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## [Re]moving bodies - a Shared Diminished Reality installation for exploring relational movement

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# [Re]moving Bodies-A Shared Diminished Reality Installation for Exploring Relational Movement

Julien Laroche<sup>1,2\*</sup>, Loup Vuarnesson<sup>3,4</sup>, Alexandra Endaltseva<sup>5</sup> and Asaf Bachrach<sup>2</sup>

<sup>1</sup> Center for Translational Neurophysiology of Speech and Communication, Italian Institute of Technology, Ferrara, Italy, <sup>2</sup> UMR7023 Structures formelles du langage, St Denis, France, <sup>3</sup> École Nationale Supérieure des Arts Décoratifs, Paris, France, <sup>4</sup> Emotic, Nantes, France, <sup>5</sup> INSERM U1276 Centre d'étude des mouvements sociaux, Paris, France

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### \*Correspondence:

Julien Laroche  
lajulienroche@gmail.com

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In this article we explore an epistemic approach we name dis/embodiment and introduce “Articulations,” an interdisciplinary project bringing together Virtual Reality (VR) designers, cognitive scientists, dancers, anthropologists, and human-machine interaction specialists. According to Manning (2009), our sense of self and other emerges from processes of bodying and relational movement (becoming oneself by moving in relation with the world). The aim of the project is to exploit the potential of multi-person VR in order to explore the intersubjective dynamics of relational movement and bodying, and to do so with scientific, artistic and therapeutic purposes in mind. To achieve this bridge, we bring up a novel paradigm we name “Shared Diminished Reality”. It consists in using minimalist representation (as inspired by the perceptual crossing paradigm of Auvray et al., 2009) to instantiate users’ bodies in the virtual space. Instead of using humanoid avatars or full body skeletons, we reduce the representation of the moving bodies to three spheres whose trajectories reflect the tracking of the head and the two wrists. This “diminished” virtual rendition of the body-in-movement, we call dis/embodiment. It provides a simple but clear experience of one’s own responsive movement in relation to the world and other bodies. It also allows for subtle manipulations of bodies’ perceptual and cross-perceptual feedback and simplifies the tracking and the analysis of movements. After having introduced the epistemic framework, the basic architecture, and the empirical method informing the installation, we present and discuss, as a proof-of-concept, some data collected in a situated experiment at a science-art event. We investigate motion patterns observed in different experimental conditions (in which participants either could or could not see the representation of their own hands in the virtual space) and their relation with subjective reports collected. We conclude with reflection on further possibilities of our installation in exploring bodying and relational movement.

**Keywords:** virtual reality, interpersonal coordination, phenomenology, joint action, social interaction, shared experiences

## INTRODUCTION

How can we use Virtual Reality (VR) to better study the role of the movement interactions in our experience of self and other? To approach this question, we propose an epistemic framework, “dis/embodiment,” where the body is not taken for granted as physical but is actively constituted and experienced through the relational movement between “the self” and “the other.” After explaining this approach, we demonstrate the benefit of using VR as a dis/embodiment technique. We then introduce the concept Shared Diminished Reality (SDR) to describe a minimalist multi-user VR design. To demonstrate the potential of SDR to support dis/embodiment research, we describe “Articulations,” an interdisciplinary project at the border of philosophy, art installation and empirical cognitive sciences. We present an analysis of the data collected at the event “Moving Humans: with CREATE” at the Tate Modern, a proof-of-concept situated experiment within a public museum event. Finally, we discuss how “Articulations” and its design contributes to the philosophical and scientific questions about relational movement and bodying.

### From the Experiential Body to Bodying Together Through Relational Movements

According to Erin Manning (2013), bodies do not pre-exist as objects within a pre-existing environment (or world); bodies as subjects co-become with the world they move in. Philosopher Brian Massumi builds on this: “*movement moves individuation, and in the process makes that ultimate chunk we call our body an event requiring a verb—bodying*” (Manning, 2013, p. xxiii). Hence moving is at the heart of bodying and worlding, and it is through relational movement that the subject-world is constituted. An epistemic shift from the “movement of bodies” to “bodying” enriches our understanding of movement with emotional and ethico-affective dimensions: how emotions, motions, and consciousness feed into each other (Foolen et al., 2012) in the ongoing formation of what we call “our body.” It invites the study of body-in-movement as “*the knowing self [which] is never finished, whole, simply there and original (...) able to join with another, to see together without claiming to be another*” (Haraway, 1988, p. 586).

This relational perspective on movement relates to Goffman’s (1978) research into how selves are constructed through their performative interactions with objects and persons, and to Blumer’s (1969) description of how meanings of self and others are made in interaction. We extend Goffman’s (1978) and Blumer’s (1969) constructivist approaches, inviting an understanding of the body as an emergent relational happening. We draw our epistemic inspiration from Donna Haraway’s notion of “apparatus of bodily production” (Haraway, 1991) which points to how things and bodies—material bodies, semiotic devices, and discursive tools—are always in relational becoming. We also build upon the enactive approach that situates the emergence of embodied experiences in a relational sensorimotor loop between an agent and the world she engages with (Varela et al., 1991)

together with others (De Jaegher and Di Paolo, 2007; Fuchs and De Jaegher, 2009).

A number of psychologists and philosophers have long argued that interactions with others in particular take an important place in the constitution of the self and its behavior (Merleau-Ponty, 1960; Vygotsky, 1975; Penuel and Wertsch, 1995; Kyselo, 2014), blurring and making malleable the boundaries between the self and other (e.g., Mead, 1934). The inherent circularity between the movements of self and other has been described as a self-organized, dynamical process by the enactive approach, which has discussed how movements of interacting agents get coordinated within the interaction process itself (De Jaegher and Di Paolo, 2007; Dumas et al., 2014; Laroche et al., 2014). Manning (2009) names such interpersonal (or, as she puts it, trans-subjective) dynamics “relational movement.” According to Manning (2009), by moving together, we are bodying each other. In that sense, the experience of our (and others’) bodies, or “bodyings,” emerges from relational movements, both during development (Stern, 1985) and during the microgenesis of our instantaneous interactions (Manning, 2013; Sheets-Johnstone, 1999).

This body we experience as relation can potentially be the locus of a variety of disorders related to disembodiment as well as “relational” syndromes (for schizophrenia, see Varlet et al., 2012; Kyselo, 2016; (for autism, see for example De Jaegher, 2013; Koch et al., 2015; Fitzpatrick et al., 2016; Peper et al., 2016). We speculate that if bodying emerges through relational movement then abilities and disabilities, cognitive and body norms and deviations can be approached through the understanding of the qualities and properties of relational movement. In other words, what has been perceived as a “faulty” or “broken” body might be approached as a relational mismatch. The relational perspective in disability studies understands dis/ability as a relationship between an impairment and environment (Moser, 2006; Shakespeare, 2014; Goodley, 2017). While we do not directly address the topic of dis/ability in this paper, this relational perspective has served us as an inspiration for how the inquiry of bodying and relational movement could be enriched and taken further.

Erin Manning’s articulation of “bodying” offers an opportunity for alternative epistemic approaches to the bodies that differ or deviate from medical or heteronormative “norms”: bodies (and not only human bodies) which are multiple and compose with each other, bodies which escape fixation. We therefore inquire about ways of studying bodies without taking them for granted: how to stick to relationality and movement in the scientific interrogations of the body? “Not taking for granted” in scientific interrogations of (not only) bodies is what we learn from feminist embodiment approaches (e.g., Haraway, 1989) to compose our conceptual frame. This does not mean a plunge into constructivism. Rather, this move is somewhat close to Latour’s (2010) “compositionist manifesto”—a refusal to fall into universalism or relativism in knowing the world and a commitment to rethink the modes of being/acting in the world of scientific facts. For Latour (2010, drawing on Whitehead), bifurcation between the objective and subjective,

appearances and reality is a slippery slope in “nature” and “future” debates. Meanwhile, compositionism, putting diverse parts together without threatening their diversity, is “a search for the Common” with “caution and precaution” (ibid, pp. 487–488; also in Endaltseva and Jerak-Zuiderent, 2021). When it comes to bodies, Latour’s claim that “the task of searching for universality but without believing that this universality is already there, waiting to be unveiled and discovered” (Latour, 2010, p.474) might start from removing bodies as we know them. This is not to neglect the traces of socio-cultural and hierarchical compositions we embody but to intake that “what is to be composed may, at any point, be decomposed” (Latour, 2010, p.474). We propose that bodying and disembodiment are conceptual sisters—moving each other into action, composing and decomposing what is known with, about, and from the body which is always in relational movement with people and things at place. Manning (2009) argues that “we move not to populate space, not to extend it or to embody it, but to create it” (Manning, 2009, p.12). Thinking together with Manning and Latour we endeavor to operationalize an epistemic and methodological configuration that does not take bodies for granted, harnessing the movement between disembodiment and bodying as part of the apparatus. We name this conceptual turn “dis/embodyment”: by suspending the habit we call “our body,” we can provide a novel window (from first and third person perspectives) into the diversity of bodying experiences.

In the next section, we show the benefit of using VR as a technique to approach dis/embodyment, then we propose a materialization of such a methodology in a device called “Articulations” using multi-person VR along minimalist design, a technique we call SDR.

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## Virtual Reality as a Tool for Dis/embodyment

We propose that VR is a vehicle to approach dis/embodyment. By providing highly realistic and immersive stimuli, VR tools can easily fool the cognitive system and therefore alter the perception of the world and the self. This allows for paradigms that are “valid and highly ecological without compromising experimental control” (Loomis et al., 1999). Different kinds and degrees of dis/embodyed experiences can then be designed and tested. Moreover, VR tracking systems allow for precise measures of the users’ kinematics, without requiring an additional motion capture system. Practically speaking, VR setups are now easy to transport and to install in various venues. Therefore, such setups are easily reproducible “in the field” in experiments with identical parameters and sensorial conditions, as well as quickly customizable to fit the actual environmental configuration (dimensions, length of experimentation, number of participants). What follows is a brief review of empirical research on/in VR which we introduce as a demonstration of its potential for dis/embodyment studies.

The question of the body and its appearance in the virtual world is one of the most important topics in the design of VR environments (Murray and Sixsmith, 1999). Indeed, the constitution of our body’s experience seems to be as complex

and subject to multiple factors in the virtual world as it is in “normal” reality. The “Proteus effect” (Yee and Bailenson, 2007) describes how manipulating the features of a person’s avatar modulates her behavior and her affect, with effects lasting even after the immersion. In other words, VR can induce new perceptions of one’s own emotional and physical capacity. For instance, people behave more confidently with taller avatars (Yee and Bailenson, 2007; Yee et al., 2009) and they report more negative and aggressive thoughts if their avatars are dressed in black or in Ku Klux Klan outfits (Peña et al., 2009). In general, differential embodiment effectively modulates and changes the way we think, feel and move in socially and culturally patterned ways (Banakou et al., 2013; Kilteni et al., 2013; Peck et al., 2013).

