# Here and Now: Creating Improvisational Dance Movements with a Mixed Reality Mirror

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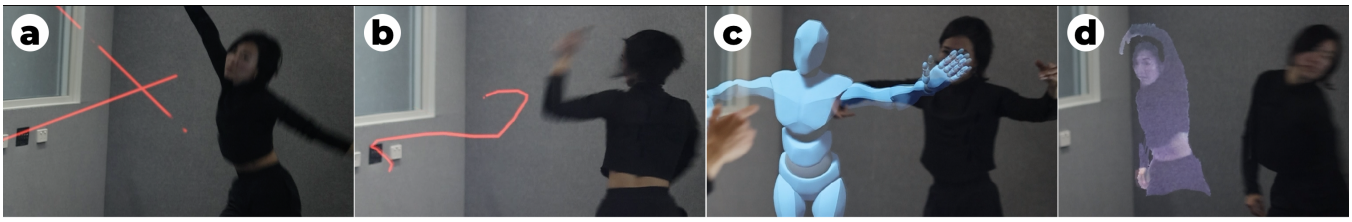


**Figure 1: Visualisation functions designed to help create improvisational dance movements. (a) Point-point-Line creates lines between two body joints of the dancer. They remain in place after creation, and can be erased; (b) Air Drawing leaves movement traces of the dancer's drawing hand. They remain in place after creation, and can be erased; (c) Embodied Estrangement masks the reflection of the dancer's body using a featureless avatar; (d) Delayed Presence renders a delayed 3D capture of the dancer's moving body in the mirror next to their present reflection.**

## ABSTRACT

This paper explores using mixed reality (MR) mirrors for supporting improvisational dance making. Motivated by the prevalence of mirrors in dance studios and inspired by Forsythe's Improvisation Technologies, we conducted workshops with 13 dancers and choreographers to inform the design of future MR visualisation and annotation tools for dance. The workshops involved using a prototype MR mirror as a technology probe that reveals the spatial and temporal relationships between the reflected dancing body and its surroundings during improvisation; speed dating group interviews around future design ideas; follow-up surveys and extended interviews with a digital media dance artist and a dance educator. Our findings highlight how the MR mirror enriches dancers' temporal and spatial perception, creates multi-layered presence, and affords appropriation by dancers. We also discuss the unique place of MR mirrors in the theoretical context of dance and in the history of movement visualisation, and distil lessons for broader HCI research.


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## CCS CONCEPTS

• **Human-centered computing** → **Empirical studies in HCI**; **Mixed / augmented reality**; • **Applied computing** → **Performing arts**.

## KEYWORDS

dance, mixed reality, augmented reality, mirror, improvisation

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## 1 INTRODUCTION

Over two decades ago, the prolific choreographer William Forsythe published *Improvisation Technologies*, a series of video lectures designed as a pedagogical tool in the form of a CD-ROM [28]. It presented demonstrations of a choreographic vocabulary, mapping the relationships between different parts of the dancer's body and the surrounding space. The video recordings were augmented with computer-generated and animated shapes, forms, and figures to illustrate the choreographer's improvisation techniques and theoretical principles for creating new dance movements [27]. Since then, it has been widely adopted and studied by choreographers and researchers in dance studios and in academia. Improvisation Technologies owes

its success and impact not only to Forsythe's choreographic concepts, but also to the implementation of the state-of-the-art CGI technologies at the time that seamlessly blended visual annotations in the video-captured space (Figure 3-5) [32]. The visual augmentation directly over the body and the space was crucial for the effectiveness of the lectures because it enabled the audience to intuitively visualise "the connection between states of the body and compositional processes", and conveyed "a knowledge inscribed in and through the body as thinking" [37, 44]. Inspired by this approach, we explore the plausibility of bringing the visual augmentation into the dance studio by incorporating them into mirrors. Our goal is to enable real-time interaction with lines and images annotating and masking the reflected body and space, supporting dancers' and choreographers' improvisational creation.

