other hand. We now turn to articulate the different results and their interpretation within the YUMI model of collective creativity.

4.1 Why is agency confusion positively correlated with a tendency to follow?

In complex human networks, various patterns of leader-follower dynamics emerge spontaneously to facilitate group coordination (Calabrese et al., 2021). A core feature of followership is the extent to which the state of an agent depends on the state of others. Therefore, the more an agent is open to being affected by its environment (including a partner), the less her behavior is independent and self-driven - in other words, the blurrier her agency becomes. To go back to the experience of couple dancing, such as in tango or Contact Improvisation, dancers often report that in highly satisfying dances they find it hard to tell who initiated a movement or a

change. This is, in a sense, the heart of the YUMI model. The experience of agency confusion is the phenomenological counterpart of being part of an interdependent system (captured here by the measure of cross-correlation).

4.2 Why is agency confusion positively correlated with less predictable head movement?

The more participants were confused about their agency, the less predictable was their head movement. Both these variables were also associated with the degree of followership. One possible explanation for the decreased predictability is therefore the increased amount of variability that can be found in followers' movement to compensate for misalignment with the leader (as reported in the context of the Mirror game by Noy et al., 2011, and in tapping tasks as observed by Fairhurst et al., 2014). However, leader-follower dynamics were observed in hands' movement. Head movements, whose lack of predictability was correlated with confused agency, were on the other hand more synchronous.

That the head movement of more confused partners was more unpredictable might instead (or in a more general way) be related to the consequences of interdependence on postural organization (Varlet et al., 2011). The more a system in a network is coupled with other systems, the more it will be affected by the network and, as such, will display less habitual patterns than its intrinsic dynamics usually lead to. It is not surprising that postural organization (indexed here by head movement) will be less predictable when a person is more coupled with their environment, as postural organization bears the hallmarks of individual history and habitual being-in-the-world (Godard 2004; Hall et al., 2023). Less predictable postural organization would then result from or index an undoing of the individual patterns by interconnectedness (Ishigaki et al., 2022).

4.3 The building blocks of creativity

It is noteworthy that despite the fact that most participants felt their creativity enhanced by the installation, we did not find a correlation between the responses to that question and that of agency confusion. This seems surprising given the link the YUMI model makes between these two dimensions of experience. One straightforward explanation to the lack of correlation is the relative low variability in the response to the creativity question (a sort of a ceiling effect). Furthermore, creativity is a complex construct that contains a number of components that in future research we will evaluate separately (e.g., originality and effectiveness, Corazza, 2016; surprisingness, exploration and exploitation Hart et al., 2017). In effect, we believe that the two movement parameters that correlate with agency confusion are indices of creativity or of the conditions that enhance creative behavior.

As discussed above, agency confusion is positively correlated with the tendency to follow one's partner. Perhaps because creativity is often conceived as the exceptional achievement of an individual which others can then benefit from (Glăveanu, 2012), it is often expected that, in dyadic creative activities, a leader would exhibit creativity while the follower, simply, well, follow, or, at best, endorse the creative outcome (Chauvigné et al, 2018). However, this view seems over-simplistic. In couple dancing for instance, following is not about merely echoing what the leader did a little earlier (Gentry & Feron, 2004). Following involves continuous choice making: what is the leader proposing or suggesting? Which suggestion should I respond to, how, where and when? To what aspects of the suggestion should I relate to? (Thommes et al., 2020). Following the work of the dance improviser Joao Fiadeiro, we have argued elsewhere (Kalaydjian et al., 2022) that the choice of action of the follower gives meaning to the actions of the leader - it does so by establishing a relation between actions that confers sense-making a participatory nature (De Jaegher & Di Paolo, 2007).

We found out that agency confusion was correlated to less predictable head movement (but not hand movement). We speculate that more complex or less predictable postural organization (indexed by head movement) is an important component in collective movement creativity as it relates to the connection between postural organization and potential for action. According to somatic theories and movement analysis theories

(Godard 2004) the potential of our gesturing (amplitude, versatility, adaptability etc..) is rooted in our postural (sometimes named pre-movement) organization. The more our postural organization is flexible and adaptive, the greater is our gesture or movement potential (Nomura et al., 2016). It is possible to speculate that the observed increase in head movement unpredictability is a proxy of a more complex and flexible postural organization that, in turn, supports a richer set of potential movements or gestures. This is particularly important when being a follower, as your postural system needs to adapt to unexpected directions or dynamics. As we have seen above, increased agency confusability is indeed related to a tendency to follow one's partner. Indeed, further analysis of the results reveal a relation between the tendency to follow one's partner hands movement and the relative unpredictability of head movement. In other words, the two findings above appear related, which make sense from the perspective of YUMI. The more a node is integrated in a system, the more it will present posture variability and the more it will present the follower characteristics and system integration is associated with the phenomenology of agency confusion.

4.4 YUMI in IDMI, towards bond-enhancing digital mediation

We questioned our capacity to connect with a partner through IDMI and to be creative together. Many setups have allowed collaborative creativity in digital meditation (Alahuhta et al., 2014; Men et al., 2019; He et al., 2020; Bourgeois-Brougrine et al., 2022), and it has been shown that embodying in virtual avatars exempt of cues about participants' identities increased mutual creative engagement (Bryan-Kinns et al., 2007), but to our knowledge none of them ever deviated from offering a clear distinction between individuals taking part in it, whether represented by realistic, semi-realistic, abstract or minimalist avatars. The YUMI model proposes to go beyond this frontier by provoking mixes and encounters. We were surprised to see some of our participants experience high levels of connection, despite the fact that they didn't know each other, and that this fragile balance between familiarity and unfamiliarity sometimes seemed to reach an ideal equilibrium. We saw how some seemed to find harmony by balancing their movement qualities, while others were satisfied with the surprise and unexpectedness of their partner's movements. This would seem to suggest that there is an ideal level of mixing for each encounter, allowing some to achieve harmony more quickly, while leaving others with a constant renewal that keeps their respective curiosities stimulated.

This experience raises questions about our use of digital technology and the impact that this medium has on the way we communicate. Social networks are sometimes criticized for acting as an echo chamber, confronting us more often than not with opinions that satisfy us or reinforce our beliefs (Cinelli et al., 2020; Terren & Borge-Bravo, 2021). In the light of our observations, however, it would seem that digital interfaces have a completely different role to play in creating bridges and blends between identities and characters. Can sharing an avatar have an impact on our ability to understand others? By forcing us to step back, negotiate and adapt our actions, such systems could reinforce the logic of cooperation and problem-solving in creative and playful ways. By blurring the boundaries between my partner and me, it becomes possible to temporarily break down hierarchies and misunderstandings, and to look for a sweet spot where our actions and opinions collide in a way that makes new shared meaning emerge. By applying this principle to learning tools, an individual could be reinforced in what he or she has already learned, while being transported at an appropriate pace into new and unknown, potentially creative territories. Furthermore, by applying this principle to remote communication tools, it becomes conceivable to develop moments of sharing that emphasize co-presence, mutual understanding and collaborative creativity.

Overall, the YUMI model questions how, by blurring the perception of our self-agency with the perception of other-agency, we can be pushed outside of our comfort zones, triggering a will to adjust and grow, which can actually bring us closer to each other.

5. CONCLUSION

This study introduces a novel approach to VR design by shifting the focus from individual embodiment to relationality and co-creation through a "second person" perspective, where a shared avatar is controlled by multiple participants. This approach was first implemented in an installation called 'the Median'. To probe participants' experience of the installation and to provide a proof-of-concept, we proposed a protocol that amplifies the blurring of self and other agency. Analysis of participants' subjective experience of the Median and of their movement supports the YUMI model, suggesting that blurring the boundaries between the agency of the self and the other can foster processes involved in (co-)creativity. More generally, by employing Shared Diminished Reality (SDR), this proof of concept highlights how simplifying VR renditions can be beneficial for research and VR design by focusing on specific aspects of interaction.

6. REFERENCES

- Alahuhta, P., Nordb, E., Sivunen, A., & Surakka, T. (2014). Fostering team creativity in virtual worlds. *Journal For Virtual Worlds Research*, 7(3).
- Ayache, J., Connor, A., Marks, S., Kuss, D. J., Rhodes, D., Sumich, A., & Heym, N. (2021). Exploring the "dark matter" of social interaction: Systematic review of a decade of research in spontaneous interpersonal coordination. *Frontiers in Psychology*, 12, 718237.
- Boker, S. M., Rotondo, J. L., Xu, M., & King, K. (2002). Windowed cross-correlation and peak picking for the analysis of variability in the association between behavioral time series. *Psychological methods*, 7(3), 338.
- Bourgeois-Bougrine, S., Bonnardel, N., Burkhardt, J. M., Thornhill-Miller, B., Pahlavan, F., Buisine, S., ... & Lubart, T. (2022). Immersive Virtual Environments' Impact on Individual and Collective Creativity. *European Psychologist*.
- Bret, M., Tramus, M. H., & Berthoz, A. (2015). Creation no. 2. La Funambule virtuelle, Hybrid. *Revue des arts et médiations humaines*, (2).
- Bryan-Kinns, N., Healey, P. G., & Leach, J. (2007, June). Exploring mutual engagement in creative collaborations. In *Proceedings of the 6th ACM SIGCHI conference on Creativity & cognition* (pp. 223-232).
- Calabrese, C., Lombardi, M., Bollt, E., De Lellis, P., Bardy, B. G., & Di Bernardo, M. (2021). Spontaneous emergence of leadership patterns drives synchronization in complex human networks. *Scientific Reports*, 11(1), 18379.
- Chang, A., Kragness, H. E., Livingstone, S. R., Bosnyak, D. J., & Trainor, L. J. (2019). Body sway reflects joint emotional expression in music ensemble performance. *Scientific reports*, 9(1), 205.
- Chauvigné, L. A., Belyk, M., & Brown, S. (2018). Taking two to tango: fMRI analysis of improvised joint action with physical contact. *PLoS One*, 13(1), e0191098.
- Cinelli, M., Morales, G. D. F., Galeazzi, A., Quattrocioni, W., & Starnini, M. (2020). Echo chambers on social media: A comparative analysis. *arXiv preprint arXiv:2004.09603*.
- Corazza, G. E. (2016). Potential originality and effectiveness: The dynamic definition of creativity. *Creativity research journal*, 28(3), 258-267.

Cui, D., & Mousas, C. (2022, December). Evaluating the sense of embodiment through out-of-body experience and tactile feedback. In *Proceedings of the 18th ACM SIGGRAPH International Conference on Virtual-Reality Continuum and its Applications in Industry* (pp. 1-7).

De Jaegher, H., & Di Paolo, E. (2007). Participatory sense-making: An enactive approach to social cognition. *Phenomenology and the cognitive sciences*, 6, 485-507.

de la Rosa, Stephan, and Martin Breidt. "Virtual reality: A new track in psychological research." *British Journal of Psychology* 109.3 (2018): 427-430.

Döllinger, N., Wolf, E., Botsch, M., Latoschik, M. E., & Wienrich, C. (2023, April). Are embodied avatars harmful to our self-experience? the impact of virtual embodiment on body awareness. In *Proceedings of the 2023 CHI conference on human factors in computing systems* (pp. 1-14).

Fairhurst, M. T., Janata, P., & Keller, P. E. (2014). Leading the follower: an fMRI investigation of dynamic cooperativity and leader–follower strategies in synchronization with an adaptive virtual partner. *Neuroimage*, 84, 688-697.

Fribourg, R., Ogawa, N., Hoyet, L., Argelaguet, F., Narumi, T., Hirose, M., & Lécuyer, A. (2020). Virtual co-embodiment: evaluation of the sense of agency while sharing the control of a virtual body among two individuals. *IEEE Transactions on Visualization and Computer Graphics*, 27(10), 4023-4038.

Gabora, L. (2017). Honing theory: A complex systems framework for creativity. *Nonlinear Dynamics, Psychology, and Life Sciences*. 21(1), 35-88.

Gentry, S., & Feron, E. (2004, October). Musicality experiments in lead and follow dance. In *2004 IEEE International Conference on Systems, Man and Cybernetics (IEEE Cat. No. 04CH37583)* (Vol. 1, pp. 984-988). IEEE.

Glăveanu, V. P. (2012). Habitual creativity: Revising habit, reconceptualizing creativity. *Review of general psychology*, 16(1), 78-92.

Godard, Hubert. "Gesture and its Perception." *Writings on dance* 22 (2004).

Gueugnon, M., Salesse, R. N., Coste, A., Zhao, Z., Bardy, B. G., & Marin, L. (2016). Postural coordination during socio-motor improvisation. *Frontiers in psychology*, 7, 1168.

Hagiwara, T., Sugimoto, M., Inami, M., & Kitazaki, M. (2019, March). Shared body by action integration of two persons: Body ownership, sense of agency and task performance. In *2019 IEEE conference on virtual reality and 3d user interfaces (vr)* (pp. 954-955). IEEE.

Hale, J., Ward, J. A., Buccheri, F., Oliver, D., & Hamilton, A. F. D. C. (2020). Are you on my wavelength? Interpersonal coordination in dyadic conversations. *Journal of nonverbal behavior*, 44, 63-83.

Hall, Karlee J., Karen Van Ooteghem, and William E. McIlroy. "Emotional state as a modulator of autonomic and somatic nervous system activity in postural control: a review." *Frontiers in neurology* 14 (2023): 1188799.

Hart, Y., Mayo, A. E., Mayo, R., Rozenkrantz, L., Tendler, A., Alon, U., & Noy, L. (2017). Creative foraging: An experimental paradigm for studying exploration and discovery. *PloS one*, 12(8), e0182133.

- Hartmann, M., Carlson, E., Mavrolampados, A., Burger, B., & Toiviainen, P. (2023). Postural and gestural synchronization, sequential imitation, and mirroring predict perceived coupling of dancing dyads. *Cognitive Science*, 47(4), e13281
- He, Z., Du, R., & Perlin, K. (2020, November). Collabovr: A reconfigurable framework for creative collaboration in virtual reality. In 2020 IEEE International Symposium on Mixed and Augmented Reality (ISMAR) (pp. 542-554). IEEE.
- Hilt, P. M., Badino, L., D'Ausilio, A., Volpe, G., Tokay, S., Fadiga, L., & Camurri, A. (2019). Multi-layer adaptation of group coordination in musical ensembles. *Scientific reports*, 9(1), 5854.
- Himberg, T., Laroche, J., Bigé, R., Buchkowski, M., & Bachrach, A. (2018). Coordinated interpersonal behaviour in collective dance improvisation: the aesthetics of kinaesthetic togetherness. *Behavioral Sciences*, 8(2), 23.
- Ishigaki, Tomoya, et al. "Characteristics of postural control during fixed light-touch and interpersonal light-touch contact and the involvement of interpersonal postural coordination." *Human Movement Science* 81 (2022): 102909.
- Ishigaki, T., Imai, R., & Morioka, S. (2017). Association between unintentional interpersonal postural coordination produced by interpersonal light touch and the intensity of social relationship. *Frontiers in Psychology*, 8, 1993.
- Kalaydjian, J., Laroche, J., Noy, L., & Bachrach, A. (2022, December). A distributed model of collective creativity in free play. In *Frontiers in Education* (Vol. 7, p. 902251). Frontiers Media SA.
- Kim, C. S., Jung, M., Kim, S. Y., & Kim, K. (2020). Controlling the sense of embodiment for virtual avatar applications: methods and empirical study. *JMIR Serious Games*, 8(3), e21879.
- Kimmel, M., Hristova, D., & Kussmaul, K. (2018). Sources of embodied creativity: interactivity and ideation in contact improvisation. *Behavioral Sciences*, 8(6), 52.
- Konvalinka, I., Vuust, P., Roepstorff, A., & Frith, C. D. (2010). Follow you, follow me: continuous mutual prediction and adaptation in joint tapping. *Quarterly journal of experimental psychology*, 63(11), 2220-2230.
- Laroche, J., & Kaddouch, I. (2014). Enacting teaching and learning in the interaction process: "Keys" for developing skills in piano lessons through four-hand improvisations. *Journal of Pedagogy*, 5(1), 24-47.
- Laroche, J., & Kaddouch, I. (2015). Spontaneous preferences and core tastes: embodied musical personality and dynamics of interaction in a pedagogical method of improvisation. *Frontiers in psychology*, 6, 522.
- Laroche, J., Tomassini, A., Volpe, G., Camurri, A., Fadiga, L., & D'Ausilio, A. (2022). Interpersonal sensorimotor communication shapes intrapersonal coordination in a musical ensemble. *Frontiers in human neuroscience*, 16, 899676.
- Laroche, J., Vuarnesson, L., Endaltseva, A., Dumit, J., & Bachrach, A. (2021). [Re] moving Bodies—A Shared Diminished Reality Installation for Exploring Relational Movement. *Frontiers in Psychology*, 12, 539596.
- Laroche, J., Bachrach, A., & Noy, L. (2024). De-sync: disruption of synchronization as a key factor in individual and collective creative processes. *BMC neuroscience*, 25(1), 67.