The alteration of a body’s position in the virtual space can also create a physical discomfort which subjects are typically trying to compensate for, although their “real” body position was actually comfortable in the first place (De la Peña et al., 2010). The modulation of behavior and affect by bodily related experiences also happens with less anthropomorphic avatars. For instance, robot-like avatars tend to produce a certain feeling of security when facing a dangerous situation (Lugrin et al., 2016). The same goes for the shape taken by the virtual other: the mere choice of avatar skin color has an effect on the willingness of a group of individuals to collaborate (Wallace and Maryott, 2009). In contrast, a balanced combination between visual similarity among members and self-identification enhances social attraction between them, as well as their motivation to contribute to a group task and the task performance itself (Van Der Land et al., 2015). Importantly for our purpose here the feeling of social presence isn’t correlated to the anthropomorphic realism of avatars (Nowak and Biocca, 2003).

In sum, with its capacity to modify, transform or compose with the appearance of “real world” percepts (related to ourselves, others, and the environment), VR lets us reconstruct and discover new elements of our self as we perform our identity through self-exploration and role-playing (Turkle, 1995; Taylor, 2006). It allows for experiencing and experimenting with the links between bodying and relational movement in a controlled and replicable manner.

## Shared Diminished Reality: Re-moving Bodies

To investigate relational movement and bodying through dis/embodyment, we have developed a multi-person VR installation where the immersed participants are co-present via minimalist dis/embodyment. We call this minimalist paradigm SDR, as we retain basic elements of interactive behaviors yet limit the range of possible actions and the amount of perceivable information. This allows participants to focus their attention on the interaction process and permits us to capture and to analyze body motion more easily and readily.

In order to design a VR environment that challenges what is taken for granted about the body, we chose to stay away from anthropomorphic avatars and to invite users to experience bodying without most of its usual properties. Indeed, extensive research has demonstrated the ease with which we

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343 can still perceive human biological motion (Johansson, 1973),  
 344 animateness (Heider and Simmel, 1944), emotion (Dittrich  
 345 et al., 1996), and interactional behaviors (Froese et al., 2014a)  
 346 from a very reduced set of information consisting of a few  
 347 moving points. Following a similar logic, we argue for the  
 348 simplification of the virtual body's appearance to a very minimal  
 349 form (three spheres in our case). Since both our dis/embodiment  
 350 approach and our interest in relational movement eschews  
 351 anthropomorphic realism, we avoid the conundrum of the  
 352 "neutral." In other words, we do not need to create de-  
 353 sexualized/de-racialized avatars or make arbitrary or normative  
 354 choices concerning body shape and appearance. In order to  
 355 avoid confounding or distracting factors (e.g., independent  
 356 movement, additional objects, attention-grabbing details), and  
 357 facilitate real time data streaming, data recording and modeling  
 358 of interactional behaviors, we also chose to reduce to a minimum  
 359 the virtual environment itself.

360 Engaging the main theme of this special issue, SDR allows  
 361 for experimentally controlled dis/embodiment. For example,  
 362 we can manipulate the appearance, position, and dynamics  
 363 of the points representing the avatar, and we can play with  
 364 the amount of information provided by the environment and  
 365 the interacting avatars. We can thus modulate and favor the  
 366 participants' behavior, affect and interaction dynamics that are of  
 367 direct interest to us. This way, SDR enables us to investigate the  
 368 possibility for human beings to interact, being deprived of most  
 369 of the usual communication means such as voice, body posture,  
 370 facial expression, hand gestures. The underlying assumption here  
 371 is that getting rid of these sociocultural and linguistic modes of  
 372 communication would help to highlight (for the experimenters  
 373 and participants) the dynamics of relational movement that  
 374 constitute our collective bodying.

375 What follows in the next part is a detailed presentation of our  
 376 project "Articulations," which implements a specific instantiation  
 377 of SDR for the study of bodying and dis/embodiment. We  
 378 first introduce the project and the techno-scientific framework  
 379 behind the design and the construction of this device. Then,  
 380 we describe its modus operandi through a presentation of  
 381 an art-science public experimentation that took place in June  
 382 2019 on the occasion of an science-and-art event at the Tate  
 383 Modern in London.

## 385 **Articulations : A Design Project and an** 386 **Installation**

387 Starting in January 2019, the project "Articulations" has  
 388 brought together VR designers, cognitive scientists, dancers,  
 389 anthropologists, and human-machine interaction specialists.  
 390 The aim was to develop a methodological and technical  
 391 dis/embodiment installation ("Articulations") that (1) augments  
 392 and modulates users' sensitivity to the relational experiences  
 393 of dis/embodiment and bodying and (2) permits scientists  
 394 to experiment on, observe and interrogate the trans-subjective  
 395 processes that underlie dis/embodiment and bodying. The central  
 396 idea has been to offer a collaborative experience by immersing  
 397 two users, using portable headsets, in an SDR environment,  
 398 dis/embodying each of them as a set of three floating spheres  
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400 whose animation is derived from the movement of their head and  
 401 two hands. Moving between different disciplines and perspectives  
 402 on the body, the "Articulations" multidisciplinary team engaged  
 403 in a process of participatory and immersive design. As a result,  
 404 relationality and bodily lived experiences that the installation  
 405 aims at highlighting were core parts of its design process itself.

406 The development of the first "Articulations" prototype took  
 407 3 months, after which a group of artists, scientists, and  
 408 philosophers was invited to spend 3 days in a brainstorming  
 409 residency with the project team. During the residency, each  
 410 participant explored the SDR prototype with various partners and  
 411 also observed others exploring it, thereby soliciting insights from  
 412 multiple perspectives. We spent over 10 h in facilitated meetings  
 413 sharing our own experiences and discussing the potentials  
 414 and limits of the installation in order to improve its design.  
 415 Following the residency, we organized a first public event with  
 416 local volunteers (recruited through email and social networks  
 417 announcements). We developed a quantitative and open-ended  
 418 questionnaire addressing participants' lived experiences of the  
 419 device itself, of their own body feelings as well as their  
 420 relational experiences. We also designed a series of questions  
 421 to be given to participants in post-experience discussions.  
 422 The experiences shared by participants informed the next  
 423 cycle of technical modifications and the creation of a general  
 424 experimental protocol.

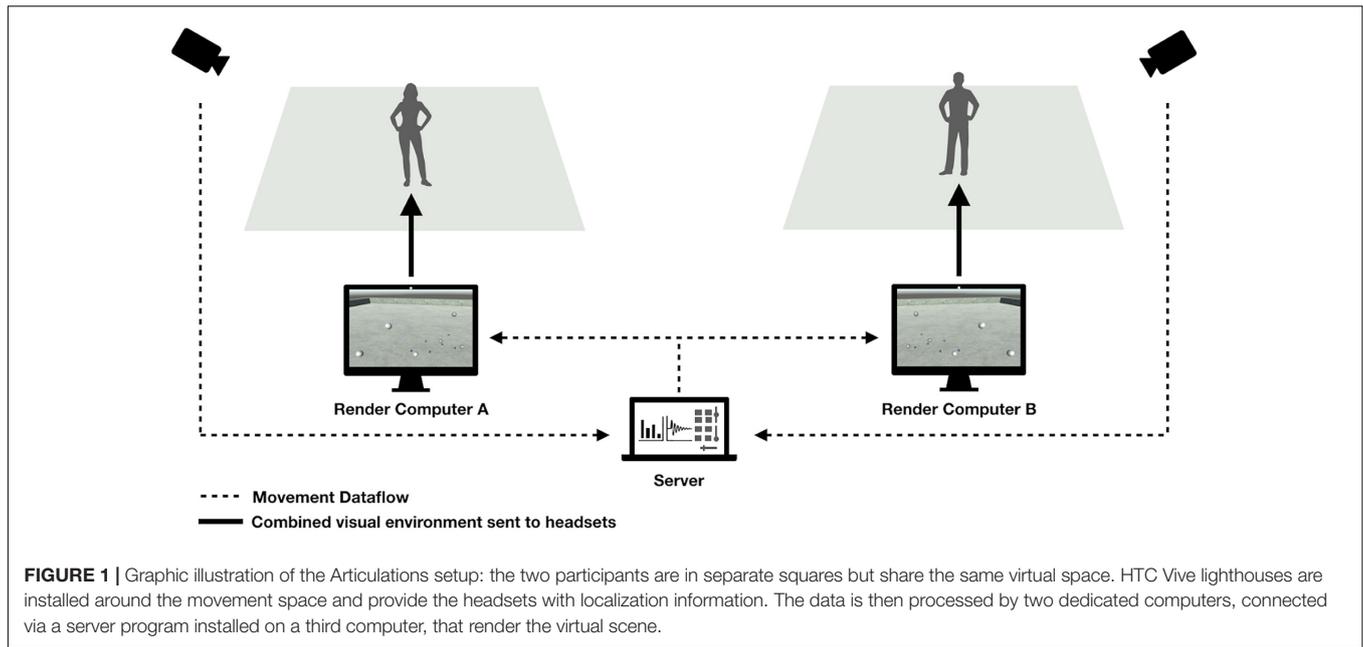
425 In this protocol, both users have been placed in separate  
 426 physical squares in order to prevent collisions (**Figure 1**) yet  
 427 participate in the same space in the virtual environment where  
 428 they can move, walk and interact in real-time. The virtual space  
 429 itself has been made exceedingly simple: users were placed on an  
 430 empty plane, under a luminous and wide blue sky (see **Figure 2**).

431 Concerning the interaction design, we conceptually draw on  
 432 Manning's proposition that dance practice orients our attention  
 433 to the movement of bodying: "*There are an infinity of ways of*  
 434 *touching on the more-than that is movement-moving. Dance is one*  
 435 *example. What dance gives us are techniques for distilling from*  
 436 *the weave of total movement a quality that composes a bodying*  
 437 *in motion"* (2013, p. 14). To observe general and spontaneous  
 438 aspects of relational movements under various conditions of  
 439 dis/embodiment, the protocol thus invites users to explore the  
 440 environment (which includes their partner) freely, in a non-goal  
 441 oriented, non-constrained manner. This is what one would do  
 442 in Collective Dance Improvisation (CDI), where the activity of  
 443 the dancers is based on the qualities they experience in moving  
 444 together (Himberg et al., 2018). Conceptually, dancing is the way  
 445 we learn to body, that is, to experience and interact with a world.

