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# Shared Diminished Reality: a new VR framework for the study of embodied intersubjectivity

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## 2 ABSTRACT

3 Something something

4 **Keywords:** copresence, dance improvisation, research-creation, multi-user experience design, enaction, non-anthropomorphic  
5 avatars, Virtual reality, mixed reality performance

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7 program "Investissements d'avenir" (reference ANR-17-EURE-0008)

## 1 INTRODUCTION

8 The question of embodied interactions has emerged as a central theme in the cognitive sciences, robotics  
9 and related fields, extending older philosophical preoccupations. Philosophers from Bergson (1939) and  
10 Mearleau-Ponty (1945), to Noë (2012) and Manning (2009) have indeed insisted on the role of bodily  
11 actions in the construction of space and perception more generally. According to the enactive cognition  
12 stance, how we move in our environment and how we experience it as a world is a circular, co-constitutive  
13 process (Merleau-Ponty 1945; Varela et al. 1991). In other words, we realize the world by interacting with  
14 it and by realizing the world, we realize ourselves: we are present (Noë 2012 ; Manning 2009).

15 The recent and growing development of virtual reality (VR) tools allows us to design new lived worlds:  
16 to construct and visit new spaces, to try new practices and to interact with new contexts. Shaping both  
17 the environment and the embodiment of the users in that virtual world, VR offers designers and cognitive  
18 scientists the unprecedented potential to explore virtually a vast set of interactions between persons and  
19 their environment, new ways to be present to oneself, to the world and to others.

20 By design, VR tools offer a formidable opportunity to revisit the very link between body movement and  
21 lived experiences and to experiment with it in a controlled, yet engaging and ecologically valid manner. In  
22 this context of application, the design of the environment is usually under focus, allowing researchers to  
23 experiment with how subjects interact with the features of the virtual environment. Yet, a more recent focus  
24 in cognitive sciences research and experience design in VR (Greenwald et al. 2017 ; Wienrich et al. 2018)  
25 concerns the interaction between persons, giving a central role to relationality itself (De Jaegher et al. 2010,  
26 Laroche et al. 2014). Indeed, when the couplings between perception and action of two or more persons  
27 become intertwined, the dynamics of bodily interactions give rise to the experience of being ‘co-present’  
28 (Froese et al. 2014a, Froese et al. 2014b). For Manning (2009), ‘relational movement’ (the way we move in  
29 relation with other bodies/selves) underlies our own sense of self (‘bodying’) and our being in the world  
30 (‘worlding’). By interacting and moving together, we participate in each other’s experiences and sense-  
31 making (De Jaegher and Di Paolo 2007). In other words, the way our lived experiences become meaningful  
32 and our world imbued with sense emerges from our active bodily encounters with our environment, and  
33 especially with others (McGann and De Jaegher 2009).

34 How can we design (virtual) environments that encourage interactions between multiple persons and  
35 that allow designers, scientists and participants (users or ‘immersants’) to explore the very process of  
36 interaction itself? A number of members of the research project previously addressed the formal study of  
37 open-ended interpersonal interaction by designing GIGs, an acronym for (in person) Group Improvisation  
38 Games. This consists in bringing groups of participants to explore their reciprocal interactions and to do so  
39 freely within a simple set of constraints (Himberg et al. 2018). How can VR support and contribute to the  
40 improvement of the methodological set-ups employed in this kind of research? And, in turn, how can this  
41 line of research inform multi-person VR design? In this paper, we propose to use the tools of VR to control  
42 and manipulate the coupling between perception and joint action and thereby evoke differential affective  
43 experiences. For this purpose we propose a conceptual framework we name “shared diminished reality”  
44 (SDR). In this framework, inspired by the cross-perceptual paradigm (Auvray et al. 2009), immersants are  
45 co-present and able to move together but their bodies, and the environment are represented in a minimalist  
46 way. This allows the user to focus his/her attention on experiencing the interaction itself and allows the  
47 designers or scientists to track the core dynamics of the interactions between participants.

48 In order to present the SDR framework, we first review the potential of VR for the scientific and artistic  
49 research around movement and in particular relational movement, focusing specifically on what we consider  
50 minimalist designs. We will then turn to the interdisciplinary design and design-history of our shared VR  
51 platform (Articulations) which represents an attempt at instantiating SDR. In this paper, Articulations  
52 serves as both a theoretical object through which to reflect on SDR and an empirical testing ground of  
53 its art-science potential. In the second part of the paper we report two forms of design evaluation, one as  
54 cognitive science research (the ‘laboratory installation’) and the other in the ‘practice as research’ tradition  
55 (the ‘research-creation installation’).

## 56 1.1 Use of Virtual Reality for the study of the cognition of movement, presence and 57 affect

58 The increase in computer graphic capacities and the rise of immersive technologies in recent years  
59 have brought about the conception of new tools for the in-depth observation, study, and manipulation of  
60 the mechanisms of bodying and worlding. VR provides the capability of creating custom experimental  
61 installations where the environment, our own appearance, and the presence or representation of others,  
62 can all evolve and adapt dynamically to (joint) behaviours while carefully controlling action-perception  
63 coupling parameters.

64 VR has seen its scientific use spread and is considered by now as “valid and highly ecological without  
65 compromising experimental control” (Loomis et al. 1999). It has been used in a wide variety of fields  
66 including psychology, anthropology, ergonomics, neurosciences, both as an experimental tool and as a  
67 therapeutic application (Okun 2017), particularly in the treatment of mental illnesses (Wiederhold and Riva  
68 2019 ; Freeman et al. 2017). It has been applied to the study of the psycho-affective dimensions of art and  
69 mediated communication (Quesnel et al. 2018), and in the exploration of social mechanisms at play during  
70 interaction, in particular the feeling of co-presence (Garnier et al. 2017).

71 Interestingly, one of the first experiments to validate the potential of VR as an experimental paradigm  
72 targeted body ownership (Slater et al. 2010). The “rubber hand illusion” experiment (Botvinick and Cohen  
73 1998) has shown that visuotactile stimulation gives the illusion of embodiment with a substitute hand. Such  
74 embodiment techniques have been shown to result in the illusion of body ownership over the surrogate  
75 body – whether a physical manikin body (Petkova and Ehrsson 2008) or a virtual body (Slater et al. 2010).  
76 The very sense of self can be altered when inhabiting an artificial envelope. Numerous studies (Banakou  
77 et al. 2013 ; De la Peña et al. 2010 ; Kiltner et al. 2013 ; Lugin et al. 2016 ; Peck et al. 2013) observed how  
78 users’ virtual appearances can affect their thinking, feeling and acting. For example, Banakou et al. (2018)  
79 explored how switching between bodies can help the user to work on personal issues from an outside  
80 point of view. Yee and Bailenson (2007) provided evidence for what they named “Proteus Effect”: how  
81 the participant avatar’s appearance affects the participant’s behaviour, during virtual experience but also  
82 following it. When it comes to social interaction in VR, Nowak and Biocca (2003) showed that the degree  
83 of empathy that immersants express for each other isn’t correlated to the anthropomorphism of the avatars.  
84 Rather, the willingness to contribute to a group task as well as the performances obtained, are more linked  
85 to visual similarities between participants and self-identification (Wallace and Maryott 2009 ; Van der Land  
86 et al. 2015). Anthropomorphism often leads to expectations that can’t be met, while iconic representations  
87 may lead to more excitement (Nowak and Biocca 2003).

88 Along similar lines, anthropomorphic cues are not necessary for copresence to emerge. For example,  
89 Froese et al. () used Lenay and colleagues’ “cross-perceptual paradigm” (Auvray and Rohde 2012), where  
90 sensory information about the other is reduced to a very minimal representation: pairs of participants  
91 explore a one-dimensional space with their finger on which they received a tactile stimulation whenever an  
92 other entity (the partner, a lure following the partner at a constant distance, or a static object) was present  
93 in their receptive field. This minimal sensorimotor structure was sufficient enough to bring about collective  
94 dynamics between human partners participants. Indeed, Auvray et al. (2009) showed that even when  
95 participants could not consciously differentiate between the (responsive) partner and the (non-intentional  
96 and sensory deprived) lure, they were attracted by each other’s movement so that they spent more time  
97 interacting with each other than with the lure (in other words, they found each other collectively before  
98 each could find the other). When participants were invited to cooperate to find each other and co-regulated



99 their interaction, they were able to recognize the other during these minimal interactions, and the feeling  
100 tended to be mutual (Froese et al. 2014a, 2014b).

## 101 1.2 Minimalist immersion

102 VR can propose either a modelisation of the real world based on an environment which imitates or  
103 mirrors the real world, or the creation of an artificial environment which does not correspond to anything  
104 which exists (Fuchs et al. 2006). It almost always also reduces or diminishes the richness of perceptual  
105 information, by design or by the limitations of the current technology. We find that this potential of VR to  
106 reduce, simplify, prune or limit the perceptual field and the sensorimotor contingencies of the experiencer  
107 echoes a fundamental aspect of both art making and experimental science.

108 The tendency towards abstraction and minimalism is indeed one of the major characteristics of artistic  
109 practice in the 20th century (Degand 1956) and can be found in a variety of artistic fields and media, be it  
110 visual, sound, or movement arts (such as dance or theatre). Similarly, a basic property of any experimental  
111 apparatus is to abstract away multiple features of the real world in order to be able to isolate the effect of  
112 specific factors or their interactions. Learning from minimalist art and science making, we suggest that the  
113 reduction or simplification of sensory data in immersive VR is a design feature rather than a problem to  
114 overcome.