- Loehr, J. D. (2022). The sense of agency in joint action: An integrative review. *Psychonomic Bulletin & Review*, 29(4), 1089-1117.
- Lombardi, M., Warren, W. H., & di Bernardo, M. (2020). Nonverbal leadership emergence in walking groups. *Scientific reports*, 10(1), 18948.
- Manuri, F., Sacco, L., De Pace, F., Sanna, A., & Kaufmann, H. (2024, September). A preliminary study of a co-embodiment approach for welding training. In *2024 IEEE 18th International Conference on Application of Information and Communication Technologies (AICT)* (pp. 1-6). IEEE.
- Men, Liang & Bryan-Kinns, Nick & Bryce, Louise. (2019). Designing spaces to support collaborative creativity in shared virtual environments. *PeerJ. Computer science*. 5. e229. 10.7717/peerj-cs.229.
- Noy, L., Dekel, E., & Alon, U. (2011). The mirror game as a paradigm for studying the dynamics of two people improvising motion together. *Proceedings of the National Academy of Sciences*, 108(52), 20947-20952.
- Padrao, G., Gonzalez-Franco, M., Sanchez-Vives, M. V., Slater, M., & Rodriguez-Fornells, A. (2016). Violating body movement semantics: Neural signatures of self-generated and external-generated errors. *Neuroimage*, 124, 147-156.
- Petkova, V. I., & Ehrsson, H. H. (2008). If I were you: perceptual illusion of body swapping. *PloS one*, 3(12), e3832.
- Pinkl, J., & Cohen, M. (2023). VR Drumming Pedagogy: Action Observation, Virtual Co-Embodiment, and Development of Drumming “Halvatar”. *Electronics*, 12(17), 3708.
- Podkosova, I., & Brument, H. (2024, March). Towards Full Body Co-Embodiment of Human and Non-Human Avatars in Virtual Reality. In *2024 IEEE Conference on Virtual Reality and 3D User Interfaces Abstracts and Workshops (VRW)* (pp. 432-435). IEEE.
- Saint-Germier, P., Goupil, L., Rouvier, G., Schwarz, D., & Canonne, C. (2024). What it is like to improvise together? Investigating the phenomenology of joint action through improvised musical performance. *Phenomenology and the Cognitive Sciences*, 23(3), 573-597.
- Salmela, M. (2021). Joint improvisation as interaction ritual. In *Philosophy of Improvisation* (pp. 122-139). Routledge.
- Sawyer, K. (2014). Group creativity: Musical performance and collaboration. In *The Improvisation Studies Reader* (pp. 87-100). Routledge.
- Schroeder, F., Samuels, K., & Caines, R. (2019). Music improvisation and social inclusion. *Contemporary Music Review*, 38(5), 441-445.
- Shockley, K., Santana, M. V., & Fowler, C. A. (2003). Mutual interpersonal postural constraints are involved in cooperative conversation. *Journal of Experimental Psychology: Human Perception and Performance*, 29(2), 326.
- Slater, M., Spanlang, B., Sanchez-Vives, M. V., & Blanke, O. (2010). First person experience of body transfer in virtual reality. *PloS one*, 5(5), e10564.
- Stephen, D. G., & Dixon, J. A. (2009). The self-organization of insight: Entropy and power laws in problem solving. *Journal of Problem Solving*, 2(1), 72-102.

- Stephen, D. G., Dixon, J. A., & Isenhower, R. W. (2009). Dynamics of representational change: entropy, action, and cognition. *Journal of Experimental Psychology: Human Perception and Performance*, 35(6), 1811.
- Terren, L. T. L., & Borge-Bravo, R. B. B. R. (2021). Echo chambers on social media: A systematic review of the literature. *Review of Communication Research*, 9.
- Thommes, M., Uitdewilligen, S., Rico, R., & Waller, M. J. (2020). Adaptive Followership in a Dynamic Context: Examining the Effect of Entrainment to a Previous Leader. In *Academy of Management Proceedings* (Vol. 2020, No. 1, p. 16516). Briarcliff Manor, NY 10510: Academy of Management.
- Torrents, C., Castañer, M., Dinušová, M., & Anguera, M. T. (2010). Discovering new ways of moving: Observational analysis of motor creativity while dancing contact improvisation and the influence of the partner. *The Journal of Creative Behavior*, 44(1), 53-69.
- Varlet, M., Marin, L., Lagarde, J., & Bardy, B. G. (2011). Social postural coordination. *Journal of Experimental Psychology: Human Perception and Performance*, 37(2), 473.
- Vuarnesson, L., Zamplaras, D., Laroche, J., Dumit, J., Lutes, C., Bachrach, A., & Garnier, F. (2021). Shared Diminished Reality: a new VR framework for the study of embodied intersubjectivity. *Frontiers in Virtual Reality*, 2, 646930.
- Whitehead, P. M., De Jaegher, H., Santana, I., Todd, R. M., & Blain-Moraes, S. (2024). Capturing spontaneous interactivity: a multi-measure approach to analyzing the dynamics of interpersonal coordination in dance improvisation. *Frontiers in Psychology*, 15, 1465595.
- Yee, N., and Bailenson, J. (2007). The proteus Effect: The Effect of Transformed Self-Representation on Behavior. *Hum. Comm Res* 33 (3), 271–290. doi:10.1111/j.1468-2958.2007.00299.x

7. END

LEFT OVERS / REMOVED etc...

HI VX LO : POUR EXPLIQUER FIGURES

First, we constituted 2 sub-groups of participants according to their self-reported experience of self-other agency confusion: HI and LO. In total, 12 participants reported being not or very poorly confused in terms of self-other agency (i.e., they responded 0 or 1 to the related item) and 5 participants felt rather highly confused (i.e., they responded 5 or 6 to the related item). Interestingly, all 5 participants who were highly confused were coupled with a partner who did not feel confused (or, in one case, expressed a neutral opinion). In other words, those who had difficulties distinguishing the effect of self and others' movement on the spheres all had partners who yet did not experience that confusion. As such, confusion was an individual experience that was poorly shared across coupled partners, who seemed to have a different perspective on the question. This might be related to the facts that partners might have enacted different kinds of movement patterns or to asymmetries in coordination within the dyad / differences at the relational level [*not sure/decided on what belong to discussion and aht belong to motivation of following analyses*].

literature on virtual co-embodiment :

From extended abstract:

In this paper we proposed the YUMI model, a novel conceptualization of the conditions for the enhancement of creativity through interaction. This model ties creativity to the blending (but not fusion) of the sense of agency of the interacting participants. We suggested that IDMI is an optimal setup to explore this model and its consequences for interaction design. We presented the Median, a SDR setup that makes use of a single avatar controlled by two interacting movers, and some qualitative and quantitative results from a pilot study of this setup. The results provide support for the YUMI model as they point out a relationship, both in the subjective reports and in movement parameters, between the sense of blended agency and creative behavior. These results also point out the potential of the Median setup (or variations on it) for the enhancement of creativity and improvisational thinking/moving.

Shared diminished reality allows us to create conditions for collaborative creative movement without direct access to our partners actions, choices, state of mind (one step further than having two musicians play in different rooms, Canonne): different degrees apply to different cases, median being one strong case, and the one we chose: *Et colle avec Yumi Hypothèse : la y a variabilité et tout le monde pas autant confus avec notre dispositif*

Pour amener a crea, faut amener dispositif numérique, comment amener chaque personne a point de confusion optimale...

Stuff from the paper:

Previous source of text

Building on the idea of the Self-avatar Follower Effect, Fribourg et al. (2020) propose studying the circumstances under which two users can share an avatar and experience a sense of agency (SoA) over co-produced movements. They introduce a fluctuating degree of control in their system, alternately given to one or the other participant, allowing them to show that SoA is positively correlated with the degree of control over the avatar, and is also influenced by the level of freedom given to users for performing actions.

The authors also show a negative correlation between locus of control and how users feel in control, suggesting that this subjective sense of control over a shared avatar may be influenced by personality traits. They further observe that it is possible to have a sense of agency even without control over the avatar, as long as participants share a common idea beforehand on how to perform a task.

In Hagiwara et al. (2020), the authors demonstrate through a similar paradigm that when two individuals share an avatar, they tend to make smoother movements with less jerk and opt for more direct trajectories, displaying a reduced reaction time compared to when they control their avatar individually. Co-embodiment thus appears to encourage the search for consensus, the only way to achieve task completion.

These various studies illustrate how spatial mediation enables navigation within the locus of control, affecting how individuals can accept being influenced and guided in their actions while maintaining a sense of agency. They also show how, through embodiment in an avatar, dynamic alteration of this control level can directly impact the action strategies developed by co-immersed participants.

However, we can observe that these studies limit actions to simple tasks (grasping, moving toward a target, etc.). Although observed trends suggest that co-embodiment could encourage coordination, they do not provide a clear view of how these techniques might influence activities involving shared creativity.

Evidence for YUMI:

Kaddouch method

Experience from duo dances (e.g.tango) where there is a sense of a thirdness

Experience from collective music improvisation

The creativity paper in CI

Co-confident motion and the sense of togetherness in the mirror game

From VR literature:

Following/synchronizing with one's own avatar in virtual co-embodiment

Sacheli et al (meta-analysis of joint action): we have explicit and implicit sense of agency for actions taken by a partner

The absence of a prescribed goal (either shared or individual) or a task to complete has a number of consequences:

- a) There is no clear optimization strategy either for the participant nor for the experimenter to evaluate the impact of the shared embodiment
- b) The illusion of agency due to the correspondence between intention and (non-controlled) movement of the avatar is less probable and harder to assess for the experimenter.
- c) Conversely, participants rarely have evoke a sense of competition about the control over the avatar. Rather, it induces a feeling of co-action / collaboration.
- d)
- e) Participants are invited to freely improvise and so (among other things) potentially generate new sequences of movement. [*can integrate some bit of:*] The lack of prescribed task allows the user and the experimenter access to the dynamics of real time interactive creativity, similar to the ones we explore in dance or music improvisation.

CATEGORIES PROPOSITION PLAN:

- **Validation de l'expérience**

ADHESION / quality of experience

EMBODIMENT

QUALITY OF INTERACTION

CREATIVITY

- **Validation du concept**

CO-EMBODIMENT

AGENCY

Adhésion (au dispositif, a la tache, à l'environnement VR):

Espace seduisant (plutot positif)

Aimé que dure plus longtemps: distribué, balance positive

Embodiment

Environnement + tache: élément m'ont extrait... (plutot pas)

Légereté: balance positive

Hors de mon corps: quite distributed

davantage que moi: distribué, minorité positive cependant, du coup intéressant

Mvt Plus fluides que d'habitude: pas beaucoup

Créativité:

Limitait mes mouvements: plutot oui (du coup intéressant de voir ceux pour qui non)

Crea amplifié : balance positive (intéressant en contraste de mouvement limités)

Curiosité

Quality of interaction

Connexion avec sphere facile: très distribué

Danse ensemble: très positif

Etre compris: bien positif

Agentivité:

Effet sur sphere

Effet partenaire sur sphere

Effet de moi sur sphere: très positif

Co-embodiment ?

**Agency:
confusion**

Results:

Some of them taken out / out of scope

Those with Less self-other distinction;:

tend to feel less self-agency across episodes (trend)

Tend to follow the partner and not lead them (those who distinguish well = less following more leading), hard to catch with indices (small trend with hands for following, difference between leading and following score = almost significant for hands)

Tend to move less than their partner (trend for head, significant for hands)

Share more mutual information with their partner across a wide range of windows, head like hands

Had partners who tended to move faster than the partners of those who distinguished self-other well, and more predictably.

////////////////////////////////////

Extended abstract:

1) Immersive Digitally Mediated Interactions (intro)

Digitally mediated interactions (DMI), mainly via smartphones and other haptic devices, are by now integral to our daily life, professionally, personally and in a variety of artistic activities. However, Immersive DMI (IDMI), such as the one offered by shared Virtual Reality platforms (e.g. Meta's metaverse), has not yet become as omnipresent as it has been projected to. Here we are particularly interested in how IDMI can shape our individual and collective creativity. To what extent these tools-spaces offer novel avenues for collaborative creativity? And what can they teach us about the nature of creative agency, the ability to guide our behavior in novel ways and/or toward novel outcomes?

2) Virtual co-embodiment

Most research on interaction between persons in virtual reality has focused on situations where two or more participants are embodied (within VR) as separate avatars. On the other hand, over the past 5 years or so, a subfield of IDMI has started to explore more systematically virtual co-embodiment: VR setups where participants share (control over) the same avatar (Fribourg et al., 2020). Virtual co-embodiment pushes the limits of earlier IDMI research and design as it makes use of VR not in order to replicate analog interactions (e.g., how to make a virtual video chat more real life like), but instead to create forms of interaction that are not possible, or at least are much less obvious, in 'real' life (such as sharing a control on one's hand with another person). Research in or with co-embodied IDMI invents and implements the forms of interaction it intends to study and at the same time questions our common sense notions of body ownership and individual agency (i.e., the control and authorship of the actions that body carries out). Virtual co-embodiment dialogues with earlier research and design installations in VR which manipulated point of view (e.g. seeing the interaction from the point of view of another (Petkova & Ehrsson, 2008; Slater et al., 2010) or offered new forms of interaction, where systems were partially fed with, and were reacting to, the user's movement (*La Funambule Virtuelle*, Bret et al., 2015). Beyond VR research-design, virtual co-embodiment touches on a number of questions that have arisen in behavioral sciences, in particular in the "joint action" literature, regarding self vs. other agency and collective agency (Loehr, 2022).

3) Creative interactions in absence of script and goal

Existing research into with virtual co-embodiment offers new insights into agency and body ownership, and exciting perspectives into ways in which IDMI can be used, such as in teaching new sensorimotor patterns to a novice (Pinkl & Cohen, 2023). Paradoxically, despite virtual co-embodiment's use of novel technologies that allows unprecedented behaviors and experiences, the question of creative agency, and more specifically the potential of IDMI for fostering collaborative creativity, has not been addressed. We note two features of this approach that hinder potential research into these issues. The first is the use of 'first person' avatars that frame the participant's experience and the researcher's focus on the individual level, and the second is the issue of body ownership. The latter, which derives from the attempt to create or manipulate a sense of body ownership, is the use of highly scripted and goal oriented tasks, which leaves very little room for creative behavior and its study.

In this paper, we report on a research-design project that expands on the virtual co-embodiment literature to address the question of collaborative creativity during unscripted interactions. The novel approach we propose shifts from the use of 'first person' realistic avatars to avatars that embody the *product* of the interaction as a fictional partner (i.e., the perceptible avatar combines information from the different partners). Unlike the existing literature, the avatar is not designed to resemble, or to extend, the participant's body (see Vuarnesson et al., 2021; Laroche et al., 2021). Moreover, it makes use of open-ended, improvisational tasks that are better suited for the exploration of creative agency in collaborative contexts.