## 448 **A SITUATED EXPERIMENT AT THE TATE** 449 **MODERN**

450 In June 2019, we were invited to present our device during the  
 451 workshop "Moving Humans" at Tate Modern museum (London,  
 452 United Kingdom) organized in collaboration with CREATE  
 453 (University of London). The event was free and open to the  
 454 public. For the purpose of this event, we created a specific  
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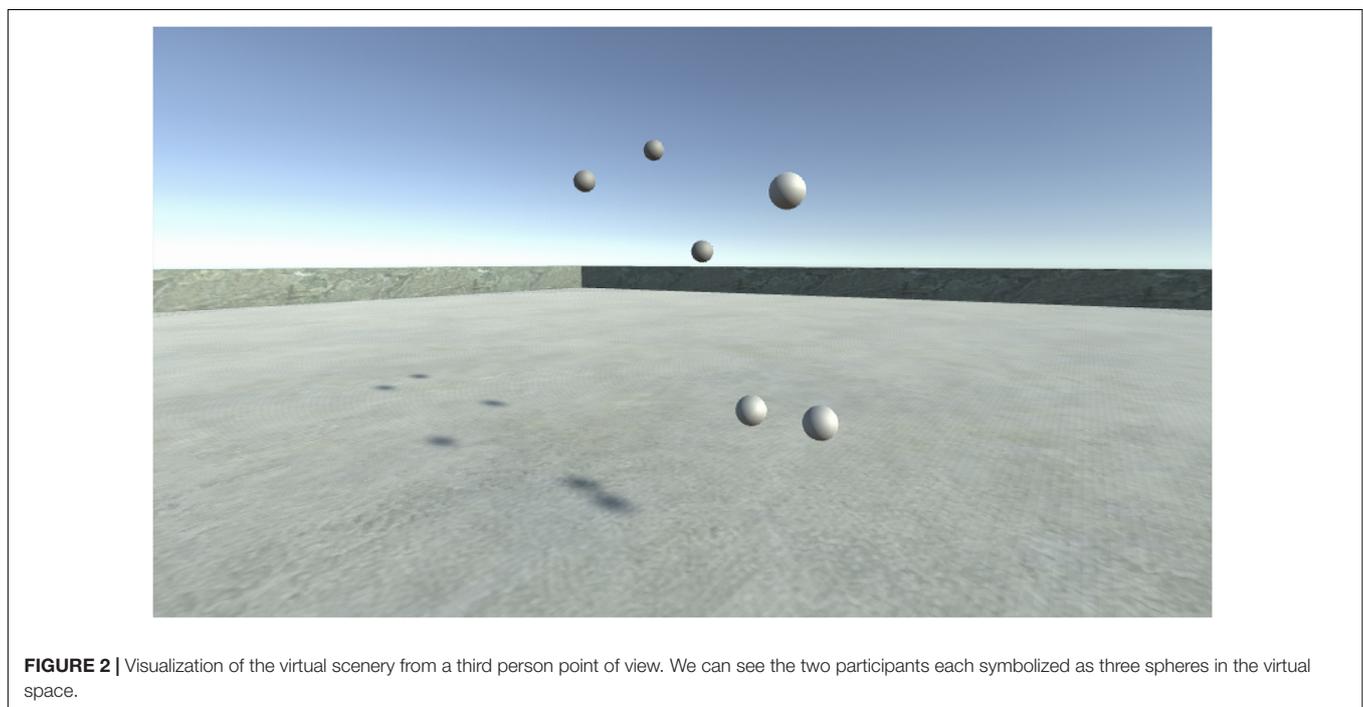
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**FIGURE 1** | Graphic illustration of the Articulations setup: the two participants are in separate squares but share the same virtual space. HTC Vive lighthouses are installed around the movement space and provide the headsets with localization information. The data is then processed by two dedicated computers, connected via a server program installed on a third computer, that render the virtual scene.

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**FIGURE 2** | Visualization of the virtual scenery from a third person point of view. We can see the two participants each symbolized as three spheres in the virtual space.

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protocol that allowed us to combine an artistic and playful experience with a scientific agenda.

## Situated Experimentation

Our interest in introducing a SDR installation into the hybrid art/science event is related to a growing trend of scientific research based on, or targeting, artistic practices (Skov et al., 2018). However, it has a distinctively different logic, inspired by Latour's (2010) "compositionist" search for new ways of acting in the world of scientific facts. We draw upon a specific

genre of "acting science" which Latour has developed throughout his collaborative "thought exhibitions" such as *Making Things Public: Atmospheres of Democracy* or *Critical Zones* to propose an extension of a "method exhibition" or "data collection exhibition." In other words, we mix data collections, reflection on the data collection, and the demonstration/explication of the data collection for finding a mode of collaborative design *in situ*. Therefore, the protocol which follows does not fit nicely into the category of a lab-experiment, nor is it simply data collection in the field or a scientific observation of an artistic process/event.

571 The protocol is linked with a particular event where the scientists,  
 572 artists and public all have their respective “agendas” which might  
 573 coincide or not (unlike the concept of a subject of a psychology  
 574 experiment that “serves” the agenda of the experimenter). The  
 575 protocol integrates multiple contingencies and specificities that  
 576 cannot be meaningfully replicated, given that it is exactly these  
 577 singularities that make the event a “happening.” For the scientists  
 578 in the project, the ambition was to be able to collect quantitative  
 579 data and to be able to observe the effect of slight modification  
 580 of the experience on the (relational) movement of participants,  
 581 relating these differences to differences in the lived experience  
 582 of the same participants. Given the singularity of the event, and  
 583 since our epistemic approach does want to embrace and not  
 584 abstract away from real-world complexity, the criteria assumed  
 585 behind standard statistical/analytical methods are often not met.  
 586 However, as part of the process of developing custom analysis  
 587 tools, we chose to apply standard methodology as an attempt to  
 588 provide connections between this epistemological approach and  
 589 more canonical experimental results in the literature.

590 The section below presents the resulting art-science  
 591 happening prototype, and some ensuing observations. It can  
 592 be thought of as a report of proof of concept(s) departing from  
 593 dis/embodiment as an epistemic framework. An epistemic stance  
 594 of dis/embodiment, we recall, allows a compositionist approach  
 595 (Latour, 2010) to the body in scientific research (and not only)  
 596 where the body and its physical composition are not taken for  
 597 granted. This suggests a possibility to study bodying experiences  
 598 as they emerge relationally from movement. The event described  
 599 below works with this suggestion, hypothesizing that a specific  
 600 form of VR, we called SDR, provides, first, a material framework  
 601 for dis/embodiment as a concept, and, second, a methodological  
 602 opportunity to experiment with it. We anticipate that our  
 603 prototype of SDR, an installation called “Articulations,” would  
 604 allow linking experiential and qualitative investigations of  
 605 bodying with experimental and quantitative examination of  
 606 relational movement. Finally, we anticipate a proof of concept  
 607 on the feasibility of situated art-science experimentation as we  
 608 present some meaningful data from an installation within the  
 609 museum, where visitors, fellow exhibitors, and casual passer-bys  
 610 become experiment participants and observers.

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## Design

614 A common feature of psychology experiments and (durational)  
 615 art installations is the use of minimal contrasts (Bateson’s  
 616 “differences that make a difference,” Bateson, 1979). Scientists  
 617 and artists often introduce subtle changes into an ongoing  
 618 “event.” For the scientist this is a way of disentangling the  
 619 cognitive correlates of a specific parameter (e.g., perceptual  
 620 changes). For the artist, minimal differences heighten the  
 621 aesthetic tension of the work (Massumi, 2015). For the Tate,  
 622 we chose to produce a 9 min continuous “scenario” within  
 623 which we introduced, every 3 min, a more or less small  
 624 change (changing the “condition,” in experimental parlance,  
 625 to allow for contrasts to emerge). We developed two such  
 626 scenarios, each exploring a slightly different set of questions:  
 627 the “Transformed Bodies” scenario, which involved changes in

628 avatars’ appearance, and the “Mirror” scenario, which involved  
 629 interacting in presence of a mirror.

630 In the first scenario (“Transformed Bodies”), the avatars’  
 631 appearances were slightly different in each condition. In contrast  
 632 to a baseline situation (where each avatar is represented by  
 633 spheres corresponding the head and both the hands), a situation  
 634 was introduced where the spheres representing participants’ own  
 635 hands disappeared (but could still be perceived by the partner);  
 636 in another one the spheres were displaced, giving the impression  
 637 of either a stretch or a compression of the arm’s length. We  
 638 expected that eliminating visual feedback of one’s own moving  
 639 body (i.e., of one’s own hands) would shift the attention toward  
 640 the other and the intersubjective space, since the sensorimotor  
 641 coupling with the other’s movements would be the locus of  
 642 feedback of one’s own movements (“perceiving myself through  
 643 the consequences of my movements on yours”). We hypothesized  
 644 that this shift would result in enhancing the coordination of  
 645 movement patterns between the participants. In contrast, we  
 646 expected that the changes in the perceived size of arms would  
 647 decrease the ability to coordinate and their associated feelings.

648 In the second scenario (“Mirror”), we proposed to gauge  
 649 the changes in behavior occasioned by the perception of a  
 650 full representation of oneself and the other (all six spheres  
 651 on the same plane), through a mirror that appeared in the  
 652 environment. We expected that it would encourage an increase  
 653 in collaborative movements in order to form shapes together.  
 654 Furthermore, we wanted to explore the phenomenal and  
 655 interactional consequences of reducing or adding color cues for  
 656 self-identification. Specifically, we wondered if an increase in self-  
 657 other differentiation would lead to an increase or a decrease in  
 658 experiential and/or behavioral intersubjective coupling. Due to  
 659 the technical problems, the data of only 6 dyads could be analyzed  
 660 for this scenario. For this reason, we concentrate this report  
 661 of proof-of-concept on the “Transformed Bodies” scenario, for  
 662 which 10 dyads could be analyzed.