115 As an important emerging medium within the digital arts, VR challenges our perception of space, time,  
116 and self for narrative and esthetic purposes. Through the use of graphic enhancement and motion capture,  
117 numerous contributions in dance and other interactive art have explored, through abstraction, the materiality  
118 of bodies themselves. Bodies can appear as made of smoke, sand, dismembered or decomposed. In  
119 “*Ballet Rotoscope*” (Euphrate, 2011), the japanese collective decomposes the movement of a ballerina and  
120 alternatively replaces it by trails drawn by her hands, or by bounding boxes. In “*Co:lateral*” (Barros &  
121 Moura, 2016-2019) and “*Unnamed Sound Sculpture*” (Onformative, 2012), the body textures are made of  
122 shades, sparky particles and smoke, making the movement and the body limits blurrier. In “*CLINAMEN*”  
123 (Harcier, 2020), three dancers are composed of multiple spheres, moved by randomly placed movement  
124 trackers on their whole bodies. Bodies are mixing, making it harder to differentiate one from another. In  
125 these artworks, dancers’ expressivity remains perceivable through the abstracted qualities of motion, and  
126 through their appropriation of space.

127 These experiences and artworks demonstrate how VR design choices impact the way we build our  
128 representation of the world. Digital paradigms can also affect our sense of self and allow one to play with  
129 the contours of otherness, and limits of human-like entities. In “*Body Remixer*” (Desnoyers-Stewart et al.  
130 2020), several users see their own silhouettes displayed as particles on a wall, and a single user experiences  
131 the scene through a VR headset. In “*Your Place And Mine*” (Sra et al., 2018), the authors explore the idea  
132 of moving and dancing simultaneously in different locations, embodied into realistic human avatars. In  
133 “*Spheres, a Dance for Virtual Reality*”, Sarah Neville (2019) adds the idea of haptic connexion to others.  
134 A single participant interacts in VR with abstract silhouettes and some luminous spheres are connected  
135 to their hands. When they enter in contact, the participant feels a vibrating feedback from the controllers.  
136 Some VR platforms now allow multiple users to dance together with different levels of avatar realism  
137 (DanceVR, WaveVR, VRChat). While the user can only control the hands and head of the avatar (no foot  
138 tracking), the rest of the body is animated in either autonomously or in a concordance with the tracked  
139 members. Taken together, this corpus exemplifies that more than being a technical constraint, the idea of  
140 reducing the set of perceptive information coming from our own body and from social interaction offers  
141 new directions for inquiry and artistic creation.

142 Building on these ideas, in January 2019, we initiated the Articulations project, a collaboration between  
 143 the virtual spaces design research group at the ENSADLab and the ICI project (Himberg et al. 2018)  
 144 research group interested in the study of interaction through joint dance improvisation. The project led  
 145 to several public presentations as well as the formalization of a concept that we call Shared Diminished  
 146 Reality (SDR). We next discuss the platform and its design process, and then propose a formalization of  
 147 SDR and two different evaluations of our approach.

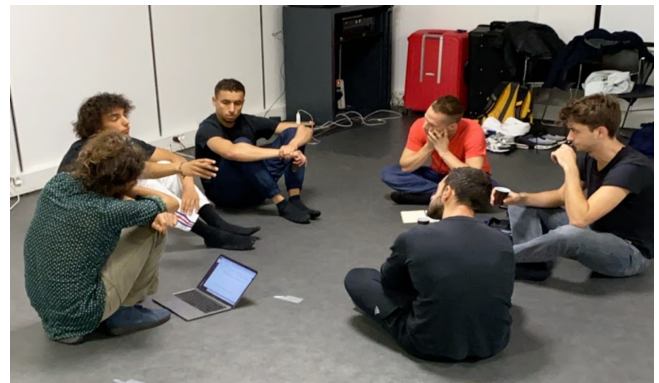
## 2 THE ARTICULATIONS PLATFORM

### 148 2.1 The research creation process

149 Financed by the new ArTec graduate school (<http://eur-artec.fr/>), the Articulation project stands at  
 150 the tangential point between the artistic and scientific practices, exploring what minimalistic body  
 151 representation in VR can offer, both as an artistic material and a research tool. The initial idea of this  
 152 research was to study interpersonal dynamics and emergence of autotelic creative behaviours through the  
 153 abstracted representation of movement and bodies, made possible by the use of virtual reality.



**Figure 1.** On the left: Two participants testing the platform during the ENSAD public event.



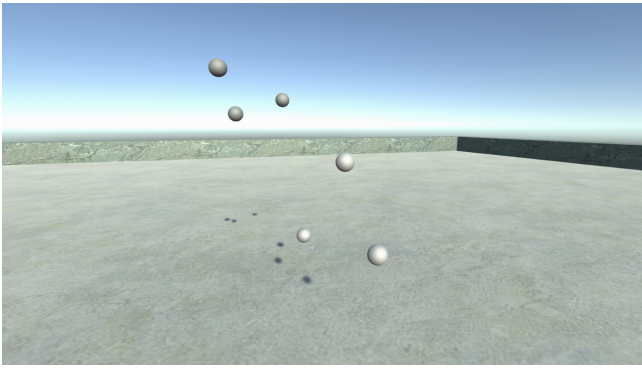
**Figure 2.** On the right: Articulations team preparing the performance with two hip-hop dancers

154 The operating principle of the project was to foster a real-time innovation dynamic between the artists,  
 155 the scientists and the designers through constant iteration between interface development and technological  
 156 improvements. The process included in-group residencies and workshops, structured experimentations and  
 157 performances open to the public.

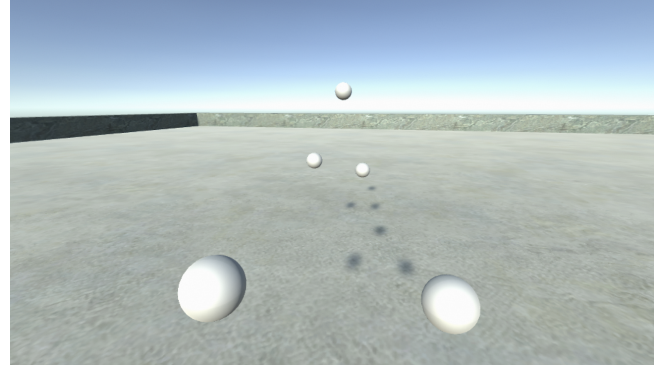
158 In the three residencies that took place in 2019, we invited the team and various guests – artists,  
 159 cognitivists, philosophers, anthropologists, designers – for a collaborative experience, letting everyone’s  
 160 domain of knowledge or practice influence the design process. Immersing ourselves in a shared virtual  
 161 reality scene, we explored what seemed relevant, avoidable, and essential to let a playful sense of self  
 162 emerge.

163 As questions and suggestions arose about the virtual surroundings and the form of the avatars, we took  
 164 advantage of the quick editing capacity of VR, manipulating at will the reduced bodies and environment  
 165 appearances. Designing through experience, as well as through debriefing and sharing, we sought to reach  
 166 a balance between shaping a comfortable visual experience, and keeping a relatively abstract scene that  
 167 would let us explore how body diminution influenced our willingness to engage in the virtual relationship.

168 The creative residencies also allowed us to collectively formulate hypotheses we then tested more  
169 formally during a series of public sessions and open-ended aesthetic insights that led to the development  
170 of a VR-dance performance. Collectively, they led us to the development of the Articulations platform: a  
171 minimalist environment where subjects interact in a minimalist manner.



**Figure 3.** Third person point of view

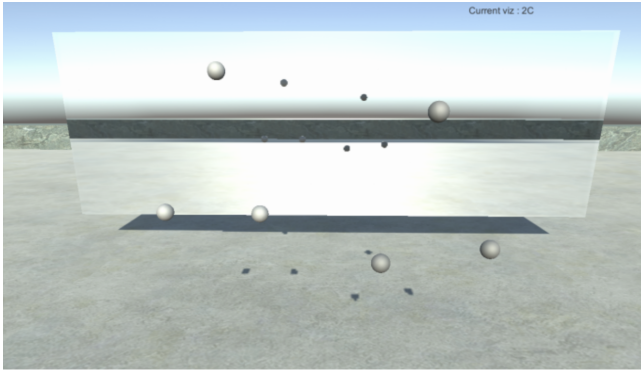


**Figure 4.** First person point of view

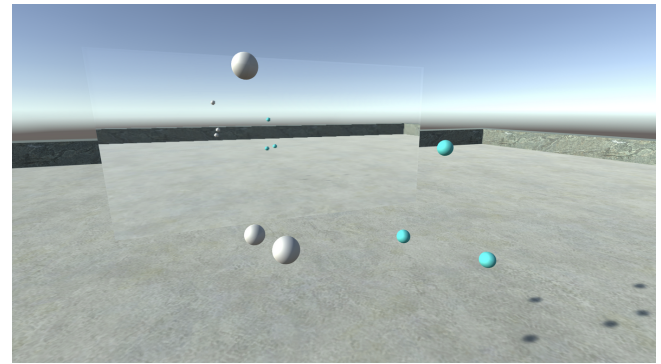
172 In this platform, participants are equipped with virtual reality helmets and two wrist trackers. Once  
173 immersed, they see two spheres representing their own hands that move in accordance with their movements.  
174 When the scenario is started, the other participant appears, consisting of three spheres representing the  
175 positions of their hands and head (fig. 3 & 4). Several changes in the environment and the appearance of  
176 the participants can be automated or manually controlled by the team via an external interface.