4) The YUMI model

To guide our research on creative interaction, we offer a theoretical perspective that we name YUMI ('you'-'me'), and which draws from our own research in creative pedagogy (Laroche & Kaddouch, 2014, 2015), IDMI design (Vuarnesson et al., 2021) and collective improvisation (Himberg et al 2018), existing literature in

joint action, as well as our own experience in different improvisational practices. The central insight behind YUMI is that creativity is enhanced during interaction where the boundary between our own contribution and the contribution of others to a shared outcome is partially blurred (but does not disappear). Specifically, this model holds that being able to recognize the impact of our own actions (movement, sound, visual traces...) while being uncertain about the exact nature of that impact invites us to break away from our most spontaneous and habitual behavioral tendencies and motivates the exploration of new behavioral possibilities. A variety of creative interactions seem to be conducive to such states, for example being in the ‘zone’ during a jazz improvisation (Sawyer, 2003), or when an unexpected sequence of actions is produced during a Contact Improvisation dance duet (Torrents et al., 2010; Kimmel et al., 2018). However, generating such states or manipulating them experimentally is not straightforward (Himberg et al 2018). To overcome these issues, we designed and tested a specific instantiation of shared VR, which, by allowing participants to experience, and researchers to experiment on, YUMI dynamics, holds the potential to study and eventually enhance collaborative creativity.

5) The median: YUMI in VR [5 + 6 = SET-UP, then TECHNICAL ASPECTS and METHODO PROTOCOL]

To focus participants on the interactive and shared nature of their agency, we developed a novel dyadic VR protocol we name ‘the median’. In this protocol, as in other existing virtual co-embodiment protocols, participants do not receive direct visual feedback of their own motion, nor that of the partner. Instead, participants interact with an avatar that combines their own movement information with that of their partner. Participants can thus recognize that their own movement contributes to the movement of the avatar, but because they cannot disentangle it from their partner’s, they can neither fully appreciate the extent of that contribution, nor can they fully predict the effects their ongoing motion will have on the avatar.

This novel protocol differs from those employed in the canonical virtual co-embodiment literature in a number of ways. First, the shared avatar is not materialized or spatialized as a plausible homologue or extension of the participant’s body but rather as a partner situated at a distance. Compared to more canonical forms of virtual co-embodiment, this shifts the focus of inquiry from body ownership effects (and the risk of the participants experiencing a body semantic violation; see Padrao et al., 2016) to the relation between self and other agency. Second, we do not prescribe particular actions to the participants but rather let them freely improvise and explore what the set-up affords. The absence of a prescribed goal (either shared or individual) prevents participants from having a sense of competition (about the control over the avatar or the task at all). Rather, it focuses them on their experience of the process of interaction, and on their collaborative generation of novel movement sequences or combinations. Moreover, it brings forth a creative product (the improvised performance materialized by the Median) that coincides in time with the processes of creation (the co-movement of the partner) that can be captured and analyzed. The Median set-up thus grants both the user and the experimenter access to the dynamics of real time interactive creativity. As such, it is particularly well suited for the exploration of the YUMI model of creative interactions.

In this paper, we present the YUMI model and the Median set-up where pairs of participants were invited to experience YUMI dynamics by interacting with/through the avatar. As a proof-of-concept, we present results regarding their reported experience on a user questionnaire, and more focused analyses regarding their feeling of self-other agency distinction in relation with kinematic analyses of their movement.

6) Set up

The VR approach we have previously named Shared Diminished Reality (SDR, Laroche et al. 2021; Vuarnesson et al. 2021) provides a remedy for the complexity inherent in naturalistic group movement improvisation: movement information is reduced to a minimal form, which further focuses partners on their interaction and eases the tracking and the analysis of creative behaviors. As such, this allows ecological validity to coexist with strong experimental control. Building on the principles of Shared Diminished Reality, the ‘median’ is a co-embodied avatar constituted of three spheres situated in the VR space in front of the participant, as if it was a

dance partner. The spheres' motion is generated by the combination of the participants' movement, captured by three body sensors that track their hands positions and head positions (six points in total). Two small spheres are animated respectively by the participants' mirror hands (left hand of dancer 1 and right hand of dancer 2, and vice-versa), while the third sphere is medium-sized and its position is always at the barycenter of the participants' six tracked points. The median dancer thus moves in synchrony with the two dancers, as they both feed the system with their respective movements.

7) Protocol

The experiment took place at the Pouchet center of CNRS in Paris, France. It lasted one week in December 2022. We tested 22 dyads, all having an experience with dance and improvisation. After a phase of relaxation and introduction of the experiment, our participants were placed into two respective zones, equipped with a VR headset and immersed in our minimalist visual paradigm. In the spirit of SDR, they were surrounded by a large arena, topped by an infinite blue sky. Participants were located into two separate physical spaces but shared the same virtual space, allowing them to move freely without the risks of hitting each other. In front of them they could see their median avatar, which moved synchronously with their movements.

The experimenters explained to the participants how the movement of the avatar was generated, and that they were co-controlling it together with the other participant. Once the experiment started, our dancers were asked to perform a series of 10 dance sequences, improvising with the other dancer through the median avatar. During these experiments, the participants' movement was recorded using the VR body sensors. After the 10 sequences were completed, the participants filled an online questionnaire regarding their experience.

8) Results

First, we analyze responses to the post-experiment questionnaire to explore how the Median set-up was experienced by participants. Our key item was the assertion “*Throughout the episodes, I couldn't distinguish my own contribution to the movement of the spheres from that of my partner.*”, which the participants were asked to rate between 0 and 6 (0: totally disagree, 6: totally agree). One particularly interesting result in the context of the YUMI model was a correlation between the ratings of the key item and the feeling of being more than one self during the experience. We focused further investigation on the kinetic characteristics that differentiated participants who found it easy to distinguish the effect of one self and the other on the avatar (low rating of the key item), and those who did not (high rating). Patterned signatures of this distinction were observed: participants reporting parsing self and other contributions poorly moved less than their partner and were following the latter more. Regarding aspects of creativity, they also tended to explore the space more and to produce more complex, less predictable patterns of movement.

9) Discussion

In this paper we proposed the YUMI model, a novel conceptualization of the conditions for the enhancement of creativity through interaction. This model ties creativity to the blending (but not fusion) of the sense of agency of the interacting participants. We suggested that IDMI is an optimal setup to explore this model and its consequences for interaction design. We presented the Median, a SDR setup that makes use of a single avatar controlled by two interacting movers, and some qualitative and quantitative results from a pilot study of this setup. The results provide support for the YUMI model as they point out a relationship, both in the subjective reports and in movement parameters, between the sense of blended agency and creative behavior. These results also point out the potential of the Median setup (or variations on it) for the enhancement of creativity and improvisational thinking/moving.

References

- Bret, M., Tramus, M. H., & Berthoz, A. (2015). Creation no. 2. La Funambule virtuelle, Hybrid. *Revue des arts et médiations humaines*, (2).
- Fribourg, R., Ogawa, N., Hoyet, L., Argelaguet, F., Narumi, T., Hirose, M., & Lécuyer, A. (2020). Virtual co-embodiment: evaluation of the sense of agency while sharing the control of a virtual body among two individuals. *IEEE Transactions on Visualization and Computer Graphics*, 27(10), 4023-4038.
- Himberg, T., Laroche, J., Bigé, R., Buchkowski, M., & Bachrach, A. (2018). Coordinated interpersonal behaviour in collective dance improvisation: the aesthetics of kinaesthetic togetherness. *Behavioral Sciences*, 8(2), 23.
- Kimmel, M., Hristova, D., & Kussmaul, K. (2018). Sources of embodied creativity: interactivity and ideation in contact improvisation. *Behavioral Sciences*, 8(6), 52.
- Laroche, J., & Kaddouch, I. (2014). Enacting teaching and learning in the interaction process: "Keys" for developing skills in piano lessons through four-hand improvisations. *Journal of Pedagogy*, 5(1), 24-47.
- Laroche, J., & Kaddouch, I. (2015). Spontaneous preferences and core tastes: embodied musical personality and dynamics of interaction in a pedagogical method of improvisation. *Frontiers in psychology*, 6, 522.
- Laroche, J., Vuarnesson, L., Endaltseva, A., Dumit, J., & Bachrach, A. (2021). [Re] moving Bodies—A Shared Diminished Reality Installation for Exploring Relational Movement. *Frontiers in Psychology*, 12, 539596.
- Loehr, J. D. (2022). The sense of agency in joint action: An integrative review. *Psychonomic Bulletin & Review*, 29(4), 1089-1117.
- Padrao, G., Gonzalez-Franco, M., Sanchez-Vives, M. V., Slater, M., & Rodriguez-Fornells, A. (2016). Violating body movement semantics: Neural signatures of self-generated and external-generated errors. *Neuroimage*, 124, 147-156.
- Petkova, V. I., & Ehrsson, H. H. (2008). If I were you: perceptual illusion of body swapping. *PloS one*, 3(12), e3832.
- Pinkl, J., & Cohen, M. (2023). VR Drumming Pedagogy: Action Observation, Virtual Co-Embodiment, and Development of Drumming "Halvatar". *Electronics*, 12(17), 3708.
- Sawyer, K. (2014). Group creativity: Musical performance and collaboration. In *The Improvisation Studies Reader* (pp. 87-100). Routledge.
- Slater, M., Spanlang, B., Sanchez-Vives, M. V., & Blanke, O. (2010). First person experience of body transfer in virtual reality. *PloS one*, 5(5), e10564.
- Torrents, C., Castañer, M., Dinušová, M., & Anguera, M. T. (2010). Discovering new ways of moving: Observational analysis of motor creativity while dancing contact improvisation and the influence of the partner. *The Journal of Creative Behavior*, 44(1), 53-69.
- Vuarnesson, L., Zamplaras, D., Laroche, J., Dumit, J., Lutes, C., Bachrach, A., & Garnier, F. (2021). Shared Diminished Reality: a new VR framework for the study of embodied intersubjectivity. *Frontiers in Virtual Reality*, 2, 646930.

3.3 Resultats VERBAL REPORTS

L'engagement

D1- J'ai jamais trouvé ça ennuyeux, on était assez connectées

D7 - très ludique mais assez frustrant, des fois ça répondait bien mais des fois pas du tout

D12 - Je me suis jamais ennuyé

Une énigme

D3

- On trouve la connexion au moment où on arrête de se concentrer
- Des fois je confondais ce qui était le mélange et ce qui était l'autre

D5

- i'm supposed to be connected to thomas or to me ? who am i connected to ?

D21 - des fois je me disais mais enfin est-ce que je danse avec moi même ou avec quelqu'un d'autre ?

Des stratégies et des adaptations

D7 - quand j'avais moins de contrôle je changeais mes gestes ou je la laissais faire

D10 - il y avait toujours un moment d'écoute au début pour voir à quel point ça répondait

D12

- j'essayais de copier le mouvement qu'en même temps je faisais, c'était difficile / j'essayais plein de choses pour voir ce que je contrôlais vraiment

D13

- je testais plein de choses
- j'ai jamais suivi les boules, j'ai toujours essayé de changer leur comportement

D14

plutôt que dans une improvisation libre, je me retrouvais plutôt à chercher à comprendre comment fonctionnait l'interaction

Qualité de la relation / La relation à l'autre

D15

- je suis bien avec toi, je te connais pas du tout et j'ai l'impression de te connaître / c'est trop bizarre de pas te voir surtout
- on vient pas du même monde mais on était en symbiose

D12 - En revisionnant après je me rend compte qu'il y avait encore plus de relation que ce que je vivais sur le moment

D17

- c'est intéressant car j'avais deux partenaires différents, mon sens visuel était avec l'un, et mes sens de l'audition était avec l'autre

D19

- sometimes i was dancing because i felt like it, sometimes i was interacting with them
- at a point I was so focused on the balls, I suddenly remembered that I had a partner to dance with, and it changed my approach
- I will project myself on Manuel, but it's not him
- you asked « were you influenced by the spheres », and it depends because it was a choice, sometimes i would say i'm just gonna dance, i don't care, sometimes i will really focus, and i'll dance according to that

D20 - je trouvais ça émouvant certains moments on atteignait une plénitude, quand je leadais c'était plus reposant mais plus ennuyeux

D9 - à des moments je me disais oh ok il y a vraiment un Flow alors qu'en fait pas du tout tu ne faisais rien

Sur le dispositif

D15

- c'est un super espace de rencontre
- ça pousse à aller dans du mouvement qui n'est pas le nôtre

D22 - les sphères vertes comme un espace commun d'improvisation

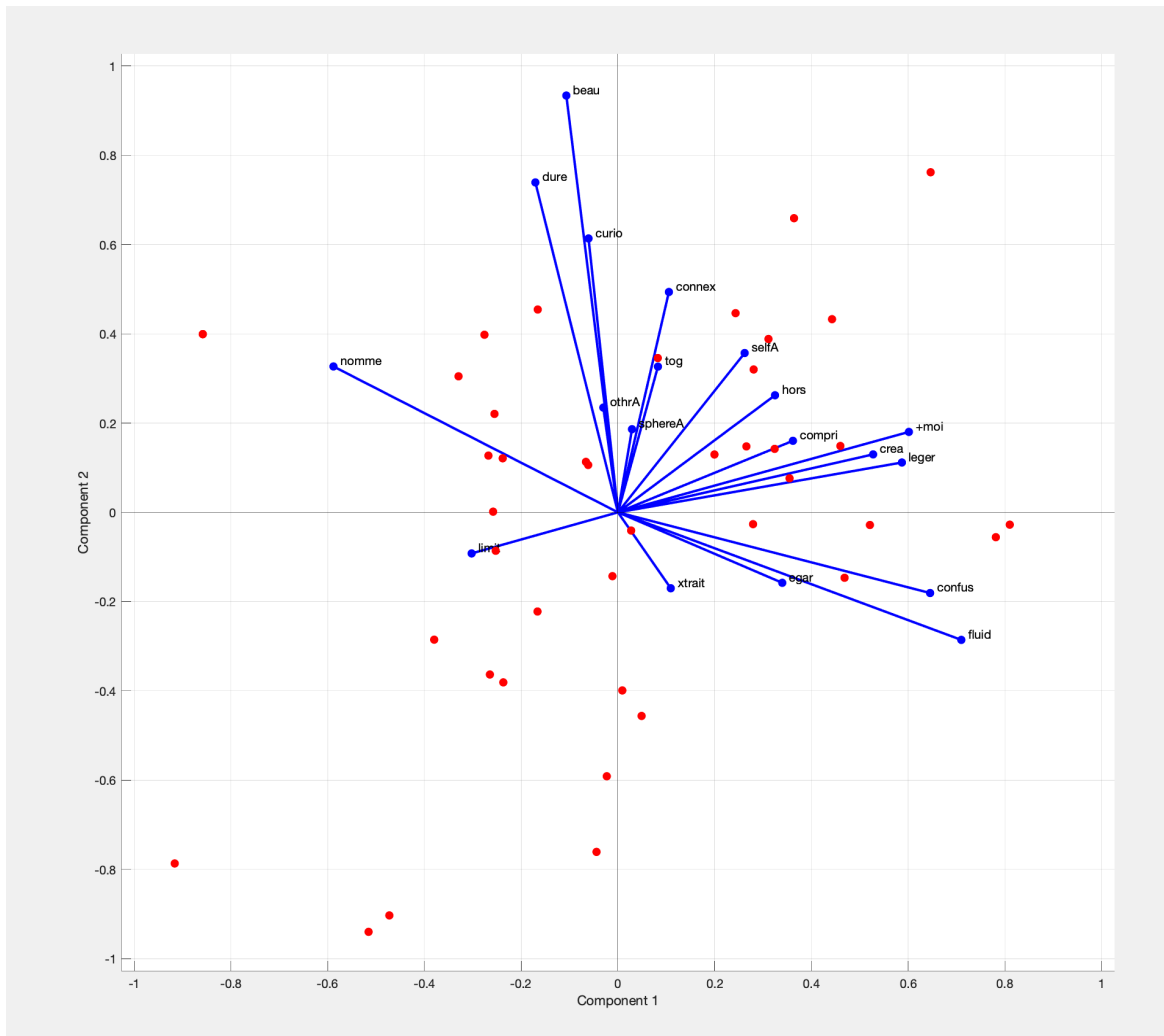
Self-reflection

D15

- humainement très enrichissant, on s'est pas vu, on se voit toujours pas
- ça questionne beaucoup, on se touchera jamais mais on peut quand même se rencontrer, le contact m'a manqué
- ça permet de se rencontrer sans les préjugés, sans se dire alala elle est bizarre quand elle bouge / on se rencontre par les dynamiques, grand petit proche loin

D17 - empathie, individualité mimétisme, questions relationnelles vis à vis du rapport avec l'autre, la distance juste pour rester en lien

3.2 Factor Analysis



Horizontal: on va de YOU (et environnement externe) à moi et plus que moi: dissolution / flow - absence subjectivisation
 Comp2: valence

N'EST PLUS PERTINENT POUR NOTRE PLAN ACTUEL:

7. [ASAF] How to engage participants in post-experience reports that can help point out specific moments or events in the experience (temporally dense reports)? This kind of data is necessary for cross-modal /perspective (1 and 3rd person) integration as well as for a more fine study of interpersonal dynamics?