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## Participation

666 Due to the particularity of the venue, the issue of participation  
 667 played a singular role in our experiment. In the context of  
 668 a museum exhibition, introduction of a strict laboratory-like  
 669 research protocol is not possible. The first challenge is the flow  
 670 of participants. In a museum, people move and wander freely,  
 671 governed by their own curiosity. We chose to work with this  
 672 open ended flow, rather than control it. We invited the audience  
 673 to stop and watch the running experiments while a screen was  
 674 showing what was being rendered in the virtual environment.  
 675 As a consequence, some participants were aware of the idea  
 676 behind the experiment before doing it, while others were not.  
 677 Some knew each other and insisted on doing the experiment  
 678 together while others were partnered randomly. This diversity  
 679 of cases and contexts had an impact on the collected data. In a  
 680 certain manner, the participants co-built the experiment with us.  
 681 We endorse this particularity as part of the logic of the design  
 682 of “Articulations”: the installation is participatory and invites  
 683 suggestions for co-construction, insight and improvement. We  
 684 consider the Tate event, therefore, a unique chance to see our

685 experimental configuration go outside our expectations, making  
686 the scientific method itself a part of the experimentation.

687 In total, 46 participants volunteered for the experiments. 23  
688 dyads were formed based on the order of arrival of participants  
689 and were randomly assigned to one of the two experimental  
690 scenarios (“Mirror” and “Transformed Bodies”). Due to the  
691 technical problems, the data of only 10 dyads (20 participants)  
692 could be analyzed in the “Transformed Bodies” (Age:  $30.4 \pm 11.4$ ),  
693 and only for the baseline condition and the condition where  
694 the visual feedback of one’s own hands was suppressed. The  
695 participants of half of the analyzed dyads knew each other well.  
696 Only three participants had a very regular dance practice and only  
697 one had a regular experience with VR.

## 698 Materials

699 The shared environment was created through three instances of  
700 the same custom created Unity program: Two Vive Pro headsets  
701 were connected each, via a Vive wireless adapter, to a client-  
702 instance running on a dedicated computer rendering the 3D  
703 environments at 60 frames per second. The third instance of the  
704 program was the server, gathering (and recording) the positional  
705 data sent by both headsets and hand trackers and sending them  
706 back to the connected clients. The server also acted as a remote  
707 controller of the two clients, triggering visual changes and events  
708 at specific times, manually or automatically. The VR headset, a  
709 wireless Vive Pro, offered a  $110^\circ$  field of view (approximately  
710  $90^\circ$  per eye), with two  $1,440 \times 1,600$  pixels displays. Coupled  
711 with two Vive Trackers strapped to the users’ wrists, this system  
712 allowed us to track and record hand and head movements in a  
713 three dimensional space (60 frames per second) as well as the  
714 voice during a specific phase of the experience.

## 715 Procedure

716 The two participants were placed in two adjacent (separate but  
717 with no occlusion) physical spaces (approximately 4 m square  
718 each). Once fitted with the headset, participants discovered  
719 an “empty” world with only two visible objects (two spheres)  
720 corresponding to the location of the sensors located on their  
721 hands (in the article we often refer to these sensors/spheres as  
722 “hands”). They were invited to walk around the virtual space  
723 and explore its boundaries. After a short while, each participant  
724 was able to see three additional mobile spheres corresponding to  
725 the hands and head of their partner. The participants were not  
726 explicitly told about the mapping of spheres to body parts.

727 The experimental protocol lasted 9 min and was divided  
728 into three “blocks” of 3 min, each corresponding to a different  
729 experimental condition and presented in a randomized order,  
730 without any interruption between them. In the “Transformed  
731 Bodies” experiment, one block served as a baseline, where both  
732 avatars were present, each consisting of three spheres of same  
733 size and color (Figure 3). In another condition (NO-HAND),  
734 participants did not see the spheres corresponding to their own  
735 hands but each of them could see the spheres representing  
736 their partner’s hands. In the RESIZE condition, the spheres  
737 representing the hands were made either more or less distant  
738 from the virtual body than they were in the baseline giving the  
739 impression of a stretching or shortening of the virtual “arm.”  
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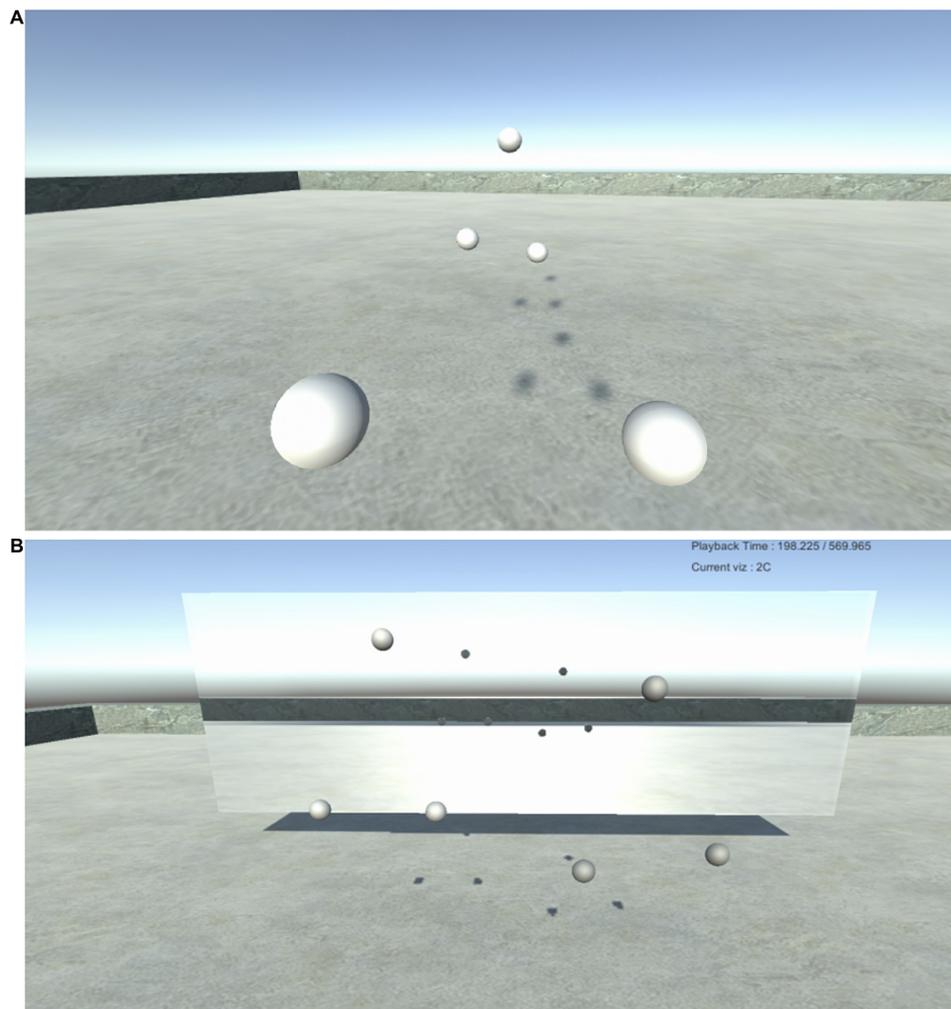
At the end of the experience, the partner’s avatar would  
disappear, and each participant would find themselves once  
again alone in the virtual environment, seeing only their own  
hands. A pre-recorded voice in the headset invited participants  
to express out loud their experience for about 1 min. The headset  
microphone allowed us to record their voice while they stayed  
immersed. After speaking, and once the tracking equipment has  
been taken off, participants filled in a questionnaire about their  
lived experience inside the virtual space. As the participants were  
finished with filling out the questionnaire, they were invited for  
an open-ended interview with one of the team members. An  
open-ended interview analysis is beyond the scope of this paper,  
however. The next section will elaborate on the logic of the  
questionnaire construction.

## 752 Experiential Reports

753 The goal of the questionnaire was not only to obtain feedback  
754 on the device and the experiences it affords but also to check if  
755 lived experiences reported by participants could be related to the  
756 observable patterns of (individual or relational) bodily behaviors.  
757 It was composed of assertions (presented on a tablet) with which  
758 participants indicated their agreement on a seven-point Likert  
759 scale. We chose this approach (rather than an interrogative form)  
760 since it matched our linguistic sources (participants’ description  
761 of their experiences on earlier occasions) and simplified and  
762 homogenized the task for the participants. We were interested  
763 in scalar responses as this would allow us to correlate the  
764 experiential reports with the movement variables. If we asked  
765 different scalar questions (e.g.: “To what extent did you enjoy  
766 the experience?”, “To what extent did you feel connected to your  
767 partner?”), each question would require an ad-hoc mapping of  
768 the specific content of the question onto a scale. The strength  
769 of adherence to an assertion, however, can be modeled as a  
770 continuous effect which is independent of the content of the  
771 assertion and which (from our experience) simplifies the task  
772 for participants.

773 The choice and wording of assertions was grounded in reports  
774 collected from the users of the installation during the previous  
775 experimentations and collective retreats. Reviewing the answers  
776 to the questionnaires and the transcripts of the conversations  
777 from these earlier events, we identified statements that identified  
778 specific aspects of personal experience that appeared more  
779 than once. We extracted representative statements and those  
780 prototypical to the categories of the experience most relevant  
781 to our research interest (relational movement, bodying,  
782 dis/embodiment). Importantly, we formulated the questionnaire  
783 by staying as loyal as possible to the wording from the first-person  
784 experiences, reformulating them only when the language needed  
785 to be specified, clarified, or stylistically adjusted. Adhering to  
786 the verbal descriptions provided by the participants themselves  
787 was fundamental to keep away from our abstractions and  
788 expectations addressing the subjective experiences directly.  
789 This approach to building a questionnaire disciplines us to stay  
790 “compositionist” (Latour, 2010) with bodying, and not taking  
791 bodies as fixed objects.

792 Most of the questions addressed the general experience (e.g., “I  
793 would have liked the experience to continue much longer,” “The  
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**FIGURE 3 | (A)** Baseline condition: Visualization of the scenery from a first person point of view. The two closest spheres correspond to the participant's hands. The three spheres at the back of the image correspond to the position of the head and two hands of their partner. Shadows of the floating objects are visible on the ground. **(B)** Mirror scenario: Visualization from a third person point of view. Here both participants are standing side to side in front of their own reflection.