177 The design goal was to play with the perception of oneself, of the other, or of movement itself, in time  
178 and space and how such changes influence the feeling of being independent or the sense of togetherness.  
179 Considering the research on Proteus effect (Yee and Bailenson 2007) and how avatar representation can  
180 influence how users behave, spheres were chosen as the embodiment shapes. Through our own experience  
181 we believed that this design simplicity would allow our users to approach the experience with a fresher and  
182 more “neutral” state of mind.

183 The virtual environment itself was chosen to provide a good balance between minimalism and comforting  
184 surroundings. The wide blue sky, the natural-like lighting and the marble floor offer something rich enough  
185 to arouse the desire and confidence to explore while focusing the user’s attention on the interaction with  
186 the other or with the behaviour of one’s avatar. At times during the experience, participants see their  
187 appearances or that of the environment change: an addition of a mirror (Fig. 5), differentiating the colours  
188 of the participants’ spheres (Fig. 6), making them invisible, replacing them with particle systems whose  
189 behaviour changes according to movement qualities, or more abstract forms.



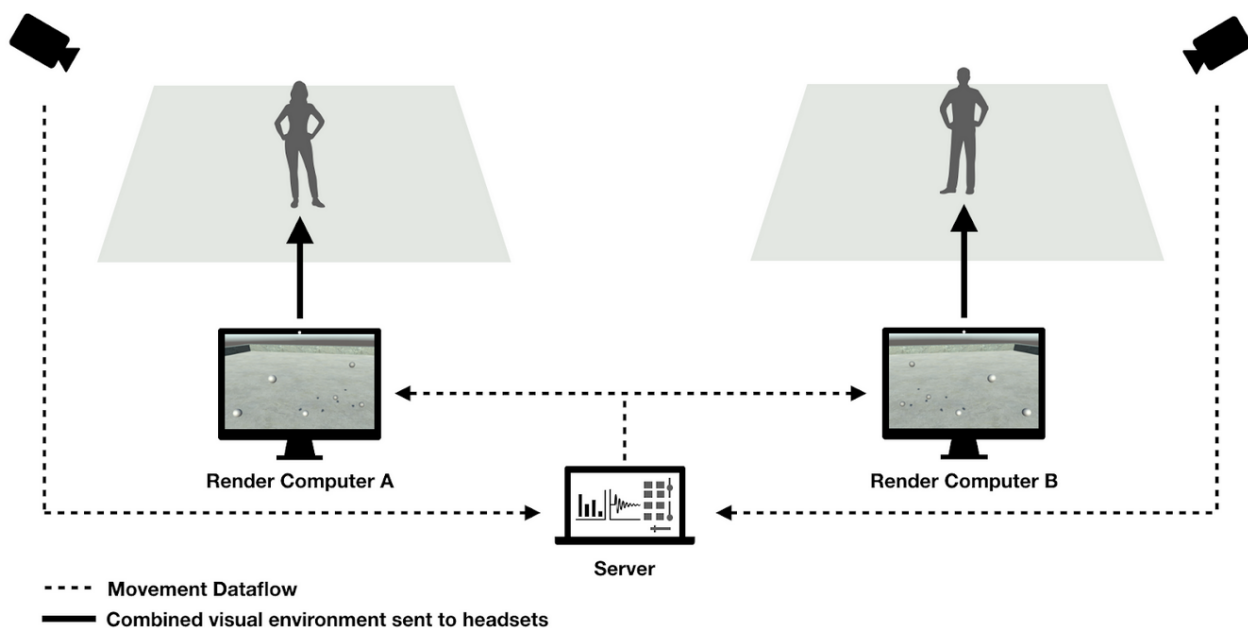
**Figure 5.** General point of view of the mirror condition with similar colors



**Figure 6.** Third person point of view of the mirror condition with different colors

## 190 2.2 Design Details

191 In terms of software, the Articulations project provides a multiuser virtual platform, with a networked  
192 client server architecture (Fig. 7), all developed using the Unity3D platform .



**Figure 7.** Illustration of the Articulations basic technical setup. Additional ‘viewer’ devices can be connected to the server.

193 For the first exploratory phase of the development, additional tools, plugins and frameworks provided  
194 by the Unity 3D community were used. This allowed us to quickly prototype a server client architecture  
195 of a virtual multiuser environment. This first version was developed in order to conduct experiential  
196 sessions during the team’s first residency, which took place in Meriel, France, in May 2019. This prototype  
197 allowed for up to four users, using the HTC Vive, to be simultaneously immersed inside the same virtual  
198 environment (VE) through a network of clients.



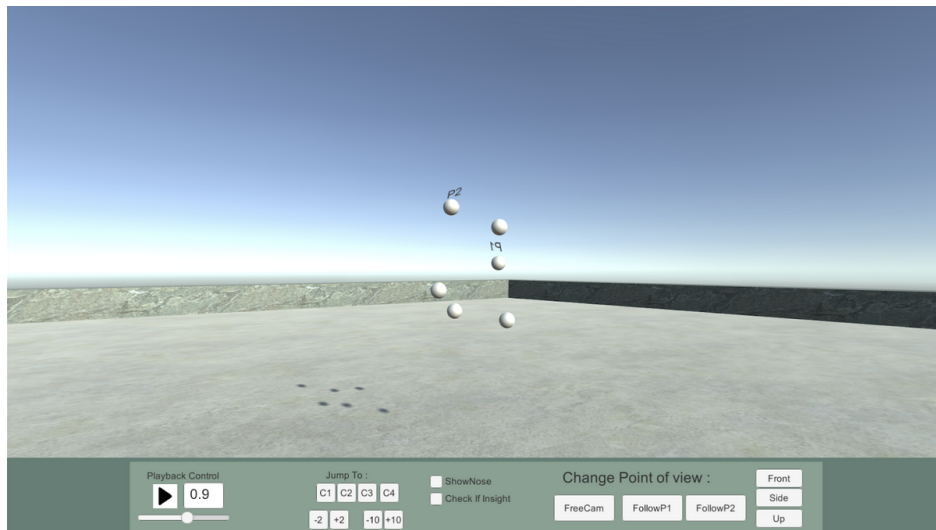
199 Each user was represented with three spheres, initially two of the same size for the hands and one third,  
200 bigger, for the head. The larger head sphere integrated a black rectangular shape where the user's face  
201 would be, in order to indicate the head's orientation. The hand spheres were driven by the Vive controllers.  
202 The goal of these sessions was to experiment with the appearance of the avatar, as well as to better define the  
203 needs in terms of environment and interaction design. During the residency, interdisciplinary discussions  
204 led to eliminating the difference between the spheres so the head and the hands were the same size and no  
205 head orientation was shown. This minimalism decreased the anthropomorphism and seemed to increase  
206 the playfulness of the encounters. Based on feedback from the Meriel residency, the second phase of the  
207 project was launched. It was decided to opt for a custom developed OSC based client/server system<sup>1</sup>,  
208 which would allow us to better handle the connections and the interactions implemented, and also render  
209 our platform independent from third party developers. This is of great importance, as Articulations is a  
210 research project and parts of it are intended to be eventually made open source, so that other researchers  
211 can further contribute to its evolution.

212 The architecture allows for a single server to host multiple clients which are assigned roles. The two main  
213 clients are the immersed participants while other clients can connect, assigned the role of a viewpoint. The  
214 server handles the evolution of the VE and the multiple conditions that are implemented in the form of  
215 scenarios. The server is in charge of creating data files to store all the information during each session, such  
216 as date and time, the conditions used, the duration, as well as the position and rotation of all the tracked  
217 body parts of each client.

218 A separate interface was designed for the viewpoint clients, which allows them to either mirror the  
219 viewpoint of one of the main clients, or manipulate a virtual camera to navigate the VE. A viewpoint  
220 client cannot alter the session and is not visible by the main clients. The view point client (Fig. 8) was  
221 conceived for three potential purposes: having a rendition of the virtual scene projected on a screen, in  
222 order to give the audience a third person point of view; tracking an external tablet that would serve as a  
223 virtual camera with the possibility to move freely into the physical space; and allowing participants to do a  
224 post-experiment re-viewing and commentary of their performance.

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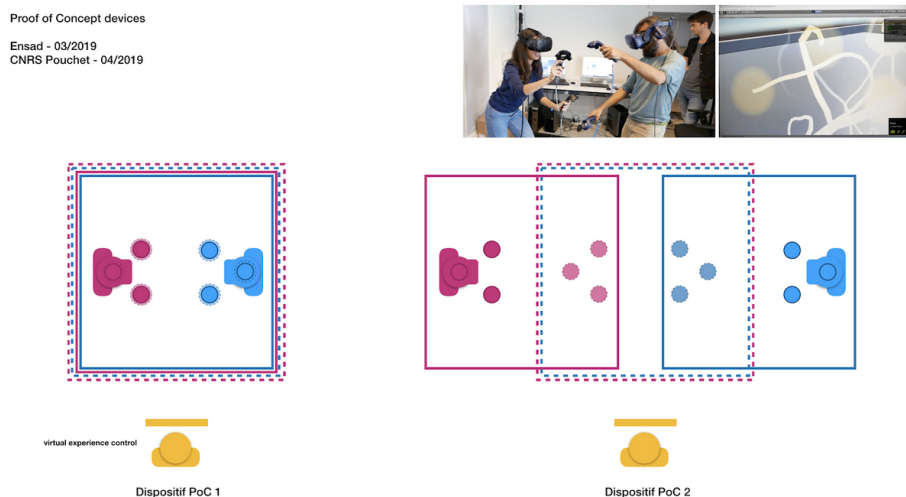
<sup>1</sup> We chose OSC as it is a widely used protocol in the field of digital art, making it easy to handle data exchange even for non-expert coders and artists. Furthermore, the whole data encapsulation system is pretty simple and straightforward, making it simpler to build a customizable and flexible networking system.