8. [ASAF] Canonne et al example

9. [LOUP] Our version of Canonne with the innovation of creating an immersive viewing apparatus: 3 stage viewing and annotation (also innovant)

10. [JULIEN] Results from the two annotation series:

Globally replicating some stats from canonne et al

Own words produce more annotations than given terms (confound of order)

To do Julien: regarde si plus de mot ou de changement ou de durée entre mots perso et mots canonne

After manual classification of terms: a nuanced version of Canonne's results (splitting 'with' to 'leading' and 'following')

Other results? Corrélation entre mots et reponses questionnaire, corrélation avec mouvement (voir canonne: qom, cross correlation, histogrammes)

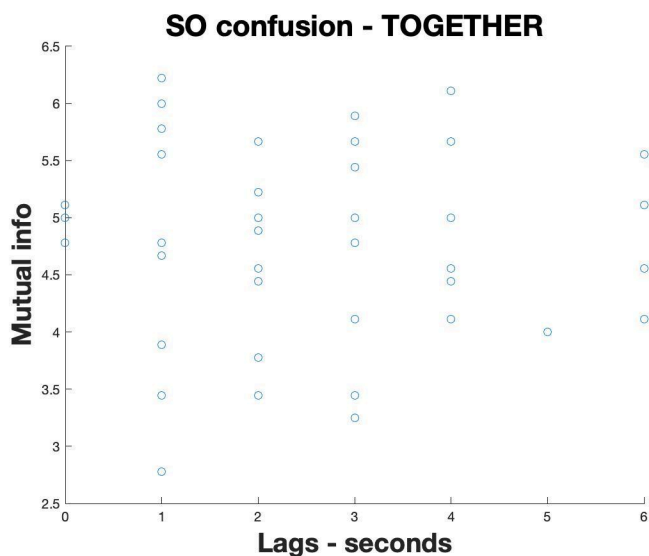
STUFFS TO READ

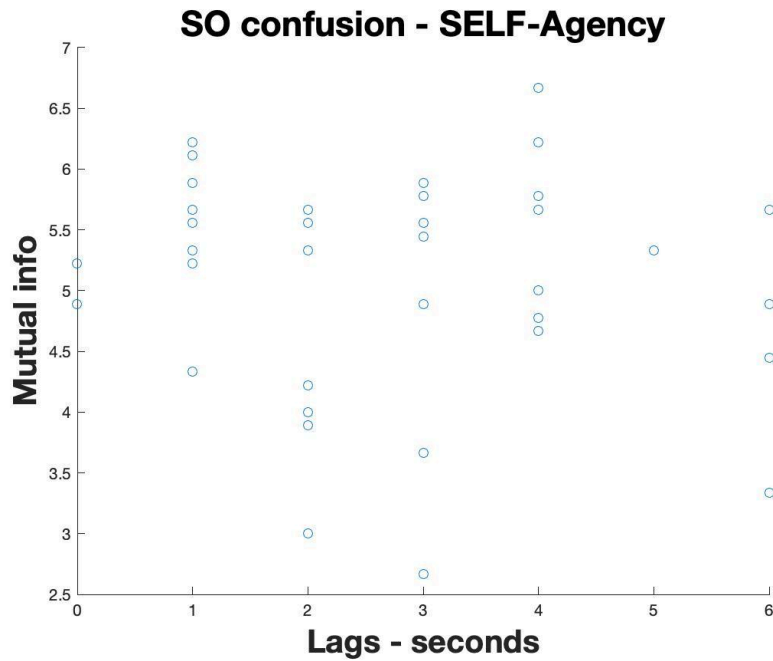
<https://www.sciencedirect.com/science/article/pii/S0001691822002736>

EX STUFFS RESULTS ETC

// **question en francais:**

A travers les épisodes, je n'arrivais pas à distinguer ma propre contribution au mouvement des sphères de celle de mon partenaire.





Mutual info = Self agency
 $X / \text{Lags} = \text{confusion self other}$

Chercher relations entre SO confusion et self agency:

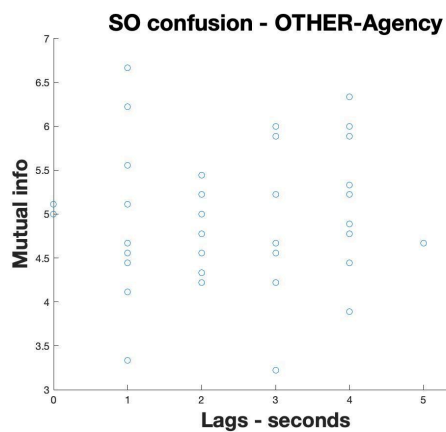
PCA

space exploration / Moved less

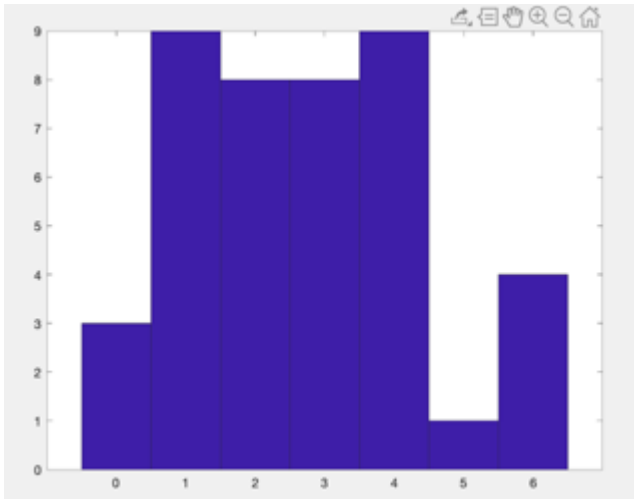
follow more

Score combinés: $(X+Y)*(XY)$

Visualization avec couleur pour créativité et garde la 2D pour les autres.



//////// ancienne exploration résultats:



Can do 3 groups or just look at extremes: those who clear experience, 0-1 vs 5-6

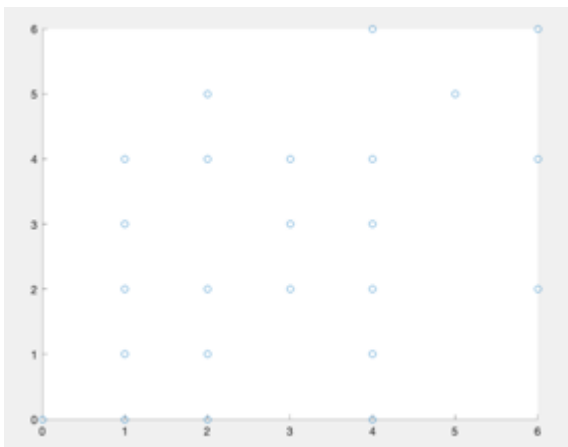
Correlation avec Q10: plus que moi

$r=.57, p=.00008$

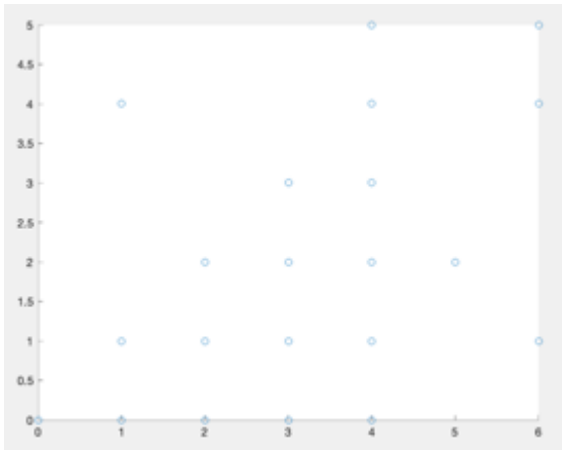
Q17: dérouté:

$r=.47, p=.0017$

Q10:



Q17:



DISTER = those who answered negatively (so they could distinguish), n=12
 NODIST = those who responses positively (they could not distinguish, n = 5

All DISTER but one responds negatively to Q10 except one 4 and one 3, seven for 0
 All NODIST but one responded positively except one: 2

All DISTER responded negatively to Q17 except one (4), eight 0 and 3 one
 All NODIST responded differently: 5 1 2 4 1

The four who responded 5 or 6 to Q10 (more than myself) 4 5 6 2 to Q20 (not distinguish others)

DISTER: 2 6oaires

Pratique danse: DISTER 3.6, NODIST: 2.6, NS

Element extrait de VR: un peu plus pour NODIST mais pas clair pour tous. 2 répondent 0 sur 5...

NODIST: mvt plus fluide. Mais pas hyper clair pour les DIST: NS

NODIST: maybe more freedom but NS

NODIST: crea amplifié +: significatif que contre ceux du milieu

DIST: more self-agency overall , trend: significatif pour 66/33 = qund beaucoup plus de controle, sentent moins agentivité que les DISTER

Et en 33-33, DISTER sentent plus influencé s par balle

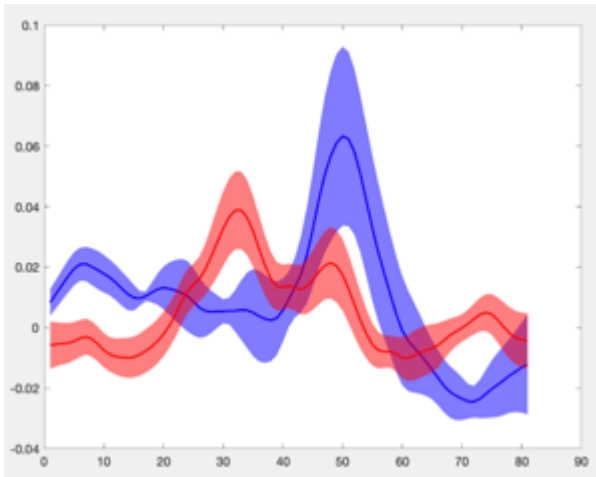
toether: 33-66 et 50-50: NODIST se sentent plus ensemble avec ce déséquilibre 33-66, et moins a 50-50

Other agency: 33-50 et 66-66: moins pour nodister..

Tous les NODIST: ont des partenaires qui votait entre 0 et 3.

⇒ CHECK if this means no distinguisher have more variable behaviors...

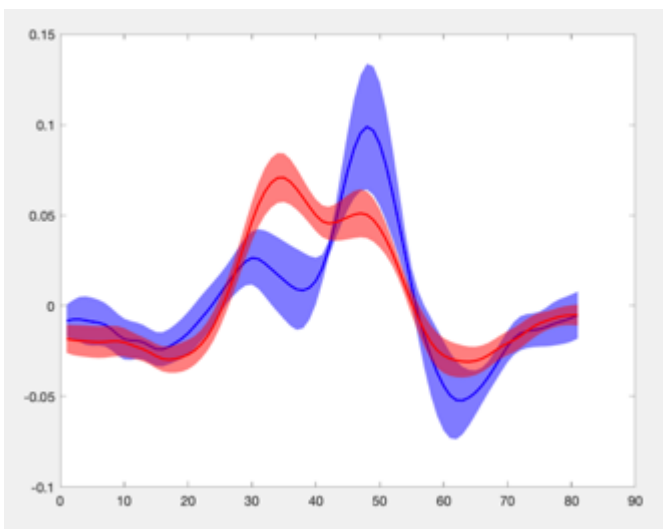
XCORR: **mains**



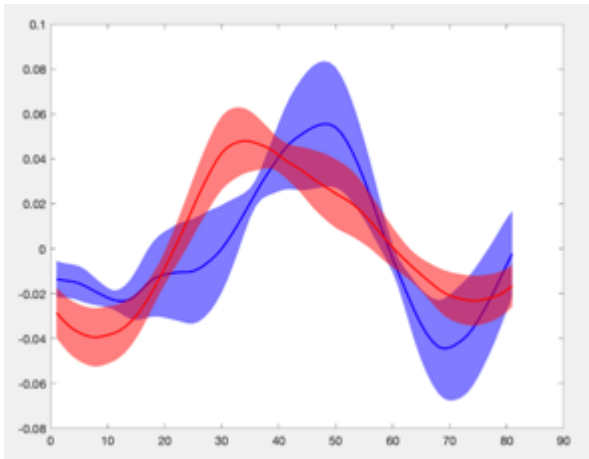
⇒ en relation avec un résultat co-embodiment

NODIST followers: 4/5

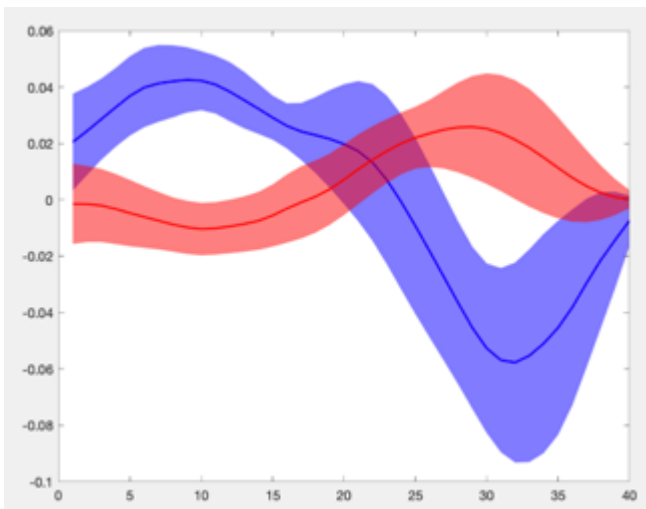
DIST: lead more, follow less



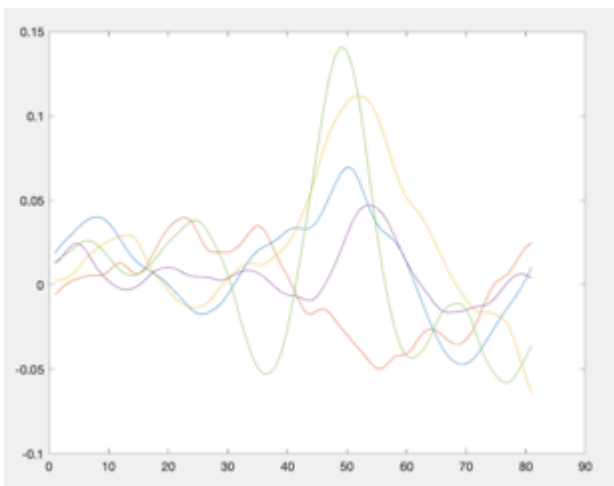
Bit same for head Y et Z



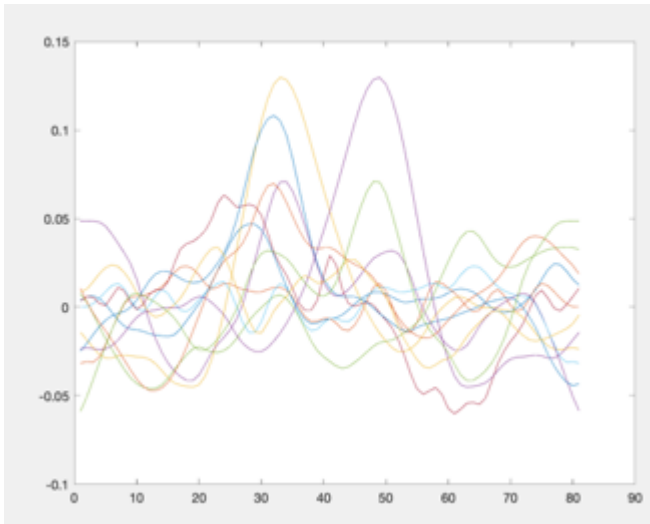
MAINS difference leader-follower



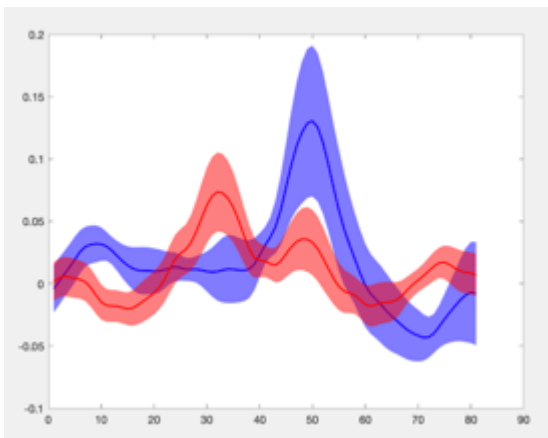
NODISTER:



DISTER:



Ajoute mains + tete



////////////////// NEW QUESTIONS ////////////////////

1) Cross two variables:

- 1) Level of agential confusion (from final questionnaire)
- 2) Level of over all felt agency (from averaging the responses to the 10 post trials question) ⇒ SELF, OTHER, or BOTH !