Within the history of technology, *Improvisation Technologies* extends a line of scientific works that attempt to visually describe physical movement using state-of-the-art technology. Through his chronophotographic works during the end of the nineteenth century, the French scientist Étienne-Jules Marey captured various types of physical movement, with the purpose of understanding them by revealing the temporal and spatial relationships between body parts [9]. Whereas Marey had to dress his subject in black with bright markers on their joints to capture their trajectory, Forsythe benefited from the technological advancement one century later, and digitally rendered animated annotations directly on and around the body parts of the dancer. The state-of-the-art CG technology today is Mixed Reality (MR) equipped with motion tracking, which offers the opportunity of real-time bodily interaction with 3D content rendered around the user. This capability shows a promising direction for advancing this line of work by visually annotating movement trajectories and structures in real-time and in 3D. This enables users to touch, avoid, and move through the generated lines and shapes. However, the need of wearing a bulky headset presents a major challenge to introducing MR to the dance community for free and unhindered bodily exploration to create new dance movements through improvisation. For HCI researchers and interaction designers, dance is a complex application domain vulnerable to potential disruption of technological integration without proper consideration of its existing customs and practices, due to its dependencies on the dancers' kinaesthetic creativity and felt experience through the creative process [69].

Mirrors are the most prevalent way in dance studios for dancers and students to visualise their postures and movements for correction, analysis, creation, etc. [23]. With the continuous development of mirror-based MR interfaces in HCI, the prevalence of large mirrors in dance studios offers a more natural alternative to headsets for incorporating MR into the dance practice [3, 67, 70]. However, there is still a need for understanding the role these mirrors play in different contexts, such as learning and improvisation [19, 23, 55]. In this work, we explore the possibilities of using an interactive MR mirror to create visualisations in its reflection around the dancers' bodies for creating new movements in an improvisational context. We conducted a study with one expert participant (professional choreographer, dancer, and dance educator), and 12 other dancers and dance students with diverse backgrounds. Using a prototype MR mirror with four visualisation functions as a technology probe, we observed dancers' behaviours and collected their comments while they improvise in front of the mirror [38]. The improvisation sessions were followed by speed dating interviews around storyboards designed to illustrate future uses of the MR mirror in realistic dance contexts to elicit further discussion [71]. We also conducted a low-tech prototyping session for participants to illustrate their designs of future technologies to assist dance improvisation. Finally, we followed up with the expert participant one week later, for further improvisation and interview sessions. Through our findings, we highlight how the MR mirror enriches dancers' temporal and spatial perception, creates a multi-layered presence, and affords appropriation by dancers in their creative process. We also discuss the unique place of MR mirrors in the theoretical context of dance and in the history of movement visualisation, and the lessons offered by this study for broader HCI research.

## 2 RELATED WORK

In this section, we first summarise the relevant literature around the theoretical and ethnographic considerations for integrating technologies in dance and choreography, which inspired and motivated our current investigation. In specific, we review previous works in dance and HCI about creating new dance and choreography works using computational tools. Finally, we review mirror-based MR interfaces and interaction techniques in HCI, and briefly discuss issues pertaining to their application in dance.

### 2.1 Theoretical and Ethnographic Considerations for Technological Integration in Dance

In our recent review on dance and choreography in HCI, we recognised the challenges faced by HCI researchers for technological integration in dance, regarding "the bodily nature of expression, the abstract meaning making through movement, and the social and technological complexities in the production." Through the review, we called for an awareness among the HCI research community of unexpected pitfalls in their designs for the highly idiosyncratic creative process of dance and choreography [69]. The difficulty in designing computational tools for dance lies largely in the felt experience associated with the expressive body movement that makes it an application domain different from others related to movement, such as sport.