**Figure 8.** The user interface named as the “Viewer”, where one can watch a live or past performance from a third point of view

225 The environment can evolve on demand: from a minimalist arena to a dance studio, or to more artistic  
 226 landscapes. The ambient light, symbolized by a sun, can go from deep night to full daylight, its intensity  
 227 varying according to the time of day chosen. A mirror (an optional feature that played an important role in  
 228 our experimentations) allows participants to see what they look like and how their movements appear (both  
 229 individually and as an ensemble).

230 A critical aspect of the installation design, whose importance we came to appreciate more fully through  
 231 experimentation, is the mapping between the physical and virtual localisation of the two movers in space.

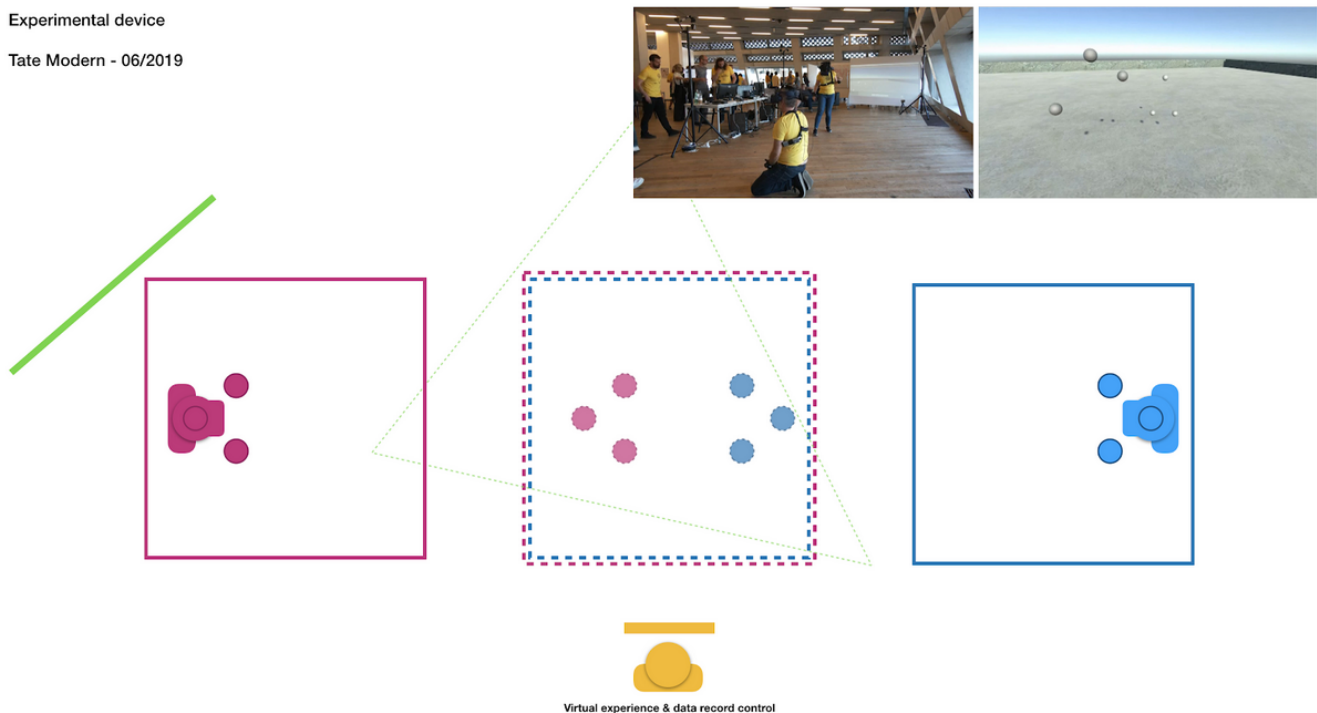


**Figure 9.** First platform proof of concept, with shared (left) and separate (right) physical spaces

232 In the first prototype we developed (on the left in Fig. 9) the physical action space and virtual space were  
 233 superposed. This choice was motivated both by an implicit heuristic of the research team to maximize the  
 234 overlap between the virtual and physical interaction and technical limits of the tracking devices. The size  
 235 of the virtual space and the location of the avatars in it were identical to the physical space (participants  
 236 could physically touch each other) and so the participants were offered a partially coherent visual, tactile

237 and auditory experience. However, since the avatars only represented 3 points on the body, the rest of the  
 238 body was invisible (partially dematerialized), generating surprising (and potentially dangerous) collisions  
 239 in the physical space.

240 For technical reasons (helmet cables getting intertwined) and to avoid recurring collisions between the  
 241 subjects, it was decided to separate the respective positions of the participants, distancing them from one  
 242 other physically, while keeping a face-to-face position in the virtual visual space (on the right in Fig. 9).  
 243 The new arrangement thus produced a different mapping between visual, haptic and auditory feedback.  
 244 The body of the other was visually dematerialized. This dematerialization was confirmed by the absence of  
 245 haptic contact. The distancing attenuated auditory cues from the partner, which also reduced and altered  
 246 the verbal interactions.



**Figure 10.** Spatial configuration used during the workshop at the Tate Modern in June 2019. The green triangle represents the viewpoint of the camera projecting a 2D representation of the experience on a screen (the green bar).

247 Fig. 6 -

248 For the public event that took place in the Tate modern museum in June 2019, we made use of the wireless  
 249 vive set-up for the first time. This setup allowed for lighter and freer movements by the participants but  
 250 required total separation of their physical positions (Fig. 10). The total decoupling of the visual spheres  
 251 from the physical position of the partner's body prevented many participants (naive regarding the workings  
 252 of the platform) from making the connection between their physical partner and the 3-sphere avatar.  
 253 Similarly, for an outside observer it became harder if not impossible to 'read' the mapping between the  
 254 physical and virtual interactions. The same spatial configuration was later used for an experimental session  
 255 in the Pouchet CNRS center in Paris.



### 3 SHARED DIMINISHED REALITY

256 Through our research-creation process, we found that dissolving (the experience of) humanness by  
257 minimizing the visual perception of one's self and one's partners seemed to enhance creativity and  
258 expressivity flow.

259 Deprived of most usual communication clues and with diminished environmental distraction, participants  
260 dynamically engaged in responsive interaction, and deployed rich ingenuity in creating a shared vocabulary  
261 through abstract movement. In line with Heider & Simmel (1944) and Lenay's group (Auvray et al. 2009 ;  
262 Deschamps et al. 2012), we observed how simple objects in movement can convey emotion, and be the  
263 basic building blocks of a relationship as long as we find in the moving object a sense of "otherness". From  
264 an experience design perspective and in dialogue with cognitive science, art performance, anthropology and  
265 sociology, we would like now to summarize how these observations address the design research field, by  
266 formalizing them into a more general concept that addresses inter-relational dynamics through abstraction  
267 in VR. We call it Shared Diminished Reality (SDR), recognizing that shared VR requires only minimal  
268 design features, and this may be ideal in foregrounding interactive copresence in a shared space.

269 As we discussed above, VR always diminishes the users' experience of their own body and the  
270 environment. By removing their bodies, we, as designers, modify their bodying experience with the  
271 world, and therefore their sense of being and presence. The SDR perspective builds on this fundamental  
272 aspect of VR to explore new paradigms of interaction at the frontiers of humanness and relationship  
273 by tweaking bodily appearances and expressive channels. New behaviours emerge through these virtual  
274 interactions, with which users compose relations and experiences.

275 Virtual bodying is afforded/possible as long as users are able to easily feel present. Sense of presence, as  
276 a concordance of senses of agency, self-location, and body-ownership (Kilteni et al. 2012), may be reached  
277 as long as the virtual world's rules are understood and integrated. In a Diminished Reality design, one aims  
278 at offering the minimal set of information allowing for rapid and intuitive self-location and self-motion  
279 perception (). However, the affordances of the environment (what one can do or how one can interact  
280 with it) should be minimized. The proximal or action space of the user should remain purposefully empty.  
281 When alone in the diminished environment, after a few seconds of uncertainty, the user has 'figured out'  
282 their location and organization in space. However, when Diminished Reality is "*shared*", body-ownership,  
283 agency and ultimately the sense of presence emerge through interaction with another. Making Sense (of  
284 self and the world) becomes inherently relational, fostering the necessity to engage with the other. The  
285 user's (re)actions create differences that are used dynamically as affordances for the sense making by the  
286 other (De Jaegher and Di Paolo 2007 ; Kimmel et al. 2018).