Teste aussi en faisant 66-33

Peut prendre ces deux variables et:

Plot 2D

3d: sur une autre variable. (CURIOSITY, CREATIVITY, PLEASURE, BOREDOM..)

2) QUALITATIVE observation of videos (2 high vs 2 medium vs 2 low confusability) 6 videos de 6 participants en 50/50 +33/66 + 66/33

3) revisit the PCA result we showed in Dresden (weight on first component), in relation to (1) also, maybe U shape relation between confusion and complexity of motion

4) Machine learning/dimensionality reduction: can we develop a measure of creative movement (extent of exploration?)

5) (suite à 2): expert notation of X creative dimensions of a dance (subtasks: which dimensions)

VOCAB julien qualité:

Surprenant

inattendu

Changement

Original

Intéressant

Captivant

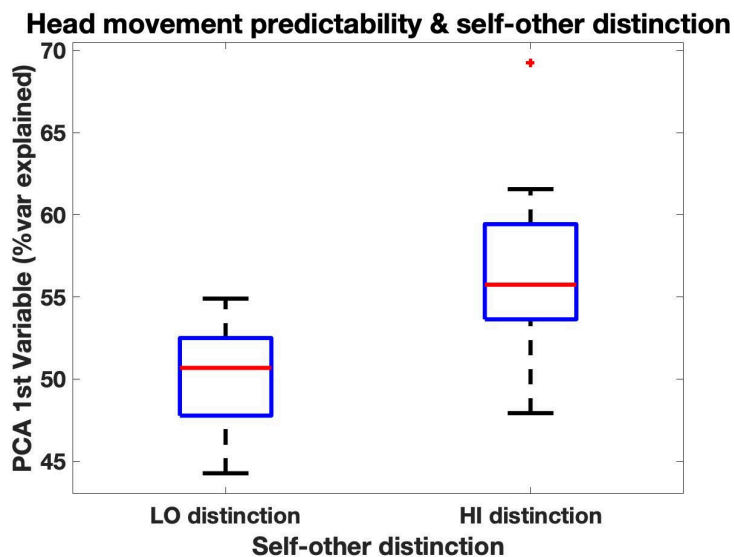
Bonne idée

Joli

Harmonieux

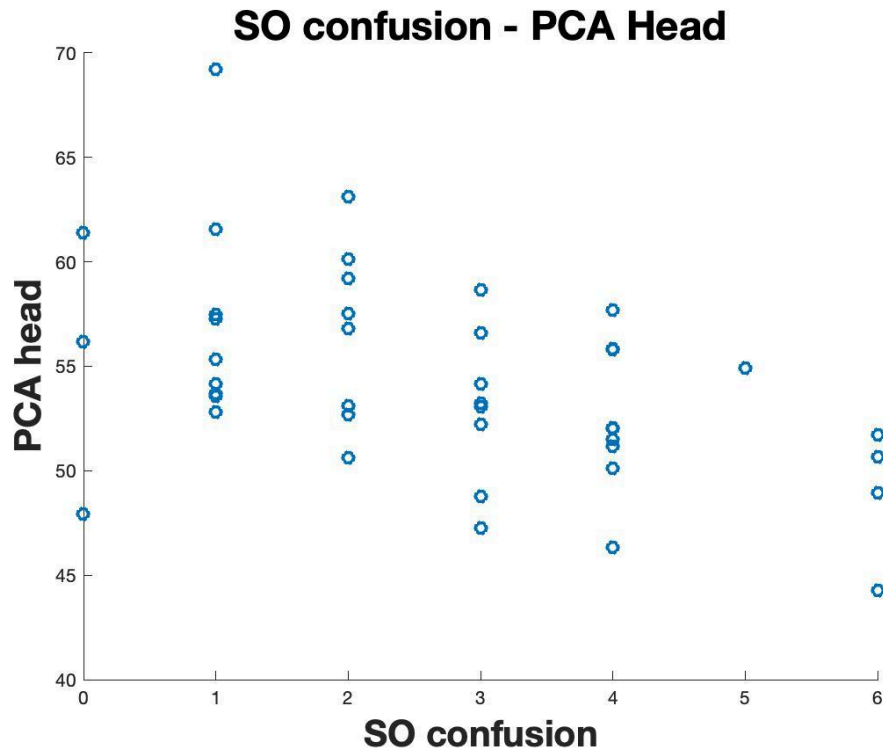
Désorganisé

ennuyeux

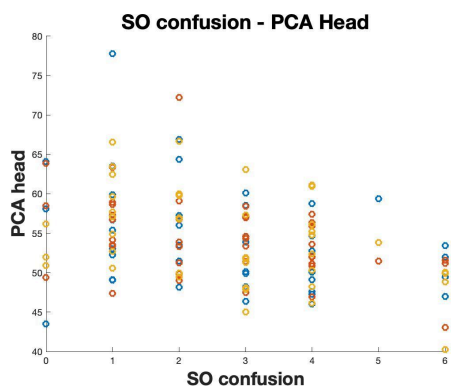


SOME RESULTS (JUNE 24):

PCA



-50:



BLEU: j'ai 33% de controle (whatever what the partner has)

ROUGE: 50%

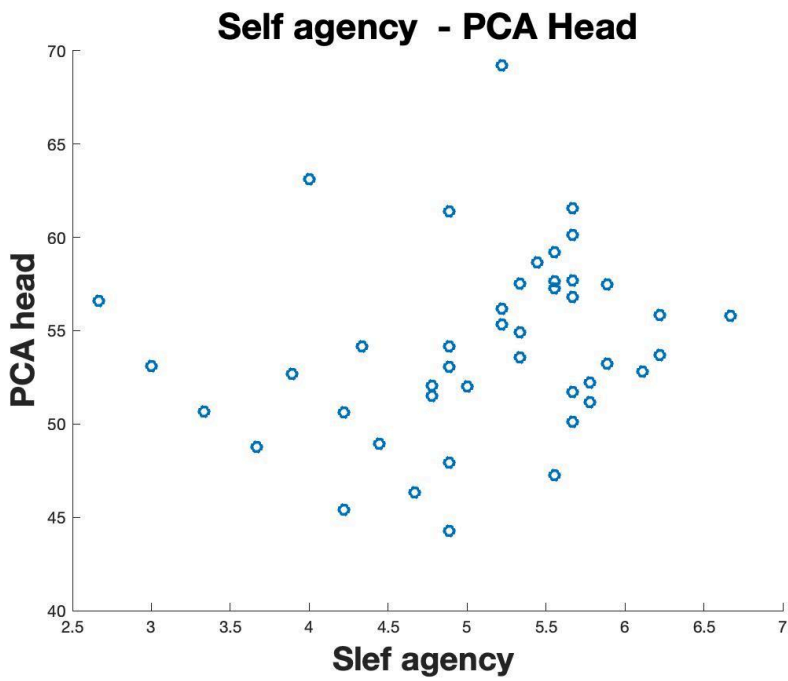
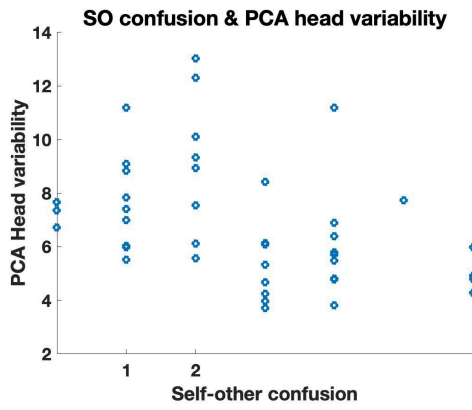
JAUNE: 66%

AGENCY (total of 9 episodes) Vs self-other confusion

⇒ depend pas des conditions de controle que le SELF a

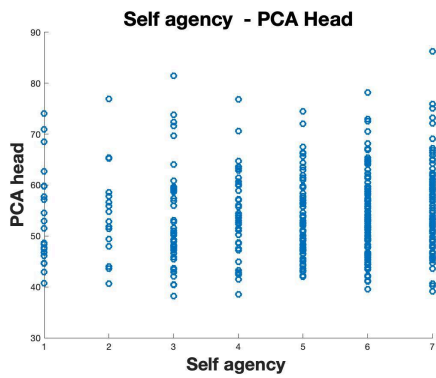
Q: variance de la PCA par SO confusion (Q20): meme chose... : -47

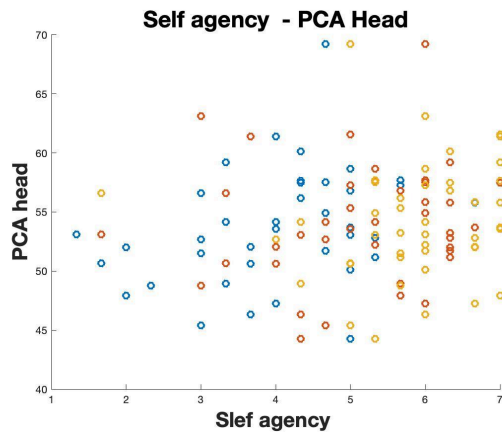
Mi lineaire et mi quadratique



INTERSTING? Average self agency: more complex head moves

Q: check with ALL points $pca * self\ agency$



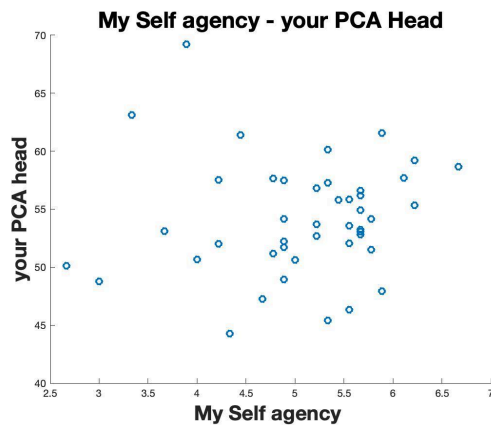


Q: quantifie relation par condition

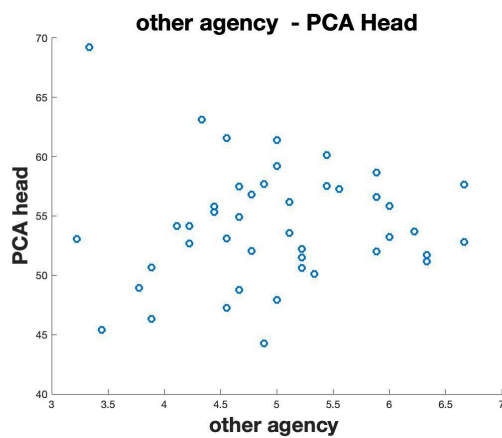
33: .28, $p = .06$

50: .15 $p = .33$

66: .23 $p = .14$

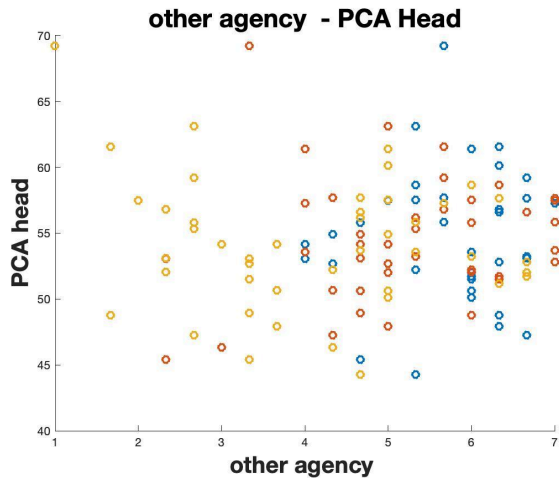


Rien de mieux en separant les conditions ME.

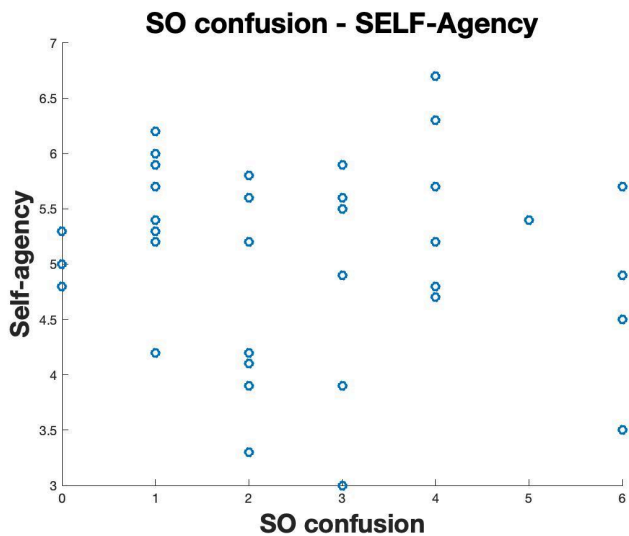


Q: mon partenaire PCA avec mon jugement !!!!!!!

⇒ donne rien



En 66: quand je suis peu predictable, j'attribue a l'autre peu d'agentivite
 Quand je suis predictable, j'attribue à l'autre soit tres peu soit beaucoup d'agentivité
 Q: split les deux: sont ils plus confused ? plus leader ? self agency ?
 Confus non. Self agency non plus
 Q leftover: do with leaders. XOX



Q: Diviser 4 quadrants de toute facon. Commencer par median split (012 vs 3 4 56): 3 est quasi la mediane, ca fait 20 vs 22 personnes par groupe et si prend pour 9 episodes a self agency cutoff de 5.25, on obtient des groupes de 10 et 11: parfait !

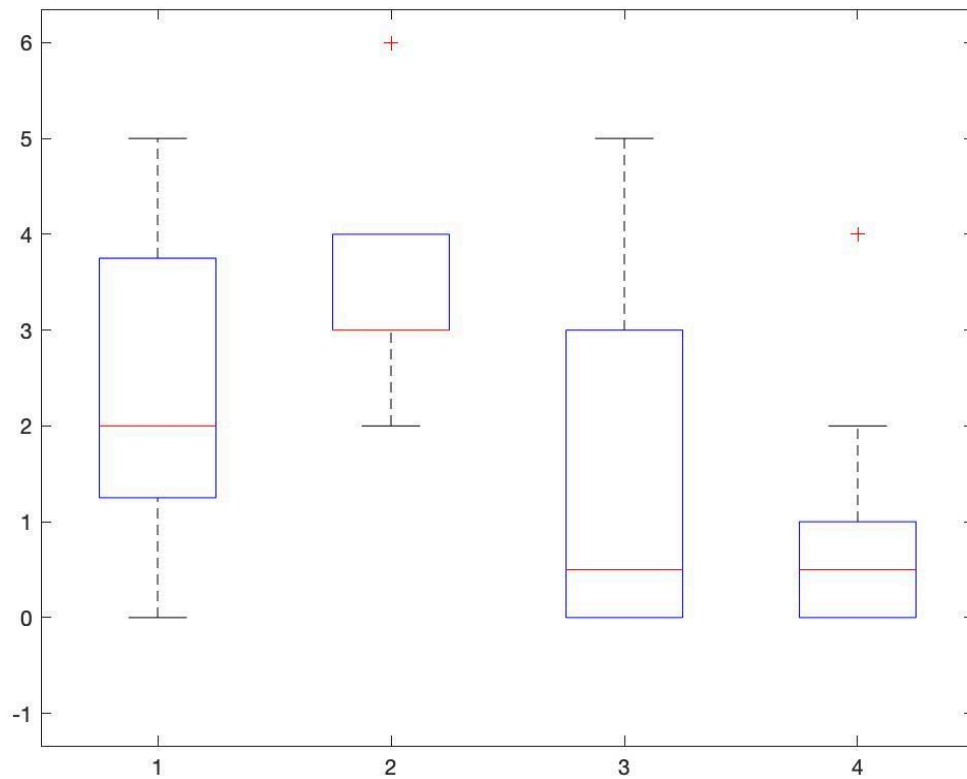
⇒ PCA, etc... question de creativité / plus que soi...