In *Introduction to the Dance*, John Martin places the idea of "movement" at the centre of his theoretical account of dance, while focusing on the responsive part of movement that we perform after experiencing external stimulus that evoke our personal feelings and emotions [47]. The concept of kinaesthetic empathy, defined by Martin as the sensation of motion experienced by a spectator when viewing a dance performance or other movement, coincided with a shift in the development of western dance towards becoming more expressive and less representational [18, 58]. Modern choreography, echoing the emergent focus on kinaesthetic empathy and awareness in contrast to the tradition of ballet, became a creative process of formulating new dance movement by translating emotional experiences into external forms, without caring as much about the correctness of positions [6]. Dancers and dance students were encouraged to use more improvisational exploration as choreographic material, while tapping into the multiple levels of presence within time and space, experiencing the conscious and the subconscious self simultaneously [6–8].

The freedom, openness, and the focus on the felt dimension of the experience in modern dance and choreography make them vulnerable to external factors that disrupt dancers' and choreographers' creative processes [69]. Further, the elusive and ephemeral nature of the improvisational choreographic process presents additional challenges for effective integration of technological tools aimed at capturing or representing dance movements [8]. Following a tradition of designing creativity-support tools, previous HCI research works have provided valuable lessons and insights for integrating technology in dance [30]. With the growing attention to somaesthetics and the lived experience of human actors [35], HCI researchers are realising the importance of nurturing kinaesthetic creativity, for creative new movements to emerge out of the active use of dancers' bodies [65].

Hsueh et al. summarised key qualities of interaction design for dance: *indeterminacy* to facilitate constructing complex relationships, *discoverability* to guide progressive learning, and *appropriability* and *correspondence* to enrich movement exploration [36]. Similarly, Alaoui et al. proposed that appropriate integration of technology in dance requires an anti-solutionnist approach, with an openness that embraces the messiness of their practice [26].

Apart from dancers' overall perception and reaction to technology in dance, previous works have also offered valuable lessons in understanding the intimate bodily relationship between dancers and technology as partners. One excellent example is Eriksson et al.'s analysis of the creative process of an opera where custom-built drones perform on stage with human performers. Through extensive observation and interviews, they revealed how the choreographer moved herself to feel the affordances of the drones' "otherness" through her own bodily experience and interactively alterd her choreography [25].

## 2.2 Creating Dance and Choreography with Technological Tools

Nearly half of the HCI research works in dance during the past two decades harnessed technological tools to *create* dance [69]. For instance, several works designed and evaluated tools for annotating and sketching body movement, aiming to help create and modify dance phrases, such as *The Choreographer's notebook* [61], *Knotation* [17], and *iDanceForms* [12, 14]. These tools enable choreographers to create and modify choreographic material by directly incorporating graphic annotations into the recordings or tracking of dancers' bodies. These works follow the tradition of visually annotating dance poses and movements led by Forsythe and his *Improvisation Technologies* [28]. Using the state-of-the-art CGI technology at the time, Forsythe and his collaborators created a series of video lectures augmented with visual shapes and images marking the spatial and temporal relationship between the dancer's body and its surroundings. This approach achieved great success in visually conveying choreographic ideas in unprecedented ways, and had extensive impact on the use of improvisational material for choreography creation [27].

Improvisation is an important method for creating new choreography and dance movements, because it encourages dancers to distance themselves from habits to better explore creative movement, using defamiliarisation to enable new perspectives in the creative process [11, 13, 16, 31]. Carlson et al. proposed a framework for human-technology choreography co-creation using defamiliarisation. Their framework included the following analytical components: Disorientation, Open-Play, Closed-Exploration, and Balanced Creativity [11]. In a review of technological systems for supporting choreography, Alaoui et al. grouped previous works by their purposes: reflection, generation, real-time interaction, and annotation [1]. They later explored the effect of movement-sound interactions for dance improvisation through live coding [29]. Mental imagery is a crucial skill for dancers and dance students to understand movement quality through bodily thinking. It is triggered by visual or kinaestetic images, including handling imaginary objects, imagining being in particular environments, and many other possible imaginary bodily states and shapes [63]. Recognising the potential of using MR for creating real-time interactive visualisations that support mental imagery in dance, Stergiou et al. categorised the most commonly used metaphoric examples as *body transformation*, *geometrical shapes and structures*, *trails*, *handling objects*, *environments*, and *actions as metaphors* [63].