287 SDR is therefore a framework for designing multi-user experiences, where the main goal is to find the  
288 right balance between removing as many bodily and environmental affordances as possible while providing  
289 the minimum needed to allow a sense of (co)presence, expressivity, and interaction. We consider that  
290 balance as central in shared VR, and decisive to give our users a space to let (collective) creative flow  
291 happen (Csikszentmihalyi 1997). SDR proposes to shape the channel of interaction so to make the (shared)  
292 sensory-motor loop lighter and more transparent to the users and researchers.

293 In Articulations, our goal was to focus on the observation of shared movement and emergence of collective  
294 creative flow. In phase with the enactive literature and priming effects that are operant also in the virtual,  
295 the world was carefully shaped with a naturalistic open sky and a vast floor, showing clearly that nothing in  
296 the global environment had to be figured out. Making use of smooth spheres as avatars, the bodies remained  
297 minimized to very basic information. We invited the users to freely explore the environment. There was no

298 ‘task’ or goal to be accomplished, leaving the users to (co)create their own experience. Finally, to minimize  
299 the presence of technology, we chose to replace the cable with a Wifi adapter, and the controllers with  
300 trackers placed on their wrists. That gave our users the ability to move into the scene with less attention  
301 regarding the hardware and keeping their hands free, concentrating on inhabiting the interactional scenario.  
302 Everything was designed to keep the focus on movement relationalities.

## 4 EVALUATION

303 The Articulations experience has been created through interdisciplinary innovation. A critical component  
304 in such a process is the (collective) evaluation of ‘working hypotheses’ regarding the effect of certain  
305 parameters on user/’in-world’ experience leading to design choices. Design evaluation is in reality an  
306 ongoing dimension of the design process itself. However, in a design research process there are ‘major’  
307 moments where intuitions, ideas, observations or accidents/surprises that emerged during the design  
308 process inform a more formal evaluation step. We present this evaluation step of the platform and the SDR  
309 framework it embodies two distinct epistemological forms:

310 - A ”laboratory” installation for movement interaction studies: An installation that takes the form of a  
311 laboratory experiment, allowing us to collect both real time kinetic data and post-experience subjective  
312 reports. The installation is used to test specific hypotheses or answer specific questions. Below we briefly  
313 discuss an experiment that used kinetic data to test our hypothesis that reduced visual feedback of one’s  
314 own body increases interpersonal coordination. We will then turn to the analysis of user reports in order  
315 to evaluate whether SDR design brings about a creative attitude in participants, a meaningful relational  
316 experience between them, and the experiential effects of the minimalist body representation, minimalist  
317 decor and open-ended scenario/invitation.

318 - A ”research-creation” installation that made use of a performative form, based on the dematerialization  
319 of bodies in dance. Research creation evaluates a proposition in terms of whether it continually generates  
320 new questions. Through the creation process that we report here, new questions emerged about the potential  
321 of the hybrid virtual-physical space as ‘mixed reality’.

322 Below we discuss these two forms separately. However, it is important to keep in mind that in practice  
323 the different installations are not separate but interwoven and interconnected.

### 324 4.1 The Laboratory installation.

325 One of the original motivations for the Articulations project was the creation of a VR framework that  
326 allows for an ecological but controlled study of movement interactions. In this section, we first present  
327 a brief summary of an experiment reported elsewhere (Laroche *et al.*, under review) to show how our  
328 platform can bring forth meaningful data on relational movement. Then, we report qualitative evaluation of  
329 user experience in SDR based on analysis of questionnaire and interview data..

330 To evaluate the potential of SDR as a fruitful context for the acquisition and the quantification of  
331 movement interactions data, we organized a number of public sessions that were conceived as ecological  
332 laboratory experiments making use of the Articulations platform. Participants were invited to explore  
333 the Articulations world in dyads (as described above). In the spirit of SDR design, there was no task  
334 or goal beyond autotelic exploration. The presence of a second participant in the virtual environment  
335 was not made explicit before the experience. As we mentioned earlier, one of the consequences of the  
336 reinforced dematerialization of the bodies through spatial dislocation, was that, if they were not warned,  
337 the participants did not immediately know the other spheres to be the physical partner. Without the ability

338 to use voice, facial expression, limbs, fingers, or even orientation of the spheres as communication cues,  
339 participants needed to invent gestural strategies to dynamically figure out what relational situation they  
340 were in, and to potentially realize that another human inhabited the other spheres. In any case, this situation  
341 entailed a very playful exploration.

342 To evaluate how the design of the installation contributed to the movement dynamics and their associated  
343 experiences, we introduced slight design variations (e.g. the suppression of the visual feedback of the  
344 spheres representing one's own hands) across the experiential sessions. Each session (lasting between 10  
345 and 15 min) was thus composed by one baseline block and 2 to 3 blocks each introducing a different kind  
346 of variation. To analyze the gestural strategies deployed by the participants, we tracked and synchronously  
347 recorded the position of the 2x3 spheres at a rather high resolution (60 samples per second). This allowed  
348 us to analyze the entire trajectory of the spheres in the 3D space, and from there we were able to derive a  
349 number of kinematic features, such as the pace or intensity of movements, as well as their similarity across  
350 partners for instance. To explore the associated experiences of participants and see if they were related to  
351 kinematic features, we used questionnaires and interviews.

352 The kinematic study, performed in the Tate modern gallery in June 2019, provided interesting results  
353 (Laroche et al., under review). For instance, suppressing the visual feedback of one's own hands increased  
354 the actual coordination of hands across partners, as if the lack of self-feedback prompted attention toward  
355 the coupling with the partner's movements. By relating kinematic features to the experiential questionnaires,  
356 we also observed that when the two partners moved more slowly and similarly in space, this correlated  
357 with their mutual feelings of closeness, particularly when they were unable to see their own hands in the  
358 virtual world. In short, the installation proved useful in revealing how changing the visual feedback leads  
359 to contrasting movement patterns and induces different qualities of experience that post-hoc questionnaires  
360 were able to probe (for more details, see Laroche et al., under review). More generally, the meaningful  
361 patterns uncovered by the experimentation demonstrate the usability and interest of SDR design for  
362 experimentation in socio-affective cognitive science.

363 We now turn to the experiential reports relating to how the SDR design was experienced by the users.  
364 The protocol and the observations described below come from a second experimental session (October  
365 2019) performed in the Pouchet CNRS center in Paris. After each dyad completed their 12 minutes of  
366 improvisation (similar to the protocol used in the Tate) we proceeded to solicit their experiential reports in  
367 3 stages. First, a pre-recorded message, played through the headset's headphones, prompted participants  
368 to verbally report their feelings while still navigating the same virtual environment with their own avatar,  
369 yet in absence of their partner's. They were asked to report their experience of the moment, as well as  
370 the changes they notice compared to the beginning of the experience, or anything else they wanted to  
371 share about the experience itself. After the headsets were taken off, the participants were accompanied to a  
372 small room where they completed a questionnaire (individually). The questionnaire was composed of a  
373 quantitative section (the participant was asked to indicate their adherence to 26 different assertions regarding  
374 the experience: from 0: not at all to 6: strongly adhering), and a section with open questions allowing  
375 for personal elaboration. Once the questionnaires were completed the two participants were interviewed,  
376 together, by two team members (an anthropologist and a psychologist) following a semi-structured protocol.

**Table 1.** Categories and quantitative results of post-experiential questionnaires

Assertion ID	Immersion	Body	Relation	Assertion	Mean	SD
A9	x			I found this visual and silent space very appealing.	4.48	1.47
A10	x		x	I often (regularly?) forgot that some of the spheres represented another person.	3.62	2.15
A11	x			Real-world elements have often extracted me from my virtual reality experience.	1.24	1.56
A12		x	x	My attention was more focused on my own movements than on the relationship between our respective movements.	2.86	1.98
A13	x	x		In this virtual reality experience, I felt like I was more than my usual self.	2.76	2.03
A14		x		My movements were smoother and easier than usual.	2.83	1.86
A15			x	The connection and interaction with the other person was easy and very natural.	3.07	1.81
A16	x			I would have liked the experience to last much longer.	3.48	1.89
A17		x		I was more aware of my body than usual.	2.71	1.92
A18			x	I didn't feel that the other person was responding to the suggestions I was making.	2.95	1.71
A19	x	x		I find that the virtual reality installation limited the potential of my movements.	2.36	1.79
A20		x	x	My movements were motivated by what I thought the other person was perceiving.	2.52	2.06
A21	x		x	My partner didn't like the experience	1.79	1.84
A22		x	x	My movements and creativity were amplified by the presence of the other person.	3.79	1.85
A23	x			The simplicity of the virtual reality environment made me all the more curious and explorative.	4.38	1.61
A24			x	I was often the one who initiated interactions with the other person.	2.88	1.52
A25	x	x	x	When we could see our spheres in the mirror, I had the feeling that our movements were one.	3.19	1.92
A26	x		x	I didn't pay attention to the reflection of our movements in the mirror.	1.83	2.13
A27	x		x	When our spheres had different colors, I felt more separated from the other person.	1.98	2.14
A28	x		x	I had the feeling that the other person was absorbed by the mirror.	1.31	1.7
A29	x	x	x	When I could no longer see my own spheres, I found that I interacted more with the other person.	2.38	2.17
A30			x	The other person's way of moving made me feel that they were seeing things different from me.	2.86	1.98
A31	x	x	x	When I couldn't see my own spheres anymore, I felt closer to the other person.	2.48	2.12
A32	x			Not having any specific instructions or goals confused and misled me.	1.83	1.79
A33			x	Co-habiting the virtual space with the other person created a feeling of intimacy.	3.14	2.09
A34		x		I had a pleasant feeling of lightness	4.29	1.57

377 The choice and wording of assertions was grounded in reports collected from the users of the installation  
378 during the previous experimentations and collective retreats. Reviewing the answers to the questionnaires  
379 and the transcripts of the conversations from these earlier events, we identified statements that addressed  
380 one particular aspect of the personal experience. We extracted those representative of or similar to the other  
381 statements and those prototypical to the categories of the experience most relevant to our research interest  
382 (relational movement, bodying, immersion). Importantly, we formulated the questionnaire by staying as  
383 loyal as possible to the wording from the first-person experiences, reformulating them only when in need  
384 to precise, clarify or stylistically adjust the language. Adhering to the verbal descriptions provided by  
385 the participants themselves was fundamental to keep away from our abstractions and expectations and to  
386 address the subjective experiences directly.