Avec PCA: pas vraiment d'interaction. Meme si micro tendance à effet positif de self agency (sur PCA head) quand la SO confusion est élevé (mais pas faible)

Avec "se sentir plus que moi", intéressant:

Clair effet de confusion: significatif dans le sens plus de confusion = plus que moi

Mais aussi interaction: $p = .03$ sans correction pour l'effet d'interaction avec self-agency: plus que moi quand beaucoup de confusion et peu d'agentivité



Legend:

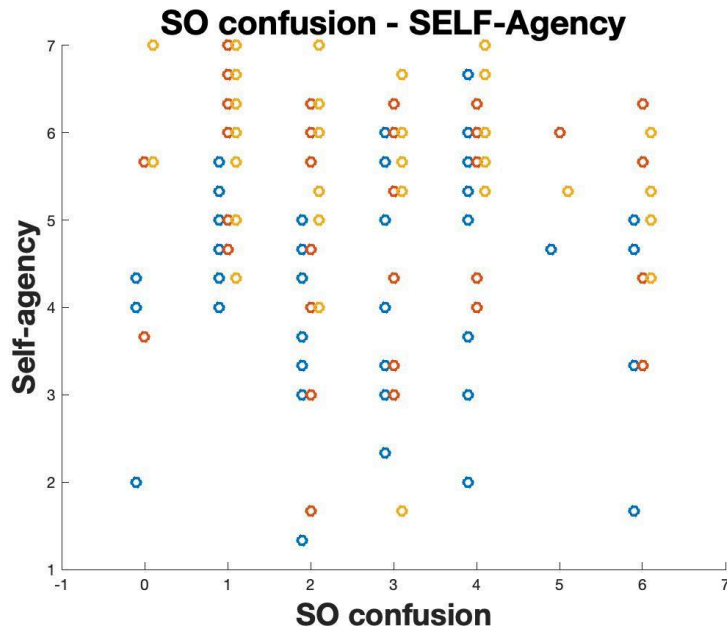
Hi confusion Hi self agency

Hi confusion LO self agency

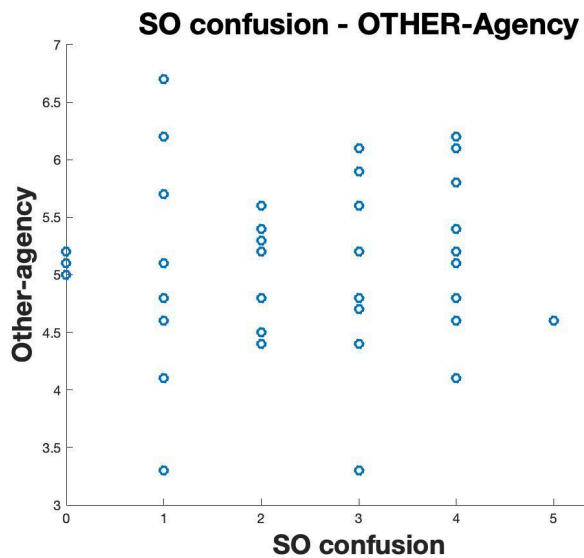
Lo confusion Hi self agency

Lo confusion LO self agency

Note: those who had a lot of confusion AND self agency felt in general self and other less different than in other conditions. Especially compared to those very confused but with poor self agency (not that compensated by elevated other agency)



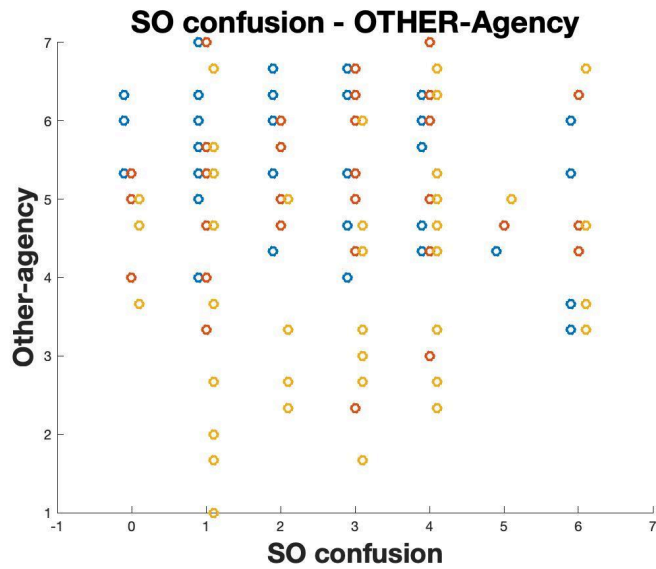
Q: TO VERIF (bleu et jaune inversé) ⇒ a priori c'est other agency DONE



Q: quadrants..

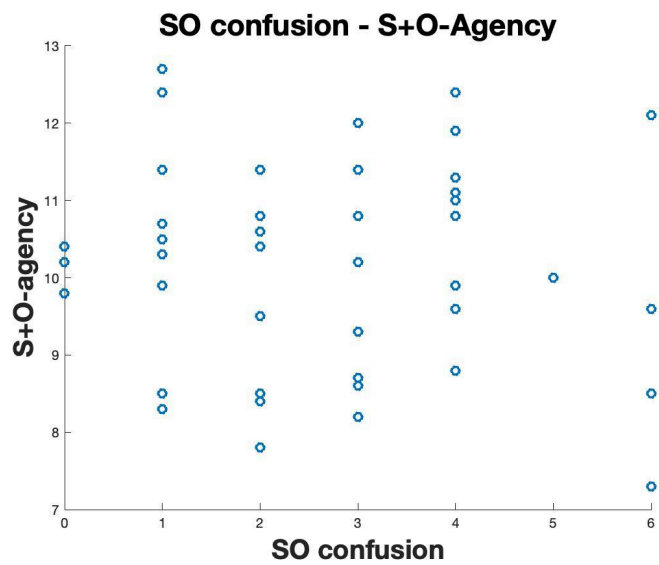
PCA: donne rien de plus du tout. plus de confusion = PCA first variable moins explicante

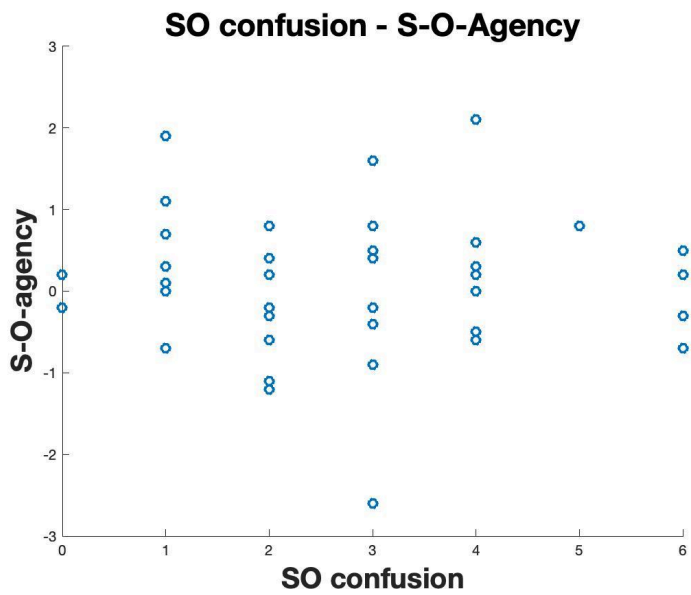
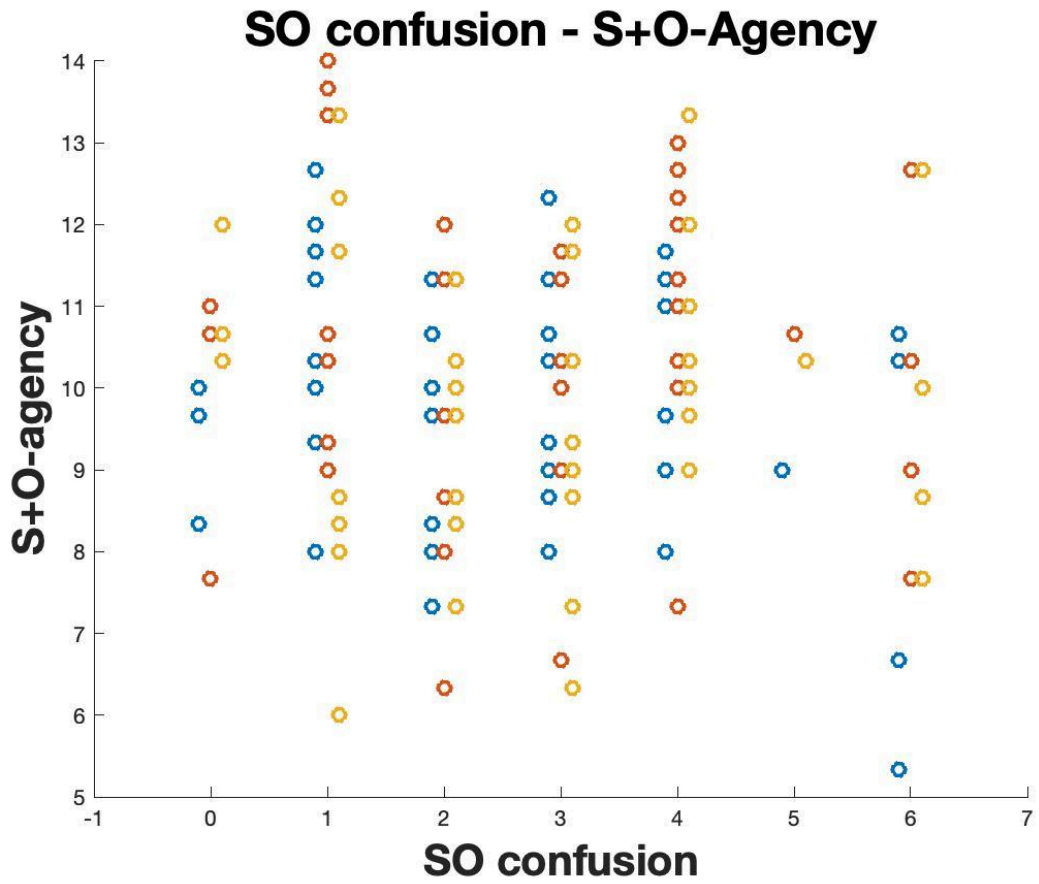
Plus que moi: peu de chose se passe, bcp de variabilité, mais LO confusion and HI other agency = le sentiment le plus faible de "plus que moi", et significativement different des hi confusion.

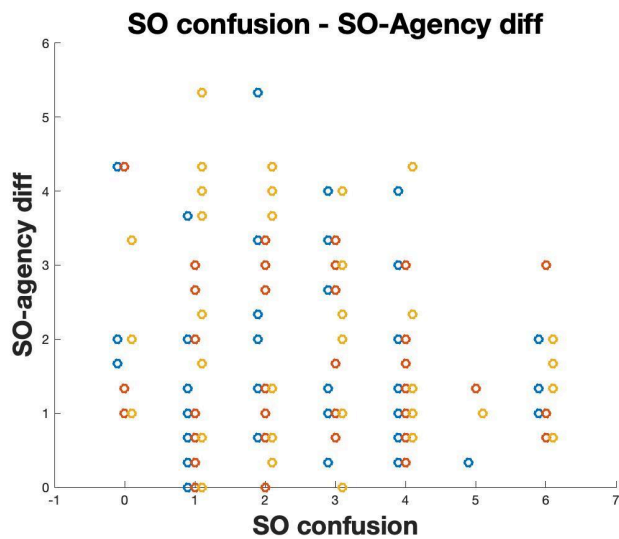
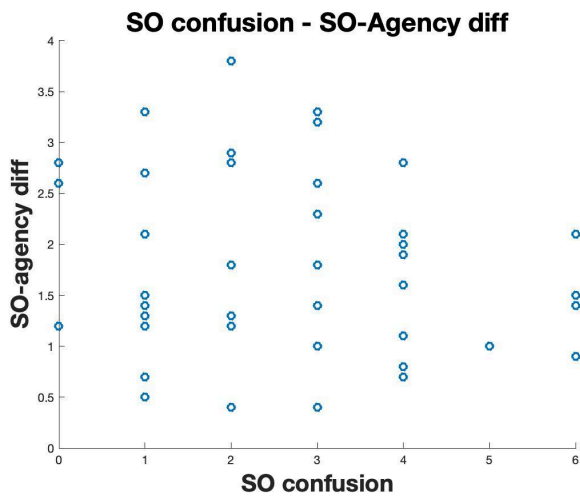
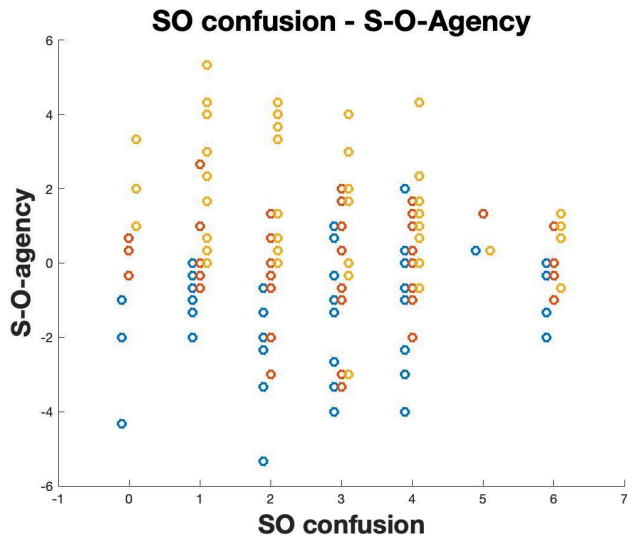


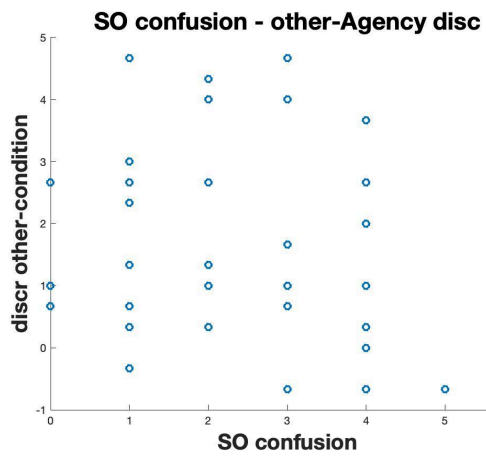
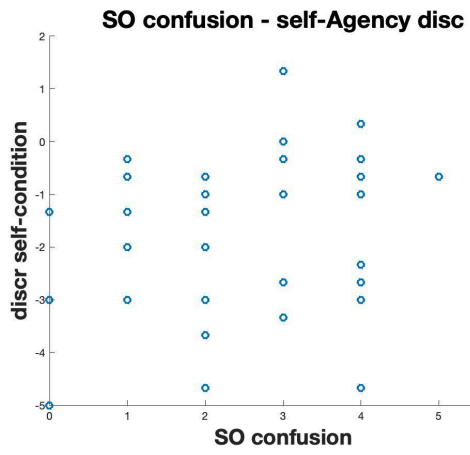
Q: quand j'ai bcp de controle, je donne a l'autre moins d'agentivité, et moins tendance a confusion
 Bcp de control et juge confusion moyenne (ou un peu basse) : peu d'agentivité attribué a autre
 peut regarder en 66 sont qui ont moins de 4 a other agency

2 facteurs intessants: mon sentiment de confusion, et que l'autre et agent, est moi suis agent