Creating external visualisations that aid the otherwise invisible bodily thinking process is an important contribution in Forsythe's *Improvisation Technologies*. This work was also used as an example for the discussion of distributed cognition [44]. In the context of dance, the visualisation of movement qualities and choreographic cues help choreographers not only in their thinking process, but also with their kinaesthetic empathy. Forsythe's later work, *Synchronous Objects*, is another step towards 3D interactive visualisations that represent choreographic ideas and movement qualities, and help choreographers and dancers understand the work in its spatial, temporal, and collaborative dimensions [18, 52]. Similarly, El Raheb et al. presented a web-based system for multimodal annotation of dance recordings, using motion capture and other technologies, to broaden the horizon of dance practice and research [24]. Anjos et al. created and evaluated 3D visualisation of movement qualities in contemporary dance [4]. Previous work have also explored the use of MR and similar 3D CG technologies to enable real-time interactive visualisation with dancers for creating interactive performances, including using projection [33, 42], virtual body extensions [5], and virtual avatars [56] which affect the dancers' kinaesthetic creativity by changing the way they move.

## 2.3 Mirrors in Dance and HCI

Large mirrors can be found in many dance studios, providing a viewing portal for dancers to observe their own poses and movements for correction, analysis, creation, etc. [23]. While playing a crucial role in the training of traditional dance, which demands accuracy in the dancers' poses and movements such as ballet, mirrors are received by contemporary dancers with mixed feelings. Studies have shown that whereas studio mirrors can benefit learning, facilitate technical growth, and provide visual representation of kinaesthetically felt movement, they may also induce negative experiences, such as body objectification, fear for mistake, and frustration towards achieving an unattainable ideal [19, 23, 55]. Specifically, Ehrenberg evaluated the use of mirrors as a technology in a university dance training environment. They highlighted how the mirror blurs between the "internal and kinaesthetic" feeling of the dancers' own moving bodies, and the "external and other" perspective as if being viewed by a teacher, choreographer, or audience. Through their results, they called for further

exploration of the mirror as a technology offering "explorative possibilities of various modes of being", and deeper understanding of the "complex relationship with the projected image of their dancing" [23].

Because of the prevalence of mirrors in domestic and public spaces, there has been continuing interest in HCI research that uses them for displaying information, especially as augmentations on the body. These devices leverage half-silvered two-way mirrors mounted on a screen. For instance, Anderson et al. created "YouMove", an augmented mirror system that overlays Kinect-enabled skeletal tracking information on users' mirror reflections for guiding them towards correct postures and movements [3]. Other works further explored the possibilities of using mirrors to enable MR experience (for a review on augmented reality mirrors, see Portalés et al. [53]). For instance, Plasencia et al. contributed a design space for AR mirror displays, and briefly discussed the possibilities and limitations of such systems [48], while Jacobs et al. explored the use of the augmented mirror space for artistic performances [39]. In our recent work, we placed a virtual humanoid instructor inside an MR mirror collocated with the reflection of the user, using view-dependent rendering enabled by motion tracking, to provide intuitive perception of the instructor's movement for training [70]. These works place the augmented mirrors within the mixed reality spectrum proposed by Milgram and Kishino [49], while recognising their spatial mapping and/or motion tracking capabilities, which afford rendering virtual content directly over the reflected view of the physical world. Following this line of work, we posit the MR mirror adopted in this work within the broader MR continuum (for an extensive discussion, see [62]) as a mixed reality experience, and discuss it in light of relevant literature, such as embodiment [22] and presence [59].