387 The 26 assertions in the questionnaire could be split into 3 overlapping categories (Table 1). (i) assertions  
388 regarding the virtual environment and the degree of engagement in the experience (ex: 'I found the virtual  
389 space silent and seductive'), (ii) assertions regarding the participants' experience of their own body and  
390 movement (ex: 'I had a pleasant sense of lightness'), (iii) assertions regarding the relationship to the other  
391 avatar/participant (ex: 'my movements were motivated by what I thought the other person could see'). 6  
392 of the assertions focused on the specific modulations introduced during the experience (ex: 'I did not pay  
393 attention to the reflection of our movements in the mirror'). The list of assertions was composed of positive  
394 and negative formulations and of evaluations associated with positive and negative valence). The ratings of  
395 the 6 assertions regarding the specific modulations were used as factors in the analysis of the quantitative  
396 data (Laroche et al., under review). Here we will focus on the rating of the assertions concerning the  
397 globality of the experience, proceeding by category. For each category we will point out assertions on  
398 which there was a relative agreement across participants (defined as a mean score higher than 3.5 or lower  
399 than 2.5, with standard deviation lower than 2, cf highlighted rows in Table 1) and will provide related  
400 qualitative statements produced by participants during the monologue or interviews.

#### 401 4.1.1 The virtual environment and the degree of engagement

402 Overall, participants found that the minimal aspect of the virtual environment was inviting (A9  $m=4.48$ ,  
403  $sd=1.47$ ) and enhanced their curiosity and creativity (A23,  $m=4.38$ ,  $sd=1.6$ ). Overall, the immersion  
404 experience was not disturbed by elements of the 'real world' (A11,  $m=1.55$ ,  $sd=1.23$ ). The absence of

405 a pre-specified goal or instructions regarding ‘what to do’ did not hinder the experience (A32,  $m=1.79$ ,  
406  $sd=1.83$ ). In the interviews, the term “silence” and the minimal aspect of the design came up a number of  
407 times:

408 *“The silence was so deep that I could imagine wind just in my head, moving my hair, probably it was by*  
409 *hearing my own breathing.”* (P30)

410 *“The fact that the environment was so minimalist allowed me to avoid parasitic variables to the experience*  
411 *so in my mind there is nothing to add.”* (P11)

412 Several participants shared that the experience produced a ‘sensation of freedom’ (P36, P43). Being  
413 immersed and totally engaged with the experience, participants had a sense that time was slowing down:

414 *“Time seemed to pass much more slowly, I was thinking of nothing but the problem of the ”spheres” in*  
415 *front of me.”* (P23)

416 Immersion in the experience could be so strong as to attenuate participants’ interoceptive awareness:

417 *”the feelings of the heat and exhaustion I accumulated while moving in this machine-heated room came*  
418 *to my awareness only at the moment I took off the headset.”* (P23)

419 This last comment highlights how VR immersion can have a powerful impact on one’s experience of  
420 their own body and movement. A theme we turn to next.

#### 421 4.1.2 The experience of one’s body and movement

422 In the questionnaire, participants reported a sensation of lightness (A34,  $m=4.28$ ,  $sd=1.56$ ), once again  
423 suggesting an important impact of the immersive VR experience on their interoceptive and kinesthetic  
424 awareness and body image. This theme appeared also in the interviews:

425 *“I still remember the first 20 seconds when I was learning to use the space, to use the absence of my*  
426 *‘body’ and the transition in which I become immaterial. This condition is a bit weird, because I felt myself*  
427 *closer to the ground than I used to be.”* (P30)

428 One participant related this sense of lightness, or absence of a relationship to the floor (gravity), to a  
429 more fluid experience of their movement:

430 *“No connection to the ground, allowing for a more fluid movement.”* (P29)

431 The impact of visual deprivation on the sense of weight also came up with respect to the scenario where  
432 the participant’s own ‘hands’ were invisible to them:

433 *“I did not feel the gravity of my hands.”* (P29) The minimal visual body representation heightened the  
434 kinesthetic quality of self awareness:

435 *“My body mass didn’t exist, only my movement.”* (P43)

436 *“The opening of my movements towards a space that is larger, a more elastic feeling and warmth, a kind*  
437 *of inner energy.”* (P20)

438 Our questionnaires did not contain assertions concerning transformation or alteration of self-identity but  
439 in the interview this theme came up regularly:

440 *“I understand myself better, it is clearer.”* (P52)

441 *“I adopted and accepted the idea of being just 3 balloons, and I decided to feel myself fragmented.”* (P30)

442 *“It is an experience that has awakened in me completely new sensations and emotions in relation to my*  
443 *body and its movements and its relationship to others.”* (P44)

444 As the last quote suggests, the experience of one’s body and one’s movement was intrinsically intertwined  
445 with the presence and experience of the ‘other’ (spheres of partner), or the relationship. We turn to the  
446 relational dimension of the experience next.

#### 447 4.1.3 The experience of the relation

448 It is interesting to note that most participants were not immediately aware that the ‘other’ three spheres in  
449 the virtual environment were the avatars of their physical partner. Some realized this only when the mirror  
450 appeared, some only towards the end of the experience and some only during the interview. Despite this  
451 fact, participants did report an important positive impact of the other spheres and the relationship with them  
452 on their experience. Participants overall agreed with the assertion that the presence of the other amplified  
453 their movements and creativity (A22,  $m=3.7$ ,  $sd=1.8$ ).

454 In the interviews, a variety of relational experiences were shared:

455 *“Here, I discover this great satisfaction of being followed or chased around. This is the main thing that I*  
456 *learned about myself.”* (P47)

457 *“This ‘innocence’ makes me say (to myself), be careful, in your relationships, be vigilant.”* (P13)

458 *“[I found out] That I’m a very solitary person because I didn’t notice the movement of my partner and I*  
459 *was happy being on my own.”* (P27)

460 *“I took it as a game, where the balls ask me for things I have to give, and then I realized it was the other.”*  
461 (P31)

462 For some, the minimal body representation of the partner limited their ability to ‘read’ them and interact:

463 *“It is very difficult to interpret the behavior and intentions of the other subject only through the movement*  
464 *of the three spheres.”* (P15)

465 *“It is by the direct experience of a body that I can represent it independently of any other virtual*  
466 *parameter (space, volume, temporality, movement).”* (P46)

467 For others, the absence of self visual feedback enhanced the interaction:

468 *“When losing our spheres, we feel like we have fewer gestural options, we are kind of more obliged to*  
469 *follow the other.”* (P37)

470 *“When i no longer see my spheres, there is a shift from global attention and awareness towards the other*  
471 *[person] ”* (P37)

472 Overall, the combined feedback from the questionnaires and interviews suggests that participants were  
473 immersed in, receptive to, and inspired by the minimalist design of the environment. This extends to  
474 the ‘minimalist’ design of the scenarios. The absence of a specific goal, explicit task or instructions of  
475 ‘what to do’ did not inhibit the movement or creativity of the participants but actually enhanced it. While  
476 the minimalist avatars made it more difficult for some to interact with their partners, they did alter body  
477 perception in interesting and novel ways, destabilized perceptual ‘habits’ and increased awareness to  
478 one’s own movement and to that of the partner. In particular, many participants did not recognize the  
479 avatars as their human partners at least for some of the experience, and as a consequence could experiment



480 relationality outside the habitual social sphere. Importantly, we found that the relation had an impact on the  
481 experience of the virtual environment in a subtle but significant way.<sup>2</sup>

## 482 4.2 A research-creation installation

483 As a research creation project, Articulations focuses on the collaboration between artists and scientists  
484 as a means of discovering new questions pertinent to each of them. For scientists this means learning  
485 how, e.g., dancers engage with and explore the embodiment potential of VR in ways that scientists and  
486 most pedestrian participants do not (the latter are more semiotic/signaling in their practice) - leading to  
487 the creation of new forms of measurement (Deleuze and Guattari 1994). At the same time, artists explore  
488 platforms like Articulations in order to develop new practices of artistic expression, including designing  
489 new sensations, through the creation of artworks. The collaborative participatory design brings about the  
490 creation of new concepts that answer these emergent questions.

491 In the process of designing a performative version of the Articulations project we proposed to two  
492 performers and a choreographer to explore the possibilities offered by this new paradigm, in search of  
493 new forms of mediation and gestural creations through the dematerialization of bodies. The resulting  
494 performance was presented to the public twice, once during the Artec “portes ouvertes” presentation in the  
495 Center of Arts at Enghien-les-bains and the second time alongside of other performances presented in the  
496 scope of the “Virtual Creativity, Collective Realities” symposium which took place in the ENSAD in Paris.