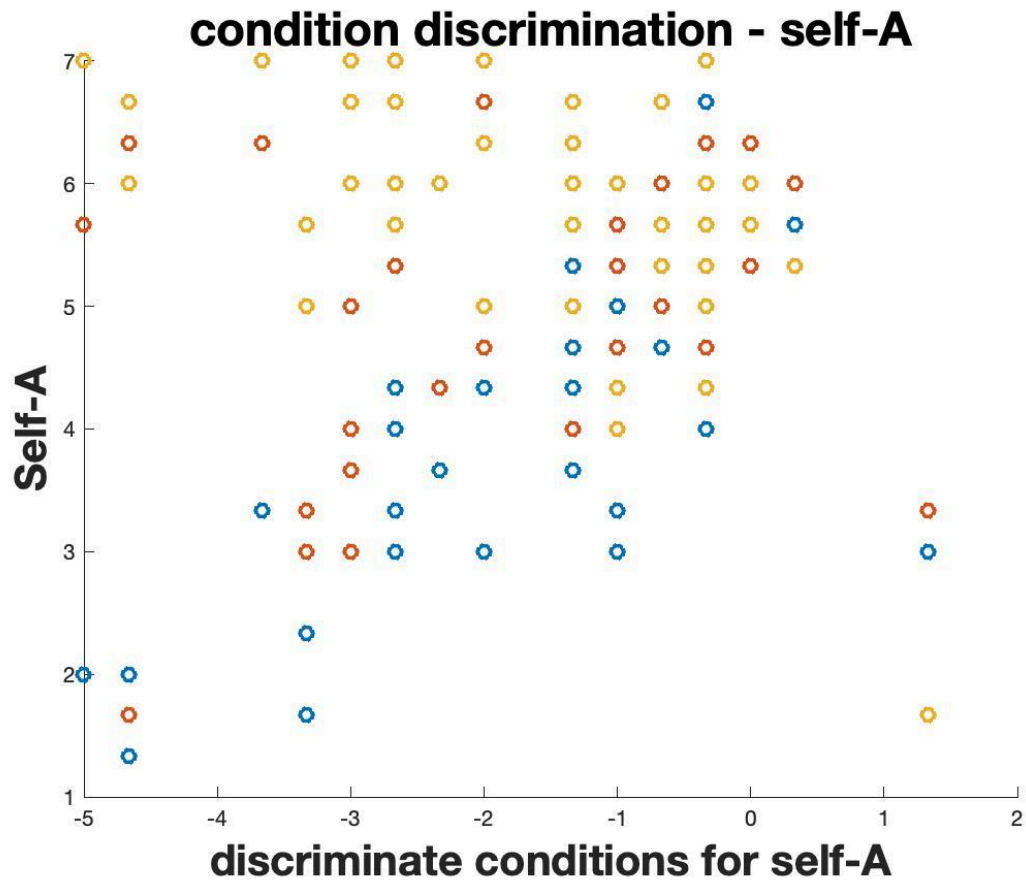








////

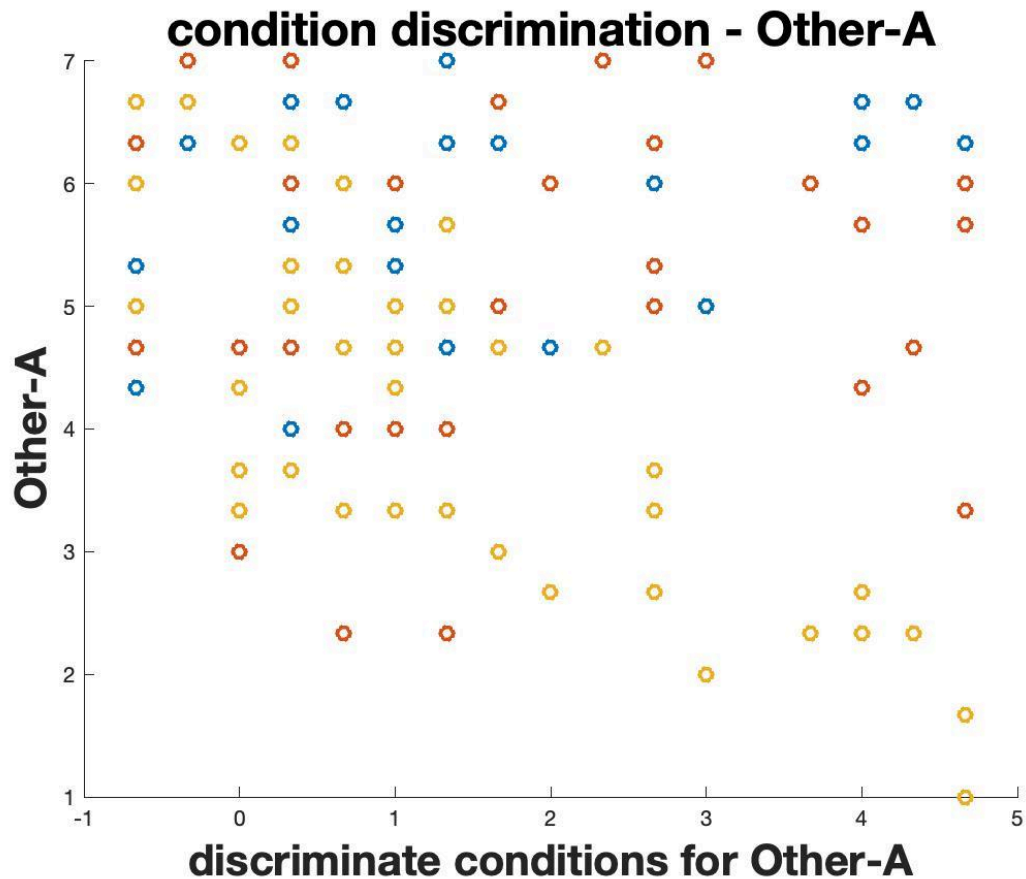


Plus je discrimine 33 et 66, plus en 33 je sens peu mon agentivité (.70 corr)

Flou en 50

Inverse en 66 -.50 : **plus je discrimine, plus je sentais mon agentivité haute en 66**

Quand j'ai peu de controle, je suis sensible a changement de mon controle (?)



.37 pour 33: plus je discrimine les conditions du pdv de l'agentivité de l'autre, plus je lui attribue de l'agentivité
0 en 50

-.80 en 66: plus je discrimine plus j'attribue du pouvoir en 66

Q: reprendre graphe original ou les 3 couleurs sont celles du partenaires

+

Q: avec CC leader follower: self agency, pca, les deux

BELOW : EX-PLAN (MORE CANONNE LIKE) AND TEXT WE STARTED, PART OF WHICH IS IN THE PRESENT PAPER

// EX- PLAN (MORE FOR CANONNE LIKE ANNOTATION PAPER) //

- 1) [LOUP] Some creative engagements are in presence while others are mediated by technology or artifacts. (orienter davantage sous le volet "- on s'hybride avec l'avatar, par la manipulation on est manipulé") ????? SOMETHING ABOUT CHALLENGE IN VR DESIGN?
Creating online together and how to design interface that solicit it ?
⇒ Interface Homme / Machine / Homme 'HCHI'
UX research: MUX? (multi-user (creative) experience)
- 2) [ASAF] In previous work we have shown that two individuals can engage in collaborative creative movement in a shared diminished reality setting (seeing only spheres).
- 3) [ASAF] Shared diminished reality allows us to create conditions for collaborative creative movement without direct access to our partners actions, choices, state of mind (one step further than having two musicians play in different rooms, Canonne): different degrees apply to different cases, median being one strong case, and the one we chose:
- 4) [LOUP] Presentation of the median avatar
- 5) [LOUP] Presentation of the protocol excluding the re-viewing (more emphasis on questions than on the manipulation of control)
- 6) [LOUP JULIEN] Results of the questionnaire : showing that people feel connected to their partner, creative etc... possibly correlations, if we find, between movement parameters and questions [variabilité distance soi avatar corrèle avec expérience]
- 7) [ASAF] How to engage participants in post-experience reports that can help point out specific moments or events in the experience (temporally dense reports)? This kind of data is necessary for cross-modal /perspective (1 and 3rd person) integration as well as for a more fine study of interpersonal dynamics?
- 8) [ASAF] Canonne et al example
- 9) [LOUP] Our version of Canonne with the innovation of creating an immersive viewing apparatus: 3 stage viewing and annotation (also innovant)
- 10) [JULIEN] Results from the two annotation series:
 - a) Globally replicating some stats from canonne et al
 - b) Own words produce more annotations that given terms (confound of order)

To do Julien: regarde si plus de mot ou de changement ou de durée entre mots perso et mots canonne

- c) After manual classification of terms: a nuanced version of Canonne's results (splitting 'with' to 'leading' and 'following')
- d) Other results? Corrélation entre mots et reponses questionnaire, corrélation avec mouvement (voir canonne: qom, cross correlation, histogrammes)

5

1. [LOUP] Some creative engagements are in presence while others are mediated by technology or artifacts. ????? SOMETHING ABOUT CHALLENGE IN VR DESIGN? Creating online together and how to design interface that solicit s cc it ?

⇒ Interface Homme / Machine / Homme 'HCHI'

Les technologies immersives actuelles mondes persistants immersifs, appelés communément Metaverses, offrent aujourd'hui de nouvelles frontières en ce qui concerne le développement des expériences sociales et créatives. Il est possible pour des individus du monde entier de se réunir et de faire groupe, de communiquer et d'innover ensemble grâce aux espaces virtuels qu'ils occupent et aux avatars qu'ils empruntent à cet effet.

Le médium employé joue alors un rôle clé, servant rôle d'intermédiaire dans la communication, et offrant des fonctionnalités plus ou moins décisives dans la capacité donnée aux participants pour nourrir ces interactions.

Influence de l'apparence de l'avatar en VR et impact des dissensus sensorimoteurs

L'apparence des corps et l'intégration du langage non verbal sont des dimensions clés dans la possibilité ou non de développer ces expériences sociales, d'autant plus lorsqu'il s'agit d'y développer une dimension créative.

Il a été montré par exemple qu'à travers l'effet Proteus, il était possible d'exacerber certains caractères et influencer sur les actions d'un utilisateur. Les enveloppes corporelles virtuelles auraient en effet une influence sur la forme donnée aux actions de l'utilisateur qui les habite.

Habiter par exemple un corps à l'apparence d'Albert Einstein influencerait sur les performances des participants face à des problèmes d'arithmétique. De la même manière, nous avons observé dans Vuarnesson et al. (2021) qu'à travers notre dispositif de Shared Diminished Reality, il était possible d'induire des états de légèreté et d'influer sur le mouvement créatif de danseurs en co-présence.

~~De nombreuses autres dimensions ont été explorées et s'avèrent effectives lorsqu'il s'agit d'induire des comportements ou d'influer sur la qualité des relations.~~

D'autres études ont montré qu'il était possible d'aller jusqu'à influencer le mouvement d'un participant en créant des écarts entre ce mouvement réel et le mouvement perçu à travers l'avatar habité.

~~— Nouveaux potentiels, get rid of physics, interact in space, travaux Spatial Media~~

~~Hors VR, il a été montré qu'il était possible pour des participants d'avoir un sens de l'agentivité pour des mouvements qu'ils n'avaient pas exécutés (REF)~~

~~both sense of agentivity (SoA) and sense of body ownership (SoBO) have been found to be reduced when a discrepancy exists between vision and motor information (REF)~~

~~both SoBO and SoA can be induced over a virtual body walking from a 1PP, even though participants are actually seated and only allowed head movements (REF)~~

~~Maselli and Slater showed that visual realism of the avatar favors the SoE, despite the presence of incongruent visuomotor and visuotactile cues (REF)~~

Dans leur article de 2020 (Gonzalez-Franco et al.) nomment cette idée "Self-avatar follower effect". Les auteurs y décrivent comment les utilisateurs ont tendance à suivre le mouvement de leurs avatars si au sein du système qui contrôle sa représentation y est introduit un offset spatial. Ceux-ci vont ainsi naturellement compenser cet offset tant que celui-ci est raisonnable. Au-delà, l'offset va être perçu comme une erreur, nuisant au niveau perçu d'embodiment.

Ce self-avatar follower effect peut alors être utilisé pour guider les actions de l'utilisateur (REF, REF)

Expériences VR collaboratives - Shared avatars

Building on the idea of the Self-avatar Follower Effect, Fribourg et al. (2020) propose studying the circumstances under which two users can share an avatar and experience a sense of agency (SoA) over co-produced movements. They introduce a fluctuating degree of control in their system, alternately given to one or the other participant, allowing them to show that SoA is positively correlated with the degree of control over the avatar, and is also influenced by the level of freedom given to users for performing actions.

The authors also show a negative correlation between locus of control and how users feel in control, suggesting that this subjective sense of control over a shared avatar may be influenced by personality traits. They further observe that it is possible to have a sense of agency even without control over the avatar, as long as participants share a common idea beforehand on how to perform a task.

In Hagiwara et al. (2020), the authors demonstrate through a similar paradigm that when two individuals share an avatar, they tend to make smoother movements with less jerk and opt for more direct trajectories, displaying a reduced reaction time compared to when they control their avatar individually. Co-embodiment thus appears to encourage the search for consensus, the only way to achieve task completion.

These various studies illustrate how spatial mediation enables navigation within the locus of control, affecting how individuals can accept being influenced and guided in their actions while maintaining a sense of agency. They also show how, through embodiment in an avatar, dynamic alteration of this control level can directly impact the action strategies developed by co-immersed participants.

However, we can observe that these studies limit actions to simple tasks (grasping, moving toward a target, etc.). Although observed trends suggest that co-embodiment could encourage coordination, they do not provide a clear view of how these techniques might influence activities involving shared creativity.

Note J: Originality: Computer interface propose nothings: let opportunity to interact

We note two aspects of the recent literature on virtual co-embodiment :

- 1) The avatar is mostly spatially located as an extension or virtual homologue of a body part of the participant
- 2) The actions to be executed are goal directed with more or less scripted trajectories
- 3) In some case, an expert ‘guides’ a novice to execute a movement in a certain way.

In this paper we present a different angle on, or a different exploration of, virtual co-embodiment.

- 2) First, the shared avatar is not spatialized as a plausible extension/homologue of the participant’s body but rather as a facing partner. If the usual setup of the virtual co-embodiment is often named first-person, we suggest to name this avatar-as partner configuration ‘second person’ . Just like in Fribourg et al 2020 study, we vary the participants’ control over the avatar parametrically but this is conceptualized as the degree of influence on a partner or the interaction, rather than on one’s virtual body part. As a consequence any experience of body semantic violation (REF).
- 3) Second, we do not prescribe particular actions to the participants but rather let them freely improvise and explore. The absence of a prescribed goal (either shared or individual) or a task to complete has a number of consequences:
 - a) There is no clear optimization strategy either for the participant nor for the experimenter to evaluate the impact of the shared embodiment
 - b) The illusion of agency due to the correspondence between intention and (non-controlled) movement of the avatar is less probable and harder to assess for the experimenter
 - c) Conversely, participants rarely evoke a sense of competition over control
 - d) The attention of the participants is not devoted to the task to complete but instead can be dedicated to the quality and unfolding of the interaction itself
 - e) Participants are invited to freely improvise and so (among other things) potentially generate new sequences of movement.

This novel version of the virtual co-embodiment paradigm is complementary to published research as it allows the study or exploration of a different (though related) set of questions or issues. The second person perspective shifts the focus of inquiry from body ownership effects to joint action and how self agency relates to joint

agency and other's agency. The lack of prescribed task allows the user and the experimenter access to the dynamics of real time interactive creativity, similar to the ones we explore in dance or music improvisation.

~~(Grâce au disembodiment, ils vont pouvoir s'alléger du poids des normes sociales de genre, de corpulence, pour se focaliser uniquement sur la tâche créative.)~~

The YUMI model

We name the theoretical perspective that guides our research on creativity during interaction YUMI ('you'-'me'). The central insight behind YUMI, that comes from our own experience in different improvisational practices, creative pedagogy and the research literature, is that creativity is enhanced during interaction when the boundary between our contribution and the contribution of others to the collective activity is slightly blurred (but does not disappear). It is when we can still recognize the fact that our own actions (movement, sound, visual traces...) have an impact but not be certain of what exactly the impact is, that we are invited to break our habits and explore new territories. YUMI states or dynamics can be found in a variety of creative interactions (for exemple being in the 'zone' during a jazz improvisation REF, or when a very unexpected sequences of actions is produced during a Contact Improvisation dance duet REF). However it is not straightforward to generate to such states or manipulate the experimentally. We propose that shared VR is an excellent tool for the study and eventually ____ of YUMI dynamics. In our protocol participants do not receive direct visual feedback of their own motion, nor that of the partner, but instead interact with an avatar that is co-composed of the motion of the two partners (as in other virtual co-embodiment protocols). When the avatar is properly adjusted, the participant can recognize that her movement contribute to the movement of the avatar but cannot be certain of the extent of the contribution nor can predict at any moment what would be the local effect of her movement on the avatar.