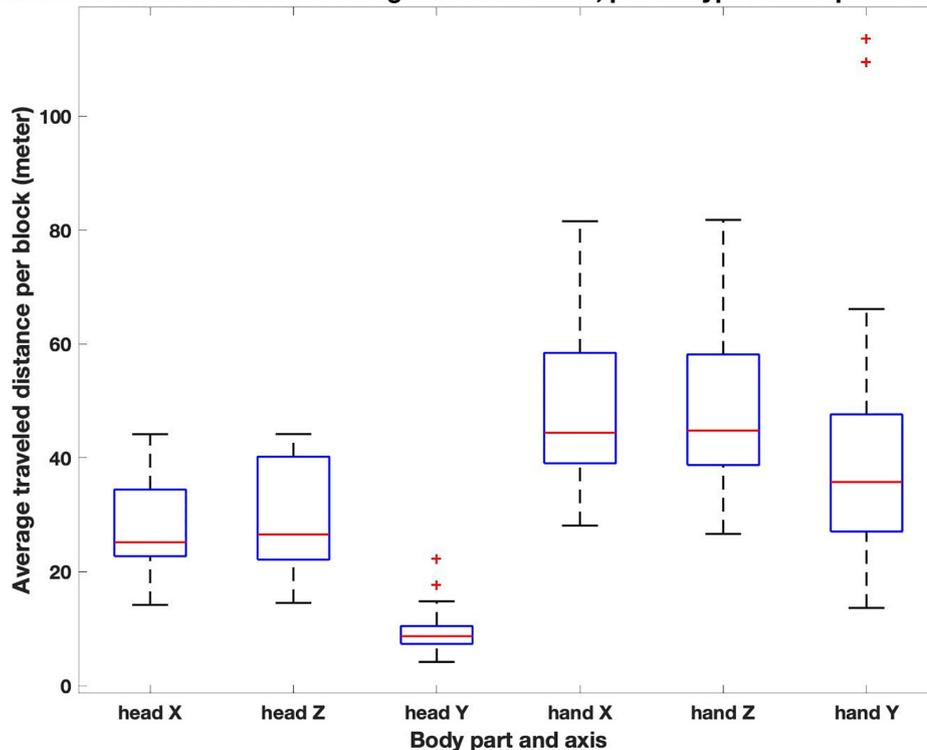
minimality of the setup made me surprisingly more curious and explorative"). A second smaller set of questions targeted the experiences specifically felt during particular experimental conditions. In the analysis presented here we focus on the responses to the latter, in particular to the two questions that inquire about feelings experienced during the analyzed manipulation. Namely the elimination of one's own "hands": (a) "The absence of my own spheres made me feel more closeness with my partner" and (b) "When I could not see my own body I found myself more interacting with my partner"). We will report how the responses to these two questions related to observed patterns of bodily behavior.

## Data Processing, Measurements, and Analysis

In order to quantify how participants moved in the virtual space across conditions, we considered hands and head motion

separately. What we mean here by "head" and "hands" are the markers provided by motion capture devices placed on the participants' wrists and the headset. As can be seen in **Figure 4**, vertical head motion happened more sparsely and only intermittently, while participants' hands explored all three dimensions equally. Though we did not collect torso motion data, we repeatedly observed that once immersed, participants mostly did not move the head as an independent effector. Rather, head movement was closely related to the overall motion of the participants trunk in the virtual space. Given these considerations, we took the head's horizontal motion as a proxy for the (horizontal) displacements of the participants in the virtual space (X and Z). For the hands, we took into consideration the overall movement of both hands in the three-dimensional space (X, Y, Z). We first interpolated the original positional time series data at 100 Hz and lowpass filtered them with a second-order Butterworth filter with the cutoff frequency set to 5 Hz in order to eliminate noisy jitter. Then, as a first step

Amount of traveled distance averaged for one block, per bodypart and spatial dimension



**FIGURE 4 |** Average amount of distance traveled by block per body part and spatial dimension. In general, distances were quite similar in the X and Z dimension, which reflects the square nature of the virtual space. For the head, displacements along the vertical dimension were significantly smaller than along the horizontal ones (signed-rank Wilcoxon tests;  $z = 4.11$ ,  $p < 0.0001$ ). For the hands, displacements along the vertical dimension are also significantly smaller than along the horizontal ones ( $z = 2.74$  and  $z = 2.71$ ,  $p < 0.01$  for both vertical vs horizontal comparisons) yet the respective amount of displacements have a comparable range.

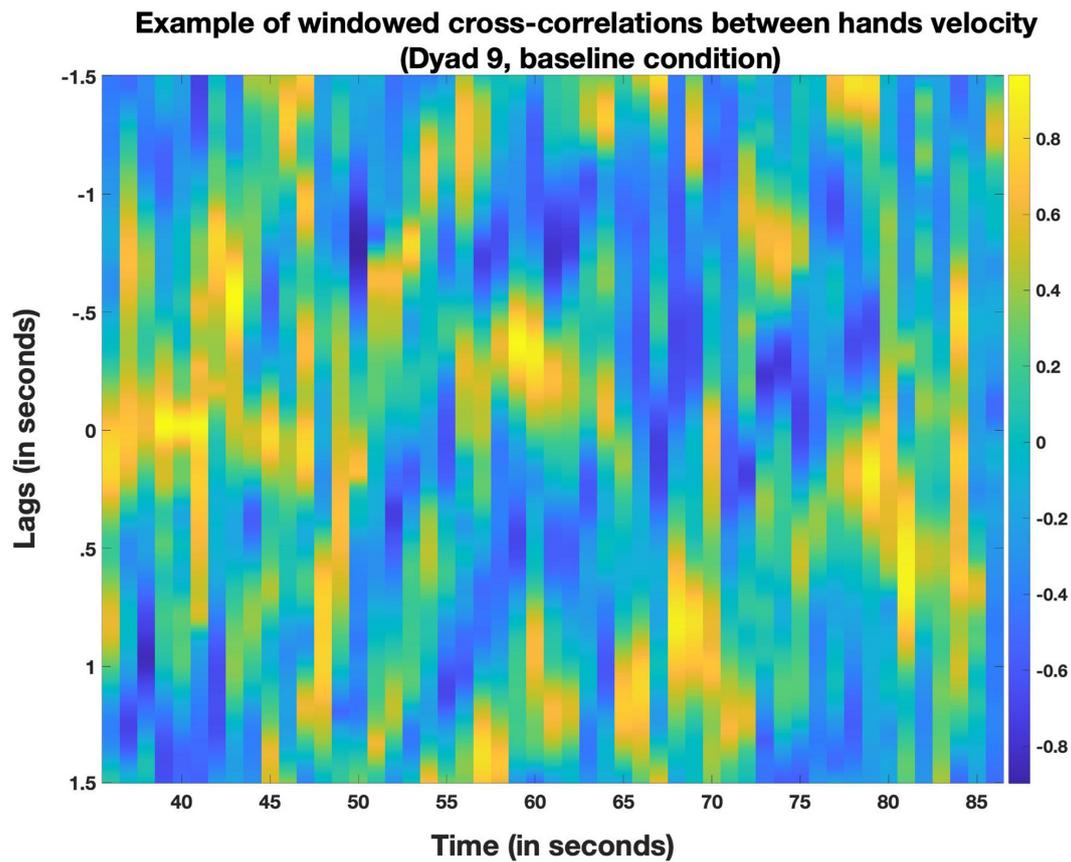
in the exploration of the data and with the aim of developing more comprehensive non-linear analysis tools in the future, we computed three types of measurements from the resulting series:

**Median Velocity (MV):** we first obtained velocity time series by differencing the positional time series of each dimension. Next, each datapoint was squared to obtain unsigned velocity values. Then, we summed the time series of the different dimensions (X and Z for the head, X, Y and Z for both hands), and we computed the square root of each resulting datapoint in order to obtain time series of the overall velocity of the hands and the head, respectively. Finally, we extracted the median of each of the resulting head and hands time series. Thus, for each subject in each condition, and for both the hands and the head, we obtain a singular value reflecting the median velocity of movement.

**Relative Head Velocity (RHV):** we computed the real-time difference in velocity between partners' head motion in the horizontal plane. To do so, we used the velocity time series described in (1) from both partners for each axis of the horizontal plane (X and Z), to compute a new time series for each axis representing the difference in velocity at every time point between partners. Next, each datapoint in the new time series was squared in order to obtain unsigned difference values. We then summed the time series of the X and Z axis and we computed the square root of each resulting datapoint in order to obtain a

time series of the real-time absolute difference between head velocity in the horizontal plane. Finally, we extracted the median of the resulting time series, which provided us with an index of the median instantaneous relative velocity for each pair of participants in each condition.

**Motion cross-correlation (MCC):** we computed windowed cross-correlations between partner's movements using the overall velocity time series described above and that we used to compute MV. We used moving windows of 2 s (with 1 s overlaps), which can correspond either to a slow movement or to a short sequence of coarticulated gestures. Cross-Correlations were computed over positive lags ranging from 0 to 5 s (by 10 ms overlaps). This allowed us to examine how the movement of each participant related to the present as well as the short-term past of the partner's movement. The 5 s lag value was chosen because movement coordination can take many forms going from real-time synchronization to delayed imitation of a gesture, and can therefore be identifiable at a wide variety of lags (Tschacher et al., 2014; see also **Figure 5**). For this reason, within each window we extracted the peak correlation coefficient whatever was the lag at which it was found. This provided us with a time series indicating for each window the maximum coordination observable between the partner's movement regardless of the delay between these time series. We



**FIGURE 5 |** Example of windowed cross-correlations between hands velocity of two partners (dyad 9, baseline condition). Each window is 2 s long. The one second overlap between successive windows entails the creation of a new window at every second of the velocity time series. For every window, a correlation coefficient with the partner time series was computed at every lag between 0 and 5 s, in this example in both time directions (e.g., correlations with what the partner did up to 5 s earlier as well as later). The resulting correlogram plots the computed coefficient for every window (x axis) at every lag (y axis). The color coding indicates the strength of that correlation coefficient, with cold, most blueish colors indicating strong negative correlation and hot, most yellowish colors indicating strong positive correlations. A positive correlation along the Y-axis 0 indicates synchronous coordination. A positive correlation at negative lags (in the upper part of the plot) indicates that a subject had similar movements to what her partner did earlier (a “follower”). A positive correlation at positive lags (lower part of the plot) indicates that the subject is “leading” (the partner will later make movements that are similar to those the subject makes in the current window). In this example, we can see that both partners first synchronously coordinated (high correlations around lag 0, from 35 to 45 s approximately) before entering a phase that can be described as turn-taking with partners shifting between leading and following.

then used the median of the Z-transformed time series of peak correlation coefficients to provide an index of coordination across time of each participant to his/her partner, in each condition, and for both the head and the hands.

As the distribution of data was not normal, we compared these three indices across conditions (baseline and NO-HAND) with Wilcoxon (signed-rank) tests. For the same reason, relating movement variables to subjective reports, we performed Spearman’s rank correlation between the responses to items of the questionnaire that targeted lived experiences during specific experimental conditions and kinematic indices.