**Figure 11.** Picture from the ENSAD Performance in Paris

<sup>2</sup> With respect to the concept of ‘shared VR’, one subtle but important finding in the analysis of the questionnaire regards the interdependence between one’s experience of the virtual environment and the dyad. We looked for assertions for which the responses of the two partners correlated significantly. We found that that was the case for one assertion: “I found this minimalist and silent environment inviting” ( $r=3.27$ ,  $p=0.032$ ). A possible interpretation of this correlation is that one’s experience of the virtual environment was affected by and/or affecting the experience of her partner.



497 As previously stated, our research and design processes included three interdisciplinary workshops as  
498 well as three residencies that nourished both the theoretical and artistic approaches to the Articulations  
499 platform. Some of these sessions included the participation of several guests who were affiliated with  
500 dancing in various ways, either as dancers themselves or as practitioners of other movement or dance  
501 related activities. It soon became clear to our research team that people with such a background not only  
502 perceive and experience the platform in another way, but also reveal a certain performative aspect to  
503 those who are observing them. Thus, the idea of creating a spectacular form of the platform through a  
504 performance emerged.

505 One of the values of the design process of a performance is that the artists push the scientific researchers  
506 to test the limits of the platform, while co-creating vocabulary for interaction for the various forms of  
507 engagement proposed by the platform. We came to realize that it is often these performative aspects of  
508 the platform itself, revealed through this process, that not only help guide platform innovations, but also  
509 create a common vocabulary between observers/researchers and the dancers/immersants. This allows for  
510 both scientific research design and performative design to converge towards a research-through-creation  
511 procedure, based on an ongoing interdisciplinary dialogue that ensures clarity for those members of the  
512 team unfamiliar with either design perspective.

513 The collaborative conception and design processes with the team and other researchers helped fuel ideas  
514 concerning the possibilities of the setup and interactions, as well as having feedback as to what they were  
515 seeing and sensing when watching the others in immersion. These experiences informed how we imagined  
516 the audience would react as the performance unfolded and how to best frame the actions so that they would  
517 best be perceived by the audience.

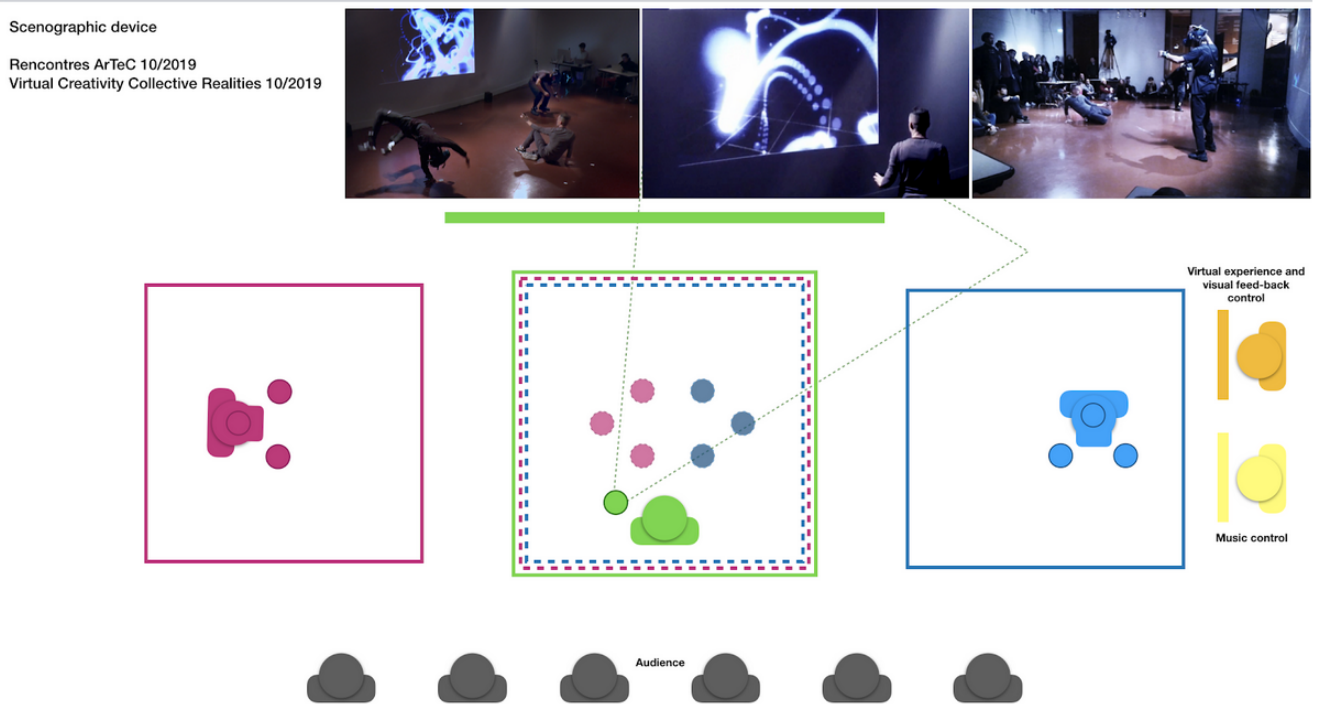
518 One important goal was conceiving a performance that was engaging, personable, accessible and that  
519 reduced the sense of distance that can occur due to barriers imposed by the elaborate technological setup.  
520 This was tackled through creating an experience that would be both entertaining and reveal the inner  
521 workings of our research.

522 Two of the performers, whose practice is based in hip-hop movement language, were outfitted with  
523 virtual reality headsets. They conversed at the beginning of the performance as if they were discovering the  
524 virtual environment and the possibilities of moving within it. This sort of low-key discussion invites the  
525 audience to understand the actions happening on stage and observe the performers and the setup without  
526 fear of a reciprocated gaze. The choreographic language was a mix of hip-hop and contemporary dance  
527 that moved in and out of unison movement accompanied by custom created music. In addition, we needed  
528 to decide the order of the execution and the effects that would be present in the video projection, while  
529 making sure this setup would work as a meaningful whole.

530 One fundamental difference in experiential design between the "laboratory" installation and the "research-  
531 creation" installation was that in the latter the audience had to be able to perceive the virtual space shared  
532 by the dancers and understand their actions and choices. The virtual reality experience had to become a  
533 mixed reality experience. Whereas in the "laboratory" installation this virtual space was only addressed to  
534 the performer and therefore had no need to be perceived in the physical space, in the "research-creation"  
535 installation it was essential to materialize their presence on stage for the audience.

536 Since the Articulations platform was originally conceived and developed to immerse participants inside  
537 a virtual environment, using it in the context of a public performance presented a number of challenges  
538 at many levels: technically, visually, scenographically and dramaturgically. Both the choreography  
539 and the performance were then conceived in a way to address these challenges and produce a shared

540 experience between immersants and audience. The technical platform itself was modified in order to  
 541 present the performers executing choreography in the physical space, while sharing feedback from the  
 542 virtual environment with the spectators, transforming their virtual experience into a shared one, by  
 543 projecting the virtual world inside the performance's physical space.



**Figure 12.** Research creation installation - The red and blue zones are the action spaces of the two dancers, whereas the green zone is the Mixed reality space - the mediator's action space superimposed on the virtual space merging the presence of the dancers.

544 Through the evolution of the platform's design the physical spaces of the participants became non-  
 545 overlapping. In the first version, the participants could physically touch and collide (Fig.9). In the more  
 546 advanced versions of the design (Fig. 10, 12), each of the dancers occupied a separate physical space. The  
 547 physical space in between the spaces of each dancer (see Fig. 12 - green square) persisted however as a  
 548 fictitious interaction zone.

549 An important innovation that emerged through the collaborative process was the turning of this fictitious  
 550 space into a mixed reality zone inhabited by the virtual presence of the two dancers and the physical  
 551 presence of a third performer, a mediator embodied by the choreographer who was not wearing a headset,  
 552 and who served as a bridge between spectator and performance space. In the version depicted in figure 6,  
 553 the fictitious zone was geometrically located halfway between the zones of the two dancers. We realized  
 554 this virtual space would remain an abstraction for the audience if it was not actualized by a presence  
 555 on stage (Fig. 12 - green figure). Thus, a "mediator" was necessary to make the link between these two  
 556 realities: that of the real bodies of the two dancers on stage, and that of their fusional and dematerialized  
 557 presence in the virtual space.

558 Working closely together with the choreographer, the designers added the ability to use a tracked VR  
559 sensor coupled with a virtual camera, as part of the performance, in which the mediator could simultaneously  
560 be on stage as a participant “filming” the avatars of the immersed performers and their interactions inside  
561 the virtual environment. The camera’s output was then projected live on a screen behind the performers,  
562 directing the gaze of the audience to the performers movements in the live space, to their virtual interactions  
563 and to the emerging relationalities in space/time. At the same time, the mediator used light touch to provide  
564 the two immersed dancers a link to the physical reality.

565 This mixed-reality shared experience is formed by multiple elements deriving from different dimensions,  
566 the physical space that includes the performers and the public, and the virtual environment that is being  
567 actualized through the performers’ gestures and interactions. Rather than conceiving the virtual and the  
568 physical as two discrete realities the mediator’s presence turns them into a “continuum” along which he  
569 seamlessly moves to provide glimpses of the events happening in another dimension.