## 3 METHOD

Inspired by William Forsythe's works on visualising embodied choreographic ideas around the dancer, and by the opportunity of integrating interactive MR technology through the mirrors in dance studios, we investigate dancers' reaction, reception, adoption, and appropriation of a MR mirror designed for helping them create new dance movements through improvisation [28, 52]. We designed and built a prototype MR mirror with four different visualisation functions, and used it as a technology probe with 13 dancers from diverse training backgrounds, to elicit their embodied experience and their feedback. We also designed and sketched eight storyboards that illustrate future uses of MR mirrors under different realistic dance scenarios, and discussed them with our participants in a speed-dating workshop [71]. At the end of the workshop, we gave participant groups low-tech prototyping art materials for them to design future technologies for dance improvisation [38, 60]. We further conducted an in-depth improvise and interview session with an expert participant, who has extensive professional experience in choreography and dance education, for richer feedback from her own perspective. Four months after the workshops, we conducted follow-up surveys with all participants to collect their reflections on the MR mirror experience better situated in their daily creative process of dance making. We also consulted an award-winning choreographer and digital media dance artist with a live demo of the MR mirror to collect further insights into its broader applicability. The study received ethics approval from the IRB at The University of Melbourne.

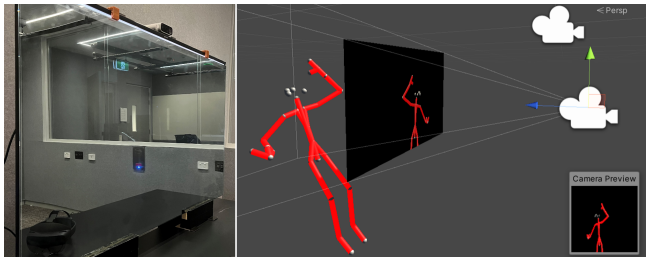


**Figure 2: Hardware and software configuration of the MR mirror in the prototype system. Left: the structure of the hardware setup consisting of a two-way mirror overlaid on a 65-inch LED TV screen. An Azure Kinect sensor is placed on top of the TV. Right: Software setup in Unity. A view-dependent render area is defined (the black quad) to show the virtual viewing area that matches the user's view of the mirror reflection (represented by the selected camera), through head-tracking provided by the Kinect sensor.**

### 3.1 Technology Probe Workshop

We adopted the technology probe method to understand the potential effect of the MR mirror on dancers' daily custom and practice during their creative process. We chose this method due to its suitability for gaining insights into how the exploratory design of MR mirror visualisations may be accepted, adopted, and appropriated by users for the complex and challenging creative process of dance and choreography [38, 69]. Specifically, we use the technology probe to elicit dancers' embodied experience of improvising with the MR mirror, which yields valuable insights through our observation of their behaviours and collection of their feedback in situ. This experience also helped dancers generate ideas for potential future use of the mirror, to aid the discussion during later speed dating workshops [38].

*3.1.1 Hardware and software setup.* We built our MR mirror based on the setup of a two-way mirror glass mounted on top of a 65-inch LED TV screen for overlaying virtual content on the mirror reflection, similar to previous works [48, 70] (Figure 2). We used the Microsoft Azure Kinect sensor which captures a high-definition point cloud for room-scale spatial mapping and full-body motion tracking. For view-dependent rendering, we used the head tracking function of the Kinect sensor and built a Unity application to adjust the viewing perspective of the virtual screen content according to the viewing perspective of the user, such that the content displayed on the mirror always appeared at their correct locations in the reflection from the user's viewing angle (Figure 2). We applied a VR occlusion shader to the point cloud of the user's body, so that the virtual content behind the user is correctly occluded in the MR mirror. We added a "Logitech R400 Presentation Remote" to the system to enable participants to draw and erase lines in space by pressing its buttons. The MR mirror was placed in a 4m x 3m observation room in our user experience evaluation laboratory.

*3.1.2 Visualisation Function design.* Using the prototype MR mirror, we designed four visualisations in simplistic visual forms, similar to the visual styles of the lines and body captures in *Improvisation Technologies* [28]. The designs are simple and open-ended, allowing

**Figure 3: Left: *"imagining lines"* from *Improvisation Technologies* [28]; Right: Point-point-Line creates lines between two body joints of the dancer. They remain in place after creation, and can be erased.**