Evidence for YUMI:

Kaddouch method

Experience from duo dances (e.g.tango) where there is a sense of a thirdness

Experience from collective music improvisation

The creativity paper in CI

Co-confident motion and the sense of togetherness in the mirror game

From VR literature:

Following/synchronizing with one's own avatar in virtual co-embodiment

Sacheli et al (meta-analysis of joint action): we have explicit and implicit sense of agency for actions taken by a partner

Curiosité mentalisante, puzzled, dépendante, une curiosité flow fun mentionne par l'autre

creativity in interaction

~~(Par cette amplification due à la boucle sensorimotrice issue de leur propre avatar et tant que le degré de contrôle reste suffisant, on peut trouver des formes d'équilibre où l'un et l'autre en viennent à se suivre tout en se sentant en contrôle de l'expérience.)~~

• VR design challenges are:

Seamlessness

Responsive interfaces

Extra-natural capabilities

Social encounters

Collaborative interface / partner / enactive interfaces

~~Enjeux à développer des expériences collaboratives et sociales qui ouvrent à de nouveaux potentiels créatifs et prennent en compte ces spécificités (corps, apparence respective, contrôle)~~

~~Est-ce qu'on peut appliquer ce principe pour une rencontre créative et sociale ?~~

~~Créer des interfaces qui favorisent la créativité, qui parviennent à mesurer la qualité d'une interaction et qui en deviennent des partenaires~~

~~Dans l'expérience précédente d'articulations, les personnes qui avaient pensé danser seules ont vécu une expérience moins bien notée~~

2.[ASAF] In previous work we have shown that two individuals can engage in collaborative creative movement in a shared diminished reality setting (seeing only spheres).

In our previous work (REF design) we have offered the concept of shared diminished reality (SDR) to describe an approach to the design of interactive VR environments/setups that builds on, rather than trying to compensate for, the rather poor rendition of 'reality' offered by current technology. Instead of trying to mimic the 'real' world (Virtual Reality) or to add digital content to the actual visual scene (Augmented Reality) we argued that the reduced nature of the digital rendition (Diminished Reality) can have an advantage for first and third person research as it allows us to discard dimensions of the actual situation that could interfere with the research question (for example, gender or body features of the co-actor, or irrelevant features of the physical environment). We presented a specific SDR installation, ArTiculations, that allows for two persons to dance freely with each other in a rarified environment (a very large open space with clear blue sky) where each participant is represented as an ensemble of three spheres (corresponding to the head and two hands).

Through questionnaires and interviews we

In our research article (REF) we reported results of an experiment that made use of the ArTiculations setup to explore the effect of the presence or absence of visual feedback of one's own body on the experience of moving together and on the movement synchronization between the partners. We found that participants (both dancers and non-dancers) tend to synchronize their movement with the (avatar of) the partner even. This synchronization takes place despite the fact that there is no physical similarity to their own body nor shared movement intention or trajectory (REF?). In addition, we reported a correlation between the extent of this synchronization and a sense of affective closeness with the partner.

The use we made of the ArTiculations setup in our previous research took advantage of the SDR approach as it allowed us, first of all, to eliminate multiple dimensions of the collective improvisation situation that complexify it to a degree that makes it difficult to track (face and gaze information, gender, race, body shape and cultural information, environmental features, the presence of experimenters...). The SDR

3.[ASAF] Shared diminished reality allows us to create conditions for collaborative creative movement without direct access to our partners actions, choices, state of mind (one step further than having two musicians play in different rooms, Canonne): different degrees apply to different cases, median being one strong case, and the one we chose:

The absence of a prescribed goal (either shared or individual) or a task to complete has a number of consequences:

- f) There is no clear optimization strategy either for the participant nor for the experimenter to evaluate the impact of the shared embodiment
- g) The illusion of agency due to the correspondence between intention and (non-controlled) movement of the avatar is less probable and harder to assess for the experimenter.

- h) Conversely, participants rarely have evoked a sense of competition about their control over the avatar. Rather, it induces a feeling of co-action / collaboration.
- i) The attention of the participants is not devoted to the task to complete but instead can be dedicated to the quality and unfolding of the interaction itself
- j) Participants are invited to freely improvise and so (among other things) potentially generate new sequences of movement. *[can integrate some bit of:]* The lack of prescribed task allows the user and the experimenter access to the dynamics of real time interactive creativity, similar to the ones we explore in dance or music improvisation.

[Loup : I would note also that, because participants don't have any other confirmation of their presence in this paradigm than the shared movement of the median avatar, understanding and controlling its movement is a condition for them to "exist", thus it forces them to engage in the interaction]

IF IT HELPS: some bits of the failed Marie Curie project:

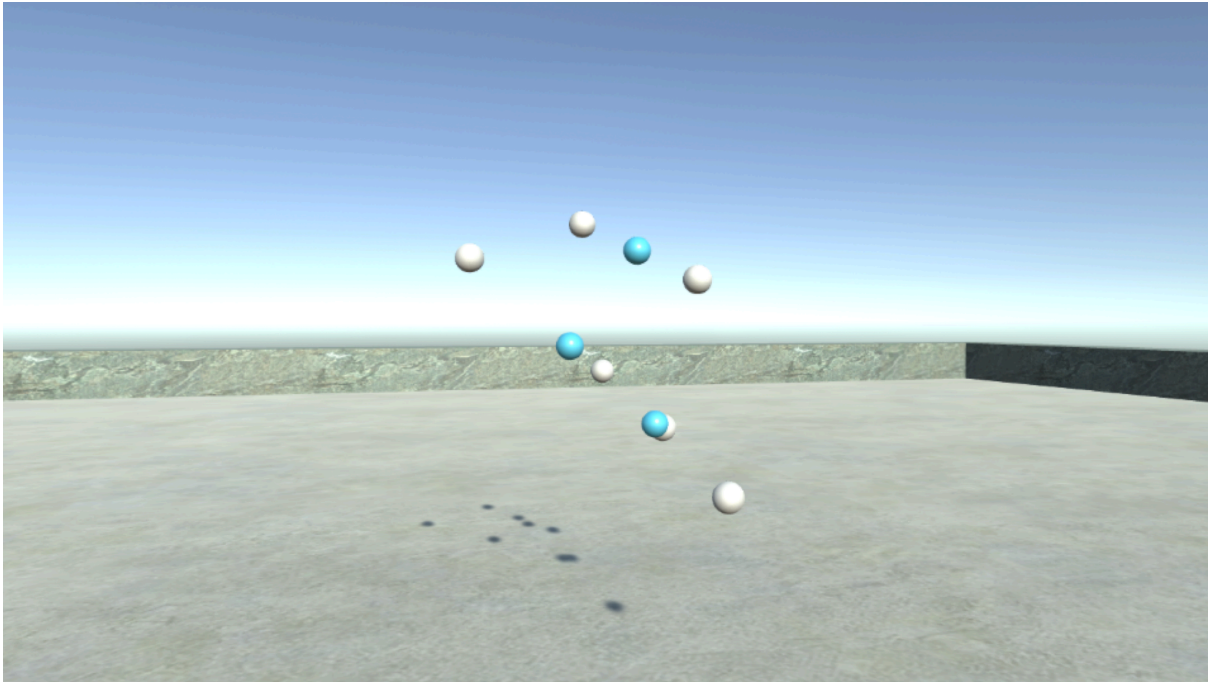
group movement improvisation provides the perfect context to fulfill our objectives: (i) it focuses participants on the agency they share over their movement interaction (ii) it makes the product and process of creativity coincide in time, enabling the study of the creative outcome and movement interaction over the same timeline (iii) as movements externalize this creative process, it can be captured and quantified.

4. Presentation of the median avatar

We introduce here the concept of the median dancer, an avatar co-manipulated and co-embodied by two participants at the same time, and seen from two different third-person point-of-views.

The two participants manipulating the median dancer are equipped with three body sensors each, located on their hands and heads (a total of six points). They face each other in a virtual environment, and between them, the median dancer appears as a set of three floating spheres. Two small spheres are animated respectively by the mirrored hands of the participants (left hand of dancer 1 and right hand of dancer 2, and vice versa), while a medium-sized sphere has its position always at the centroid of their six tracked points.

Entirely generated by the participants' movement, the median dancer is therefore a co-animated minimalistic puppet, moving in synchrony with its puppeteers.



The algorithm governing the movement of the median dancer is set as a real-time blend of our participants' sensors positions. At its balance state, each participant shares an equal amount of control over the median dancer's resulting movement (this movement is influenced at 50% by the first participant, and 50% by the second).

To allow for varying degrees of control, we have also added a weight factor, to give our participants a different proportion of control over the time. This amount of control can vary from no-control (the median dancer follows only my partner) to full-control (the median dancer follows only me).

The resulting object appears as a highly engaging interactive object. Never being exactly one, nor the other, the median dancer fluctuates onto a continuum mixing familiarity and unknown. Its movement is always in a sort attuned to each participant, while pushing the both of them in other fields of quality and intentions. In the same fashion as in Fribourg et al. (XXXX), we can observe a tendency from both participants to compensate for the clear drift that they create for each other.

We can also speculate that the interactive nature of the median dancer is due to the fact that it represents the only proof of agency for both participants.

Therefore, maintaining control over the median dancer is a prerequisite for the feeling of agency in the scene. Artificially diminishing one participant's control contributes to the jeopardization of their existence within the relationship.

The median dancer is thus the only object of attention in the scene, the sole validation of the participants' agency. As it acts only partially as one and the other, it becomes an enigma whose resolution is necessary to "exist" within the virtual environment.

- Individual commitment through jeopardization

An important aspect of this object and its engaging character is that, unlike the paradigm presented in Vuarnesson et al. (2022), here participants see neither their hands nor their partner, only the result of their movements.

They co-embody the median avatar, which is the only proof of their existence within this virtual environment. They feel as if they exist only through the reactions of this co-animated object.

- The quality of the encounter

We hypothesize that by providing only the perception of this co-manipulated avatar as feedback for their actions, participants will contribute to finding a balance between listening and proposing, and that through this inter-adaptive loop, they will each adopt the gestural qualities of their partner.

By the principle of the self-avatar follower effect, we hybridize with the avatar, and through manipulation, we are manipulated.

- From a design perspective, we are interested in how interaction can enhance and enrich user behavior. The presence of the other here adds richness to the interaction.
- We create a case/environment where I am constantly influencing and being influenced by the movements of the other; this happens continuously in real-time rather than in back-and-forth exchanges.
- Perhaps we accelerate this contagion effect, making it smoother and more forceful.
- Through the recognition of the effect I have on the median object, I begin to adopt the gestural qualities of the other.

- Mathematical formula

a: position of the median's main sphere
 b: position of the median's hand 1
 c: position of the median's hand 2

u1: position of participant 1's head
 v1: position of participant 1's left hand
 w1: position of participant 1's right hand
 u2: position of participant 2's head
 v2: position of participant 2's left hand
 w2: position of participant 2's right hand

p1: weight of participant 1
 p2: weight of participant 2
 Vc: compensation vector

$$a = ((u1 + v1 + w1) * p1 + (u2 + v2 + w2) * p2) / (3*p1 + 3*p2) + Vc$$

$$b = (v1 * p1 + w2 * p2) + Vc$$

$$c = (w1 * p1 + v2 * p2) + Vc$$

$$Vc = -(u1 * (p1 - 1) + u2 * (p2 - 1)) / 2;$$

The compensation vector allows the median avatar to remain centered despite changes in weight.

This algorithm enables us to explore different conditions:

- In the case of a 100/0 condition, 100% of the control will be given to participant 1. The spheres of the median dancer will therefore only respond to the movements of this participant.
- In the case of a 33/66 condition, two-thirds of the control will be given to participant 2, meaning they will have twice the impact on the movement of the median dancer compared to their partner.

In the case of a 33/33 condition, the situation is asymmetrical. Since each computer calculates the positions of the median dancer from its own side, it is possible to display different behaviors on each side. In this specific case, both participants perceive a different median dancer. They each have the impression of having a low impact on the experience (33%), while significantly influencing that of their partner (66%).

5. [LOUP] Presentation of the protocol excluding the re-viewing (more emphasis on questions than on the manipulation of control)

The experiment took place at the Pouchet center of CNRS in Paris, France. It lasted one week in December 2022.

We tested X participants, aged from X to X, all having an experience with dance and improvisation. Registration was done through online forms, which links were accessible via social network posts and emails sent to our own contact lists. X of them had already participated in a pilot in June 2022.

1) Pre-phase

After filling in a consent form and a personality questionnaire, we welcome participants to the experimental room.

We begin by offering them a moment of relaxation, to cut from their everyday lives, and to ease them from any kind of stress or problems that they would be carrying from outside. Mats are laid out on the floor, we invite them to lie down and to get ready to move.

We make it clear that their implication is decisive and that they are invited as experts in improvised movement.

After a few minutes of stretching, we invite them to stand up and equip them with movement sensors, a belt to measure their breathing and a ring that integrates an ECG sensor and an accelerometer.

2) Immersion

We then place them into their respective zones, equip them with a VR headset and immerse them in our minimalist visual paradigm.

In the spirit of SDR, they are placed inside a large arena, topped by an infinite blue sky. In front of them, they can read a floating text that asks them to wait for the experiment to begin.

At this moment they can see each other, embodied into a minimalistic avatar constituted of three spheres of the same size. In place of their hands are two small white spheres that move synchronously with their movements. A third sphere is located at their head position, and is only visible for the partner.

We then perform a few technical verifications, and ensure verbally that the ready participants are ready. The experiment can then begin.

3) Familiarisation

We then ask the participants to face each other but now, they both find themselves facing the median dancer (when the median dancer is visible their minimalistic bodies are no longer displayed). Participants can hear the experimenter's voice that starts to explain the upcoming setup.

We show them different median dancer configurations with different weight conditions, to make sure that they understand how the system works. We make it clear to the participants that they are facing a mixture of their respective movements here, and that in all phases they are given 1 min to interact with each of these configurations and to familiarize with these changes. Once the principle is understood, the experimental phase begins.

4) Experimental phasis

THE FOLLOWING: to be mentioned or not (if no results, maybe we can skip)

The experimental phase is composed of a sequence of 10 different control weight conditions, lasting 1min15 each. Their order is randomized.

During each phase we record the participant's three sensor movements, their ECG activity, and the acceleration of their fingers, as well as a post-condition questionnaire.

After each condition, the median dancer disappears, and we set the first person avatar visible again. Participants are then presented a set of seven questions that they can answer with their hands.

The first six questions can be answered using a Likert scale from 1 to 6, and are proposed in randomized order:

- a) My movement had a clear effect on the spheres / Mes mouvements avaient un effet clair sur les sphères
- b) The sphere's movement influenced how I moved / Le mouvement des sphères influençait ma manière de bouger
- c) I felt that the other person and I were dancing together through the spheres / J'avais l'impression que l'autre personne et moi dansions ensemble à travers les sphères
- d) This episode was particularly boring / Cet épisode était particulièrement ennuyeux
- e) I had the feeling of being understood / J'ai eu le sentiment d'être compris
- f) I felt my partner's movement had a clear effect on the movement of the spheres / J'avais le sentiment que les mouvements de mon partenaire avaient un effet clair sur le mouvement des sphères.

A final question then asks to give a mood for the whole last episode. The following question is displayed:

- g) What was the episode's mood?

And below this question are displayed several possible answers:

Curious / Curieux
 Calm / Calme
 Tense / Tendu
 Other / Autre
 Playful / Joueur
 Impredictable

This is followed by a sequence of 10 conditions, each lasting 1 minute and 15 seconds, with the order randomized across the following balances: 50/50, 50/66, 66/50, 33/50, 50/33, 66/66, 33/33, 66/33, and 33/66. The color of the median dancer no longer changes and remains green throughout the experience.

The algorithm governing the median dancer's movement is therefore a real-time blend of our participants' sensor positions. Materializing the product of interaction in the form of a shared avatar provides participants with the unique opportunity to directly sense the agency they share over their interaction