570 The notion of the continuum finds its origin in the work of Paul Milgram and his research team (Milgram  
571 and Kishino 1994). In their work, they introduced the concept of the reality-virtuality continuum. They  
572 proposed the concept of a virtuality continuum in the context of visual displays, but their ideas have since  
573 been adopted and extended to fit all domains of research around virtual and mixed reality, whether scientific  
574 or artistic (Georgakopoulou et al. 2019).

575 In their publication “Enabling a continuum of virtual environment experiences”, Davis et al. (2003),  
576 inspired by Lewis Carroll’s book, “*Alice’s Adventures in Wonderland*”, attempt to extend the concept of  
577 the continuum. They are referring to the story as a metaphor for moving through various dimensions of  
578 reality. At the beginning of the story Alice meets the White Rabbit, a creature from another dimension. At  
579 this point, they propose, the rabbit is part of Alice’s reality and at the same time it doesn’t belong there,  
580 thus augmenting her reality. We argue that in fact, the rabbit is very much part of Alice’s reality as well as  
581 part of another reality. He is able to inhabit and seamlessly move through the different dimensions.

582 The rabbit then acts as an interface, an inter-mediate, guiding Alice through immersion. Their meeting is  
583 a key point to the story, as it marks the moment where her reality becomes augmented by the presence of an  
584 element of another reality. Much in the same way in our case, during the performance, the third performer  
585 becomes the White Rabbit, assuming the role of a mediator between the multiple dimensions, while his  
586 presence augments the audience’s reality.

587 In continuing the development of the performance, a new choreographic score based on feedback  
588 accumulated during the interviews and exchange sessions with the participants would be created. The score  
589 would unveil the various experiences as well as the underworkings of the process, and would embody and  
590 reflect the sensations and observations of the various participants. In addition, working together with a cast  
591 of dancers versed in improvised dance and somatic practices would add a dimension to the project that ties  
592 the performance and the research more closely together. The question of mixed reality and the white rabbit  
593 concept that emerged through the creation process has become a (scientific) research question that will be  
594 addressed in our upcoming research workshop in 2021.

## 5 CONCLUSION

595 The recent emergence of VR has challenged designers to conceive enjoyable and satisfying experiences of  
596 free, creative joint exploration. Interacting in space through movement offers new paradigms for interaction  
597 design. In this article we proposed the notion of Shared Diminished Reality as a design guideline for  
598 such development and presented a concrete project (Articulations) that instantiates this approach. Through

599 our work on Articulations we observed how letting abstracted bodies move and interact in a minimal  
600 environment without a predefined goal can result in the creation of singular and intimate expressive patterns.

601 The design of the platform was carried out by the iteration of experiments: collective embodied hypothesis  
602 generation, prototype design, and experiential evaluation. A good example of the potential of this approach  
603 is the evolving mapping between the physical and virtual spaces. In the original design, bodies were  
604 partially dematerialized (only certain body parts were co-localized with the avatar). We then found that  
605 it was necessary to create a physical distance between users to avoid collisions between the parts of the  
606 user's physical bodies not visible in the experience. Furthermore the partial dematerialization produced  
607 a strange sense of incoherence between the virtual physical copresence. The distancing resulted in a full  
608 dematerialization of the haptic presence of the other body during the VR experiment and a liberation  
609 of the users' gestures and imagination. The distancing of the subjects has also de-anthropomorphized  
610 the experience of the 'other', as they are no longer a priori aware that they are in the presence of the  
611 representation of another person.

612 The effect of de-anthropomorphizing was evaluated using movement quantification, and experiential  
613 reports as well as the mapping between them. In turn, the resulting mixed space (empty physical space  
614 inhabited by virtual movement) inspired the scenographic and dramaturgique development of a live-  
615 audience performance. Analysis of the kinetic data (Laroche et al under review) provides additional  
616 evidence for the impact of diminished reality on behavior. These results also point to the more general  
617 potential of SDR for scientific research on interaction.

618 In the post-experience questionnaires, participants reported finding the simplicity of the virtual  
619 environment appealing, freeing, curiosity inducing, and socially creative. They were moving and co-  
620 creating their own interactional rules, even though the nature of the 'other' spheres was not always clear as  
621 to whether it was human or digitally generated. The user's usual sense of self was altered by the minimalism  
622 of their own appearance while their visual similarity fostered a social encounter that made them improvise  
623 together.

624 Furthermore, our interviews suggest that being immersed into SDR, embodied in simple and minimalistic  
625 shapes, fostered in the users calm states of mind, easing their capacity to listen and adapt to their partner,  
626 and encouraging them to be more engaged, curious and creative.

627 Future studies by us and others should examine how these minimalist interactions reveal humans as  
628 storytellers, whose emergent behavior is not just connected to their perception but are connected to the  
629 stories they are telling themselves about what is happening. These can be seen in our initial interviews  
630 to co-shape their self and environmental understandings, suggesting the deep flexibility of cognitive  
631 mechanisms that may be missed in less open-ended experimental arrangements.

632 The participants' behavior and post-experience reports regarding their interaction with the minimalist  
633 design can inspire new forms of interfaces and virtual agents. By carefully attending to relational  
634 movement, immersive experiences can become more social, but without the overdetermination of typical  
635 anthropomorphic avatars. The generative interactive vocabulary of the experience would become their own,  
636 perfectly fitting and scaffolding dynamically, suggesting Csikszentmihalyi's Flow (1997) and Natural User  
637 Interfaces principles (Wigdor and Wixon 2011).

638 In the Performative installation, the physical distancing allowed the dancers to explore new choreographic  
639 forms playing on the entanglement and fusion of dematerialized bodies in the VR space.

640 The dancers' distancing also had an effect on the scenography, creating a median space locating the virtual  
641 reality zone on the stage. This zone, inhabited and actualized by the choreographer, transformed the

642 VR experience into a mixed reality experience for the spectators and dancers. The choreographer's role  
643 then became that of a mediator, an active passer between the virtual experience and the physical stage  
644 experience.

645 Interdisciplinary art-science labs are able to create innovative approaches to VR precisely by including  
646 multiple voices in all aspects of design, and by foregrounding play and performance as necessary aspects of  
647 this innovation. Our transdisciplinary approach offered us a way to conceive an experiment that is pertinent  
648 in each of these fields separately. Our platform, and its extension to the concept of Shared Diminished  
649 Reality is the very result of the workshops and residencies, where we tried to express and adapt our  
650 concerns through the language of different research fields.

651 One important value of the hybrid research creation procedures, such as the performance design of  
652 the Articulations platform, is in allowing for the emergence of a research through creation process. This  
653 particular form allowed for extended experimentation with features and ideas that have occurred through the  
654 previous phases of the Articulations project. For example, the recording camera feature of the performative  
655 platform was an idea that has been put forth in the earlier stages of our project, long before the conception  
656 of the performance itself. In turn, the experience gathered through the performance will nourish the design  
657 of the Articulations project in its later phases.

658 By creating interdisciplinary art-science labs, practices of playful variation are brought into direct  
659 dialogue with both scientists designing experiments and designers creating virtual environments. Each  
660 participant brings not only new questions about what can be done with technology, but also brings their  
661 values, including different notions of fun, engagement challenge, and novelty. This is similar to the video  
662 game industry, where players often reinvent games through the ways in which they play creatively with  
663 glitches, "mod" the games, and play new games on top of the apparent game (Boluk and LeMieux 2017).  
664 These emergent practices often seed the next wave of games. Similarly, artists and dancers reinvent media  
665 such as virtual reality through engaging the technology within a frame of play and asking new questions  
666 (Kozel 2007).

667 The Articulations platform was developed with and for dancers. This was both a strength and a limitation.  
668 It emphasized the creation of an environment that invites interactive movement exploration without verbal  
669 language. Choreographers, for instance, noticed things about distracting environmental features, and  
670 interpersonal signaling constraints that no one else did. Similar contributions were made by visual artists,  
671 programmers, anthropologists and psychologists in the lab. The challenge of creating a performance  
672 tested the improvisational abilities of all the team members, while also providing a discrete goal to  
673 have a production-ready system. It sharpened the environmental design, the interactive formats, and the  
674 experimenters' awareness of the experience of being in diminished reality.

675 The way we shaped our experimentation protocol is also something that goes beyond our usual work  
676 habits. The questionnaires and interviews were designed based on how we, virtual reality designers,  
677 sociologists, anthropologists, dancers, and cognitivists, had each gathered behavioral data within our own  
678 disciplinary frames. Concepts such as presence, sense of self, bodying, worlding, each have their own  
679 literature and references in our fields, but this confluence allowed us to stand at the crossroads of them,  
680 allowing each of us to learn new things that we can return to our fields with, what Cohen-Cole describes as  
681 the interplay between interdisciplinary and multidisciplinary (Cohen-Cole 2007).

682 Shared Diminished Reality emerged from an interdisciplinary research creation process between the  
683 laboratory and performances. By aesthetically abstracting the gesture from other forms of communication,  
684 it highlighted and confirmed the semantic and emotional power of the gesture and its central role in



685 interpersonal communication. Scaffolding shared experiences, built on users' emergent gestural vocabulary,  
686 seems to be an interesting lead to follow. Virtual reality is certainly an art of the gesture, of the act in  
687 becoming, and this new artistic form is fully in line with the continuity of living art such as dance or  
688 improvisational theater, as much as the arts of temporal storytelling such as cinema.

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