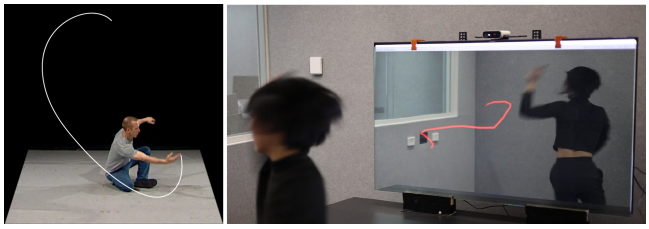

**Figure 4: Left: *"dropping curves"* from *Improvisation Technologies* [28]; Right: Air Drawing leaves movement traces of the dancer's drawing hand. They remain in place after creation, and can be erased.**

**Figure 5: Left: *"Own Body Position"* from *Improvisation Technologies* [28]; Right: Delayed Presence renders a delayed 3D capture of the dancer's moving body in the mirror next to their present reflection.**

the users to explore and reinterpret them [38]. We present snapshots from the expert participant's improvisation session while using each function, side-by-side with their inspirations from previous work (Figure 3—6). Note that whereas the snapshots were taken from a side angle, the dancer's view of the visualisations in the mirror is similar to the snapshots taken from *Improvisation Technologies*, where the virtual images are rendered over the correct locations they augmented, through view-dependent rendering provided by the prototype.

Point-point-Line (PL): This function is inspired by "imagining lines" from the "lines:point-point-line" section in *Improvisation Technologies*. It is the first lesson in the original video lecture series, conveying the most basic idea of visualising an imagined line between any two parts of the body or any two points in space. This lesson provides the basis for most of the later elaboration of visualising different complex shapes and operations demonstrated by Forsythe [28]. Our implementation allows the dancer to draw a straight line between two body joints when they press the "right" button on the remote in their hand. The two joints can be any joints of the body that are available from the Microsoft Azure Kinect's body tracking function[1], and are set as the two hands by default. The dancers are able to create as many lines as they like, which remain at the same location until the dancer presses the "left" button on the remote to erase all lines. The lines are occluded when they are behind reflections of the dancers' body parts (Figure 3). We use this function to enable participants to visualise the spatial relationship between their hands, and to create lines for aligning, avoiding, measuring, etc.

Air Drawing (AD): This function is inspired by "dropping curves" from the "lines:complex operations" section in *Improvisation Technologies*. It creates a trace of a moving part of the body, visualising the logical progression of the motion. This is the first point in the lectures where temporal information of the moving body is introduced. Our implementation is also inspired by "airdrawing" by Forsythe and Weltz, which extends "dropping curves" into a standalone artwork that visualises the continuous movement trajectory of the dancer's hand [68]. Our implementation allows the dancer to continuously draw the trace of their dominant hand holding the remote when they press and hold its "right" button. Dancers are able to create as many lines as they like, which can be erased by pressing the "left" button on the remote. The lines can be occluded by the dancers' reflected body parts if they move in front of them (Figure 4). This function helps participants visualise the temporal and spatial relationship between the movement trajectory of their body and its surrounding space.

Delayed Presence (DP): This function is inspired by "Own Body Position" from the "lines:avoidance" section in *Improvisation Technologies*. It visualises the frozen pose of the dancer's body at one point in time and space, and enables the dancer to move around it by aligning to different parts of it, or to avoid it. This is the first point in the lectures where camera-captured images are visualised instead of abstract lines. It helps dancers visualise their own poses and the volumes of space occupied by them during the past, and create improvisational phrases in relation to them. Our implementation is also inspired by Étienne-Jules Marey's "clichés géométriques", which visualises the overlay of a series of continuous poses of a movement performed by the subject, revealing each step of the formation of the movement to better understand it [9]. Our implementation creates a delayed 3D capture of the dancer's body rendered as a point cloud (Figure 5). The amount of delay is adjustable, and is set as one second by default. We use this function to enable participants to visualise their own body and its movement in the past, sharing the same space in the mirror with their real-time optical reflections. The participants could use their delayed presence to understand their own movement, or to use it as a partner, etc..