## Quantitative Observations

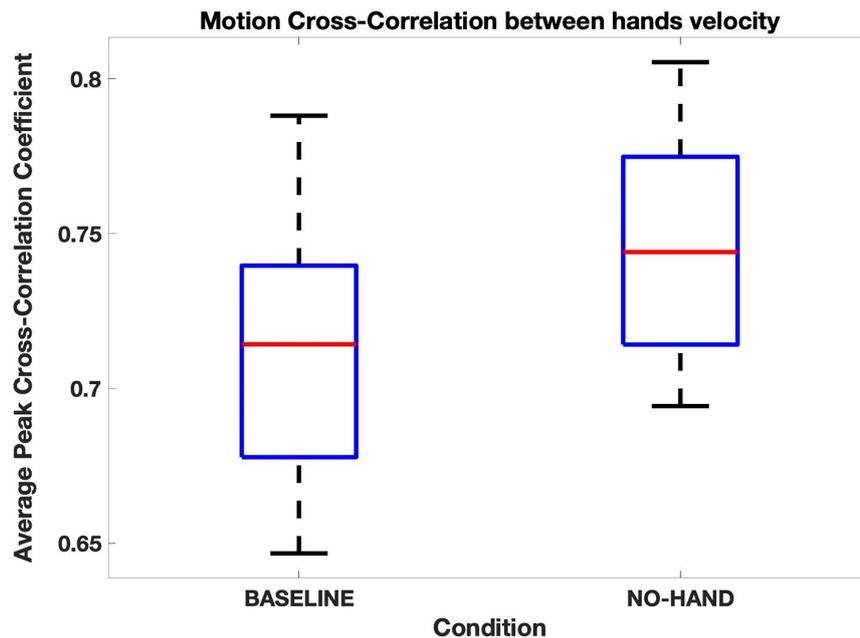
### Kinematic Measurements

The MCC between partners’ hands’ velocity was significantly higher in the NO-HAND condition than in the baseline ( $z = -2.87, p < 0.01$ ; see **Figure 6**), but no significant difference

was found for the head (see **Table 1** for all paired comparisons). In other words, partners coordinated their hands (but not their head) more across time when they could not see their own. There was no significant difference in terms of MV or RHV between the baseline and the NO-HAND condition (see **Table 1**).

### Correlation Between Kinematic Measurements and Experiential Questionnaires

We observed a negative correlation between the feeling of closeness induced by the absence of spheres (“*The absence of my own spheres made me feel more closeness with my partner*”) and RHV, but this correlation was significant only in the NO-HAND condition ( $r = -0.50, p < 0.05$ ; see **Figure 7**). In other words, when their own hands were invisible, participants who moved in space in a more similar velocity, felt closer to each other. The responses to the same question correlated negatively with the participant’s head MV, but this correlation was also significant



**FIGURE 6 |** Motion cross-correlations between hands' velocity. Average peak cross-correlation coefficients were significantly higher when participants couldn't see their own hands (NO-HAND) than when they did (BASELINE).

**TABLE 1 |** Paired Wilcoxon sign-rank tests between BASELINE and NO-HAND conditions for the different kinematics variables.

Variable	Paired Wilcoxon sign-rank test between conditions
HEAD MCC	$z = -1.08; p = 0.28$
HANDS MCC	$z = -2.87; p = 0.004$
HEAD RHV	$z = -0.97; p = 0.33$
HEAD MV	$z = -0.30; p = 0.77$
HANDS MV	$z = 0.37; p = 0.71$

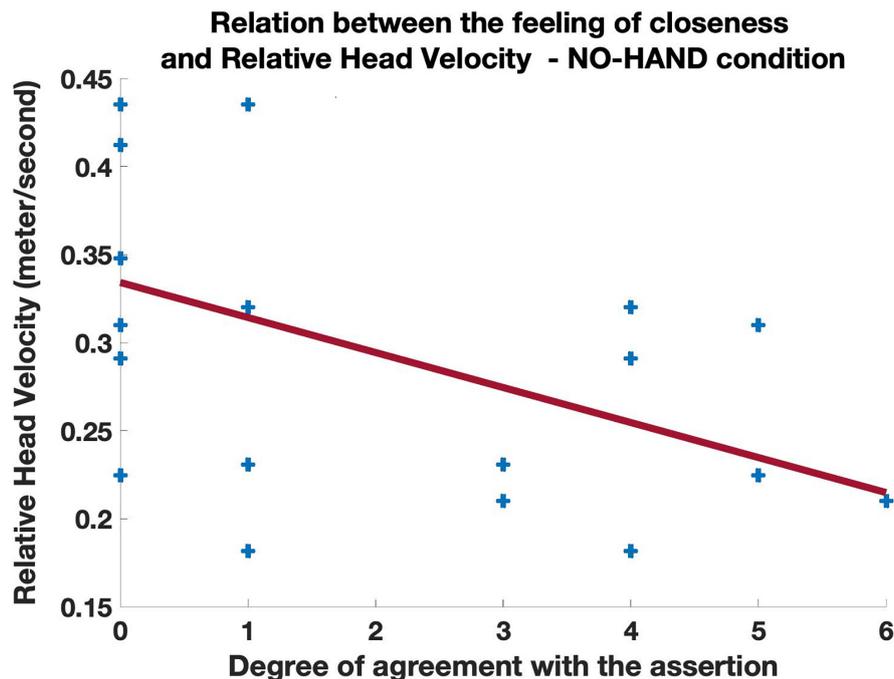
only in the NO-HAND condition ( $r = -0.46, p < 0.05$ ; see **Figure 8**). Importantly, the feeling of closeness in that condition was not significantly connected to the head MV of the partner ( $r = -0.25, p = 0.28$ ). These two results indicate that slower self-motion (but not that of the partner) was related to one's feeling of closeness but only when participants could not see their own hands. All other correlation coefficients are reported in **Table 2**. It is important to note that these two movement variables (RHV and head MV) were correlated ( $r = 0.65, p < 0.01$ ). This indicates that those who moved faster had more dissimilar head movements velocity than their partner. Given this collinearity, it is not possible to directly parse and gauge the respective and independent contribution of these two variables to the feeling of closeness.

## DISCUSSION

In this article we presented the "Articulations" installation for studying relational movement and its situated experimental

testing at a science-art event. We first outlined an epistemic framework (dis/embodiment) for the scientific study of the body as an interactive process (bodying). We then introduced the design and operative particularities of SDR as a methodological device for such interrogation, and briefly speculated on its promises for relational approaches to disability. We followed with a description of the "Articulations" SDR installation, where the users are represented most minimalistically, through avatars consisting of three identical mobile spheres corresponding to their head and hands. We finally presented some preliminary results from a situated experimentation at the Tate modern. Our goals at this event were first to test the viability of a SDR set-up to produce and capture (quantitatively as well as qualitatively) bodying through relational movement and dis/embodiment. In addition, we aimed to evaluate the relationship (and our capability to apprehend it) between felt experience and quantitative measures.

We used the specific affordances of SDR to verify if certain manipulations of the visual feedback of one's own movement ("Transformed Bodies") would have significant and differential effects on behaviors, interactions, and lived experiences. We introduced the variations in the virtual environment in pseudo-randomized orders. In the "Transformed Bodies" experiment, the baseline situation was contrasted with one of increased dis/embodiment, where participants could only see the spheres representing their partner. Our expectation was that the disappearance of one's own body (avatar) would draw one's attention to the experience of bodying through relational movement and would favor (measurable) coordination with the partner's movement as their reaction would embody or replace the missing feedback of the participant's own body.



**FIGURE 7 |** Scatterplot of the relation between the responses to the question “*The absence of my own spheres made me feel more closeness with my partner*” and the Relative Head Velocity. 0 meant total disagreement and 6 total agreement with the assertion, with values in between corresponding to more moderate responses.

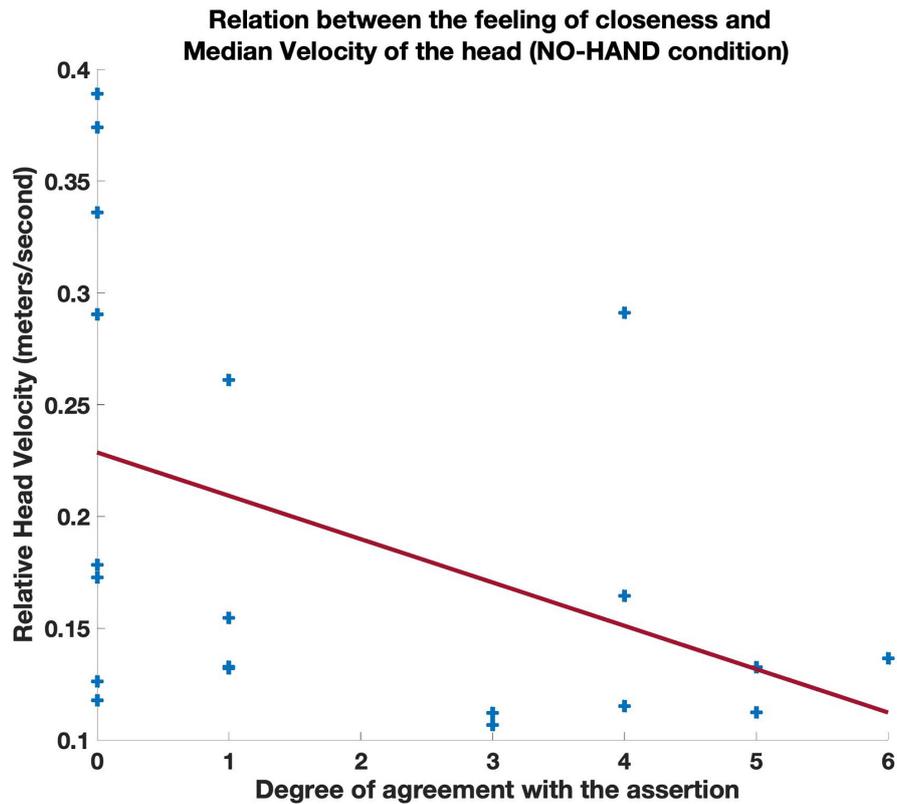
## Bodily Through Relational Movement

Behavioral results revealed that the velocity of hand movement was more coordinated across partners when the spheres representing participants’ own hands disappeared from their view, compared to the baseline situation where they could view their hands. In other words, the disappearance of one’s own spheres from one’s view, seeing only the other’s spheres, seems to have encouraged movement coupling in the dyad. We propose that this specific SDR manipulation provided for a situation where one’s own body(ing) was felt through the movement of the other. This dis/embodiment manipulation might have displaced participants’ attention toward the other and/or the dynamics of their sensorimotor relationship (in other words, the relationality of their movement). The strengthening of the reciprocal coupling between the participants might have been the consequence of an explicit attempt to communicate and/or a result of unintentional mutual entrainment. We thus interpret the increase in coupling as a reflex of bodily through relational movement. The body here is not a pre-set entity, detached from a pre-existing world; it is constantly composed as a bodily experience where the other becomes the main reference point. The “other” is active in the dis/embodiment experience since the perceptual trace of the consequences of one’s own movements in the world can be embodied only through the “other.” Thus, the visible body of the “other” co-becomes with the personal pre-reflectively lived body. This is in line with the enactive perspective, which points to the importance of interactional dynamics in the constitution of individual behavior and the coordination of interpersonal behaviors (De Jaegher et al., 2010; Laroche et al., 2014).

Our design and results support those obtained with the cross-perceptual paradigm (Auvray et al., 2009), where participants interact by controlling the most minimalistic agents possible (a unique form of sensory stimulation that signals the presence of the other agent when she is within the receptive field of the participant). This paradigm first demonstrated that individual behaviors can be driven by the collective dynamics that emerge from their interaction (Auvray et al., 2009). Our method proved useful to relate these dynamics to their associated lived experiences (Froese et al., 2014b). Finally, it helped show that even the imitation of bodily behaviors can emerge from interactional dynamics, making the explicit (reflective) perception of one’s own bodily expressions unnecessary for imitating each other’s bodily behavior (Lenay and Stewart, 2012). Our preliminary results add to this line of inquiry, indicating that the disappearance of one’s own body from our perceptual field can strengthen the coupling with the other.

## Behavioral Coupling and Lived Experiences

The correlation between behavioral coupling and lived experience (as probed through the questionnaire) suggests that the strengthening of the coupling has an experiential counterpart. Indeed, in the absence of one’s own hands, the feeling of closeness was stronger when partners’ displacements had more similar velocity (as revealed by RHV). Another finding showed that participants were more likely to signal an enhanced feeling of closeness with their partner in the NO-HAND situation when the velocity of their own displacements (but not those of



**FIGURE 8 |** Scatterplot of the relation between the responses to the question “*The absence of my own spheres made me feel more closeness with my partner*” and the Median Velocity of horizontal head displacements. 0 meant total disagreement and 6 total agreement with the assertion, with values in between corresponding to more moderate responses.

the partner) was lower. It thus seems that velocity information is linked to self-other integration in lived experience, whether in relational terms (velocity similarity) or in absolute value (individual velocity).

Velocity information has been shown to convey fundamental information for the recognition of animateness (Tremoulet and Feldman, 2000). It is also determinant in interpersonal movement coordination. Indeed, the mere perception of human motion velocity profiles interferes with the execution of arm movements (Kilner et al., 2007), and the perception of velocity profiles modulates our coordination with an external stimulation (Varlet et al., 2014). Hartmann et al. (2019) showed that hand movement and similarity in the frequency of movements of dancers influenced how observers perceive the degree of interaction between them. Regarding velocity attunement between partners, Słowiński et al. (2016) showed that “*dynamic similarity*” between the individuals’ spontaneous motion (according to an index derived from velocity profiles) enhances their interpersonal coordination. It thus seems that the respective velocity profiles of the spheres were important informational cues that led to more or less coordinated patterns through mutual interference and adjustments in the dynamical course of interactions.

Concerning the quality of lived experience associated with interactions, coordination has been recurrently shown to boost

affective rapport and/or social connection (Marsh et al., 2009). Our results are notably consistent with those of Sun et al. (2019), who observed positive correlation between head synchrony and feelings of closeness with the partner during conversations in VR. Perceived synchrony has also been shown to increase subjective empathy (Koehne et al., 2016), while objective synchrony between behaviors correlates positively with the subjective estimation of affiliation (Hove and Risen, 2009), rapport (Miles et al., 2009) and closeness/intimacy (Sharon-David et al., 2019). A number of neuroscience studies investigating brain and behavioral activities during interpersonal coordination have guided their analysis with subjective reports (e.g., Fairhurst et al., 2014). Kokal et al. (2011) showed that participants preferred to be paired with virtual agents that followed them and that this was sufficient to activate brain regions associated with reward processing. Cacioppo et al.’s (2014) results show that synchronized partners seem to be assimilated more, or processed as more similar to the self. Movement synchronization thus seems to enhance shared agency (Pacherie, 2012). Relatedly, movement synchrony has been shown to entail perceived entitativity (Lakens, 2010) and group-bonding (Tarr et al., 2015). Synchrony can thus elicit the feeling of belonging to the same unit. These results resonate with our observation of the correlation between velocity attunement and the feeling of closeness and

**TABLE 2** | Spearman rank correlation between experiential reports and kinematic variables.

Variable	Experimental condition	<i>“The absence of my own spheres made me feel more closeness with my partner”</i>	<i>“When 1 could not see my own body 1 found myself more interacting with my partner”</i>
HEAD MCC	BASELINE	$r = 0; p = 1$	$r = -0.17; p = 0.47$
	NO-HAND	$r = -0.19; p = 0.42$	$r = 0.14; p = 0.55$
HANDS MCC	BASELINE	$r = 0.34; p = 0.15$	$r = 0.11; p = 0.55$
	NO-HAND	$r = 0.17; p = 0.48$	$r = 0.11; p = 0.64$
HEAD RHV	BASELINE	$r = -0.14; p = 0.55$	$r = -0.11; p = 0.65$
	NO-HAND	<b><math>r = -0.50; p = 0.02^*</math></b>	$r = -0.33; p = 0.16$
HEAD MV	BASELINE	$r = -0.35; p = 0.13$	$r = -0.03; p = 0.90$
	NO-HAND	<b><math>r = -0.46; p = 0.04^*</math></b>	$r = -0.35; p = 0.13$
HANDS MV	BASELINE	$r = -0.28; p = 0.23$	$r = -0.05; p = 0.84$
	NO-HAND	$r = -0.10; p = 0.68$	$r = -0.18; p = 0.46$
HEAD MV of the partner	BASELINE	$r = 0.23; p = 0.33$	$r = -0.03; p = 0.90$
	NO-HAND	$r = -0.25; p = 0.28$	$r = -0.06; p = 0.81$
HANDS MV of the partner	BASELINE	$r = -0.04; p = 0.86$	$r = -0.18; p = 0.44$
	NO-HAND	$r = -0.08; p = 0.74$	$r = 0.04; p = 0.87$

point to a causal link between socio-motor and socio-affective variables. Indeed, the disappearance of one’s body increased the coupling with the movement of the other, and it is in this particular condition that we found correlations between synchrony and affiliation. It thus seems that it is the enhancement of interpersonal coordination that entailed stronger feelings of closeness, perhaps by making interacting partners’ feelings more similar (or integrated) to each other and therefore feeling more as belonging to the same unit.

Another correlational result links the slowness of a participant’s movement to their feeling of closeness to the partner. This result is consistent with Noy et al.’s (2015, Table 7) study. Using the two-dimension mirror game set-up where participants had to imitate each other’s improvised hand motion, Noy et al. (2015) found that participants reported moments of togetherness during periods of slower movement though this feeling was not reflected in the objective quantification of kinematic synchrony (co-confident motion). A possible explanation of our result is that slower movements might have allowed participants to stay more attentively focused on, and therefore aware of and affected by, their partner’s movement. Alternatively, a feeling of closeness with the partner could have encouraged the participant to slow down, especially in the challenging NO-HAND condition, to “help” the partner follow or process one’s movement, similar to how we introduce disfluencies in conversations to help the listening partner have more “time” to process the information of our speech (Walker et al., 2014). Our result that the feeling of closeness was not correlated with the slowness of the partner argues against an explanation of the feeling of closeness as causally dependent on the partner’s slower movement (*“because you move slower I feel more connected to you”*).

Here, slowing down as a joint attention mechanism is particularly highlighted when participants don’t see their own body since their own kinesthetic “feedback” integrates the movement of the partner. Overall, we favor the hypothesis

according to which slower movement might have facilitated movement coordination, which in turn strengthens socio-affective connection (with a positive valence in our experiment and in most studies available in the literature, although it can also lead to stronger connection of an opposite valence; see Di Paolo and De Jaegher, 2012; García and Di Paolo, 2018). Such a hypothesis shall be tested more specifically in future experiments, in particular with the aim of disentangling the pace of movement and the similarity of velocity, which are highly correlated in our preliminary data.

Although correlational, our results expand the literature on the links between motor and socio-affective coordination, that most often refers to rhythmical tasks, to situations where movements are free of any rhythmical constraints. They also argue in favor of the suitability of SDR for the study of relational movement and bodying, and its unique ability to create sensorimotor couplings that can help disentangle the mechanisms of intersubjective coordination. They are also coherent with the enactive perspective where the interpersonal sensorimotor coupling is at the source of experiential attunement, or the mutual incorporation of each other’s experience (Fuchs and De Jaegher, 2009). Thinking of our correlational results along with the relational approach in disability studies (Moser, 2006; Goodley, 2017) and Manning’s (2009) argument that movement creates space, we speculate that future experiments might build on our findings in searching precise articulation of the link between relational movement and intersubjective experience.

## Notes on the Method

The Tate event was a singular happening, and our challenge was to put together a prototype of an epistemological framework that takes into account the rich specificity of the event, with its inherent complexities, while allowing for quantitative observations and qualitative exploration. As a proof of concept, we gauged the capacity of our SDR set-up to provide methodological opening for a multi-perspective interrogation

1597 into the lived experiences of relational movement and bodying  
 1598 through dis/embodiment. We approached interrogation into the  
 1599 lived experiences with a self-report questionnaire which targeted  
 1600 particular experiences. The questionnaire was designed based on  
 1601 the theoretical issues at hand and using as much as possible  
 1602 formulations synthesized from the language used by participants  
 1603 in their feedback during previous sessions. One of the aims of this  
 1604 study was to see if SDR as a methodological device can produce  
 1605 meaningful experiential data.

1606 In this paper we evaluated the link between behavioral  
 1607 measurements and participants' lived experiences. The finding  
 1608 of significant correlations is encouraging since the behavioral  
 1609 measurements we used were rather general (e.g., overall lateral  
 1610 head or bimanual 3D movement velocity) and did not  
 1611 target specific movement aspects. Plus, the mere fact that  
 1612 the computations were averaged over long (3 min) trials  
 1613 masks the singularity and the variety of the coordination  
 1614 patterns observed in such ill-constrained situations. This  
 1615 prevents us from articulating detailed movement events with  
 1616 particular and locally associated lived experiences. Similarly,  
 1617 the propositions we formulated in the questionnaire addressed  
 1618 lived experiences at the coarse-grain level of specific conditions  
 1619 in their entirety, unlike in-depth elicitation protocols and  
 1620 interviews used by pragmatic phenomenologists that cover  
 1621 seconds (Petitmengin, 2006; De Jaegher et al., 2017; Ollagnier-  
 1622 Beldame and Coupé, 2019). Furthermore, our participants  
 1623 proceeded to the questionnaire only after completing the whole  
 1624 experiment in which the experimental conditions were not clearly  
 1625 isolated in time from one another but rather passed in one  
 1626 continuous run. This contrasts with neurophenomenological  
 1627 approaches where elicitation of experience is more fine-grained  
 1628 and targets trials that are much shorter (e.g., one perceptual  
 1629 event, see Lutz et al., 2002). In spite of these facts, the statistical  
 1630 significance of our results suggest that our device was successful  
 1631 in revealing bodying experience and creating a link between  
 1632 first-person testimonies and instrumental measurements. One  
 1633 particularly encouraging aspect of the results is that significant  
 1634 correlations were specific to the condition that was targeted by the  
 1635 question. Indeed, the feeling of closeness in absence of the vision  
 1636 of one's own hands was actually significantly (and negatively)  
 1637 correlated with MV and RHV in that very condition, but not  
 1638 with these indices measured in the presence of the said vision  
 1639 of one's own hands. This specificity in the correlations suggests  
 1640 that participants were able to discriminate and refer to the specific  
 1641 experimental conditions post-hoc and retrieve feelings specific to  
 1642 a given condition.

1643 In our ongoing and future research, we intend to attend  
 1644 to the above mentioned problem of granularity, in both the  
 1645 behavioral and experiential domains, by endorsing a more  
 1646 dynamical approach. On the behavioral side, we are currently  
 1647 developing non-linear tools to better capture the temporal  
 1648 evolution of the movement variables such as new methods of  
 1649 recurrence quantification (Lancia and Rosenbaum, 2018). To  
 1650 collect more temporally fine-grained experiential reports, we plan  
 1651 to offer the participants the means to revisit their experiences by  
 1652 navigating a reconstructed video of their interaction. We can then  
 1653 relate specific moments of experience with the local behavioral

dynamics. Moreover, this would allow us to interrogate partners  
 about the "same" moments in time. We hope that, with more  
 fine-grained reconstruction of the behaviors and experiences  
 and through combining temporally aligned reports from both  
 partners, we will be able to have deeper insights into the nature  
 of relational movement.

Concerning the diminished aspect, we acknowledge that  
 diminishing perceptual information in VR does not mean that  
 nothing is added in return. The nacreous aspect of the spheres,  
 the marble texture of the ground, and the day-ish light were all  
 designed minimalistically but not in the sense of proposing a  
 mere impoverishment of reality. Rather, we intended to provide  
 a comfortable and pleasant feeling of openness as well as a  
 conducive place for explorative encounters. The spheres also  
 gave inspiration to participants to create patterns and metaphors  
 and filled their imagination to build narratives about their  
 interaction. We saw how many studies explored the impact of  
 body appearance upon how we feel, think, and act. In that case,  
 we can't argue that a body made of spheres is simply a diminution  
 of reality, though it is "minimalist" (Vuarneesson et al., 2021).  
 This "something else" we added will remain as an open question  
 in this paper and should be properly investigated in the future  
 of this project.

We also would like to point out that the way we have  
 implemented SDR in our experiment does not take into account  
 the experiences of bodies with disabilities. We believe that  
 this limitation not only invites us to rethink the logic of  
 participation in the project but also opens a broader question  
 of which knowledge counts in academic research. We recognize  
 that our propositions on the capacities and promises of SDR  
 for the study of bodying have been based on and oriented  
 towards able-bodied experiences. All our participants had a  
 good command of their bodies and did not report motor or  
 cognitive disability experiences. We also recognize that this  
 methodological specification is critically examined in the broader  
 epistemological framework which we draw upon (specifically, the  
 relational model of disability or Haraway's "apparatus of body  
 production"). Though a more detailed development of this point  
 is beyond the scope of this article, we would like to mention here  
 that in our strategy for future research we take better care to  
 include heterogeneous body experiences.

## CONCLUSION

In this paper, thinking alongside Erin Manning's concept of  
 bodying, Latour's (2010) "compositionist" approach to knowledge  
 making, and literature on "body production" relational becoming  
 (Haraway, 1988; Moser, 2006), we explored how relational  
 movement underlies the emergence of our bodies and selves.  
 Our working hypothesis is that the experience of our bodily  
 self emerges in our moving relation to people and things which  
 we encounter. We add to this the humble speculation that  
 this process might then provide insights into the phenomena  
 related to dis/embodiment, the experiences of body disorders,  
 and disabilities.

1711 The “Articulations” installation is predicated on the intuition  
 1712 that a task of spontaneous sensorimotor interaction coupled  
 1713 with SDR constitutes a coherent methodological device for this  
 1714 exploration. We have demonstrated that certain manipulations  
 1715 of the virtual space and avatars allow for the modulation of bodily  
 1716 and relational experiences (dis/embodiment) and the observation  
 1717 of the behavioral correlates of this modulation. By testing an  
 1718 installation where two people can freely, spontaneously, and  
 1719 playfully move and interact in the same space, we articulate links  
 1720 between the various forms of dis/embodiment and relational  
 1721 dynamics of movement.

1722 The “Articulations” installation was conceived through a  
 1723 participatory design process, building each feature, from the  
 1724 looks of the virtual movement space to the different conditions  
 1725 to the experience measurement devices, through an iterative  
 1726 exchange among scientists, artists, designers and volunteers who  
 1727 all tested the evolving versions of the installation. This has  
 1728 allowed us to orient the design of the installation towards what  
 1729 we refer to as SDR. SDR constitutes a virtual setup where people  
 1730 can interact in a minimalist environment through avatars whose  
 1731 embodiment is deeply reduced. Such a paradigm allows to retain  
 1732 (or even experientially foreground) the conditions for bodying  
 1733 and relational movements while making kinematics of virtual  
 1734 bodies more easily trackable.

1735 We activated our device at an art-science exhibition where  
 1736 we collected movement data along with experiential reports  
 1737 about experimental manipulations where various forms of  
 1738 dis/embodiment and environmental changes were experienced.  
 1739 Although we have tested our device with only a handful of  
 1740 dyads, which limits the scope of our conclusions, it did offer  
 1741 promising results. As we predicted, suppressing the feedback  
 1742 of the movement of the self increased the coupling with the  
 1743 other. We also observed meaningful links between behavioral  
 1744 measurements and experiential reports that depended on the  
 1745 absence of feedback of one’s own hands, at both the individual  
 1746 and the relational level. Without visual feedback of their own  
 1747 movement, members of dyads that had more similar velocities  
 1748 reported a stronger sense of proximity with their partner.  
 1749 This was expected since we created a situation where the  
 1750 visual feedback of one’s own movement exists only in the  
 1751 other’s movement and in the influence we have on her, which  
 1752 facilitates the orientation of attention toward the coupling  
 1753 process itself. Furthermore, in the same condition participants  
 1754 who moved slower (relatively to other participants) felt closer  
 1755 to their partners. A possible explanation of this last result is  
 1756 that slower movements could enhance the attention toward  
 1757 the partner and the intersubjective relation itself, and/or that  
 1758 the feeling of closeness could bring the participant to slow  
 1759 down as a collaborative strategy. While the causal directionality  
 1760 of this correlation requires further experimentation, it appears  
 1761 that slower movement facilitates the emergence of a relational  
 1762 bodying unit (or “*joint body schema*”, Soliman et al., 2015).

1763 The results of this proof of concept show that our SDR  
 1764 methodological device is suitable for exploring the link between  
 1765 bodily lived experiences (especially relational experiences) and  
 1766 movements patterns (whether they refer to patterns of motion  
 1767 observed in individuals or in their relations). Yet, a number

of improvements must be considered for further work with  
 our installation: methodological, epistemological, and analytical.  
 Deeper qualitative analysis of the open-ended interviews with  
 the participants and new forms for eliciting experiential reports  
 are needed to enrich our inferences and attend to the specific  
 emotional and social conditions that weave into their experiences;  
 advanced statistical methods are required to improve the  
 detection of relational attunement beyond linear synchronicity  
 or delayed imitation of patterns; semiotic analysis of gestures  
 appropriate for the specific register of spontaneous sensorimotor  
 interactions should be deployed; inviting experiences beyond  
 those of the able-bodied.

Some directions we hope to explore in the future include:  
 qualitative studies of relational experiences with and within  
 SDR; exploration of how dis/embodiment induces novel gesture  
 qualities, and communication strategies; and implications for  
 health and dis/ability fields. More precisely, our interest in the  
 promises of SDR in the context of disability is not about “fixing”  
 or rehabilitating “a body”. Rather, we would like to question  
 if relational bodying within the SDR space may inform ethico-  
 affective understanding of dis/ability configurations. We hope  
 that the device we have described here, and its potential for  
 dis/embodiment could contribute to thinking of the ways in  
 which the body is “done” and “undone” collaboratively and to  
 displacing dis/ability from within one’s body to the relational  
 ecological network of social and material conditions of its  
 emergence (Moser, 2006; Ginsburg and Rapp, 2013; Shakespeare,  
 2014; Goodley, 2017).

## DATA AVAILABILITY STATEMENT

The datasets generated for this study are available on request to  
 the corresponding author.

## ETHICS STATEMENT

Ethical review and approval was not required for the study  
 on human participants in accordance with the local legislation  
 and institutional requirements. Written informed consent to  
 participate in this study was provided by the participants’ legal  
 guardian/next of kin.

## AUTHOR CONTRIBUTIONS

All authors designed the experiment and wrote the manuscript.  
 LV, AE, and AB collected the results. JL analyzed the data. JL and  
 AB discussed the results.

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- Conflict of Interest:** The authors declare that the research was conducted in the 2124 Q21  
 absence of any commercial or financial relationships that could be construed as a 2125  
 potential conflict of interest. 2126
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