Embodied Estrangement (EE): This function is inspired by previous HCI dance research works on altering the dancers' body images using avatars or other visualisations [5, 33, 42, 56]. We use this function to explore the possibility of using the MR mirror for visualising virtual images other than simple lines, shapes, or realistic captures of the dancer's body. Learning from previous work, we chose to visualise a humanoid avatar to enable dancers to defamiliarise with

[1]https://docs.microsoft.com/en-us/azure/kinect-dk/body-joints

**Figure 6: Left: *"invisible avatar"* from *Choreomorphy* [56]; Right: Embodied Estrangement masks the reflection of the dancer's body using a featureless avatar.**

themselves, to experience the embodiment of an alternative form, and to observe their own movement more objectively [11, 13, 16]. We also aim to observe how the altered bodily presence may affect the dancers' felt experience and change their movement quality [56]. Our implementation renders a featureless humanoid avatar[2] that masks the reflection of the dancer's body. The avatar is controlled in real-time by the dancer with all the joints tracked by the Kinect (all major body joints apart from the fingers) (Figure 6).

## 3.2 Speed Dating Workshop

We designed our technology probe to give participants the embodied experience of the opportunities and limitations of MR mirror technology. Our goal was to allow a deeper investigation of the felt life, embodied experience, social interaction, and self-presentation within a familiar context of dancing in front of a large mirror [38, 71]. To expand our investigation to broader futuristic scenarios beyond the current capabilities and limitations of the technology, we followed the technology probe workshop with a speed dating workshop featuring a storyboard interview and discussion sessions [71]. Having experienced the interaction with the prototype MR mirror as user enactment, the participants would be in a better position to envision the future scenarios in the story boards more easily. Through the group interviews and discussions in this workshop, we aim to gain insights into a wider range of situations and contextual factors of interacting with the MR mirror for dance, and to determine a better future with the technology by reframing this problem and opportunity space with the dancers [71]. At the end of the workshop, we conducted a low-tech prototyping activity, and provided participants with art supplies like paper, sticky notes, and coloured pens and highlighters. We asked them to create concepts of future technologies that could help with improvisational dance-making, inspired by their experience with the MR mirror and the storyboards [38, 60].

*3.2.1 Storyboards.* We designed and illustrated eight storyboards representing future uses of the MR mirror for different purposes and within different contexts. We present three example storyboards in the paper (Figure 7-9), and include all eight in the supplementary materials. We developed scenarios of imagined uses of the MR mirror upon dancers' familiar daily context of dancing in front of a large mirror in the dance studio, and investigate how the integration of MR visualisation technology may reveal possible futures. We designed

[2]https://www.mixamo.com/

**Figure 7: Understanding character movement style by embodying a virtual avatar in the mirror: (1) Nola is creating a new show; (2) She has a problem with a character who is an elderly man with two solos in the performance; (3) Nola uses an avatar of an elderly man in the MR mirror to better understand the different strengths, limitations, and potentials of this body type different from her own; (4) When she discovers a phrase she likes, she freezes the avatar and take notes for future use.**

**Figure 8: Understanding the spatial constraints of the stage by visualising it in the mirror: (1) Nola rehearses her choreography in the studio; (2) But when she gets on the stage, she has trouble judging distances because it is much smaller than the studio; (3) She uses the MR mirror to define and visualise the parameters of the stage space; (4) She can also visualise which parts of the space she occupies more, to adjust her movements further.**

these scenarios based on the participants' experience with the prototype visualisation functions in the technology probe, but extended them into different aspects of their daily practice and creation of dance and choreographic phrases.

We consciously made the illustrated scenarios as cases of simplistic integration of technology without too much consideration of the dancers' existing custom and habits. For instance, some of the illustrated functions could have been achieved using ordinary video recording. However, we restricted the scope of the discussion to applications in the MR mirror to push participants past their comfort zone, and to gain insights into their real need that may be fulfilled by the technology. The storyboards were intended for interviews and discussions conducted with participants in groups, to encourage them to reflect on the others' opinions, and elicit insightful discussions from new perspectives [71].

## 3.3 Follow-up Survey

In the speed dating workshop, we intended to learn participants' feedback through associating the MR mirror with their daily creative experience using the storyboards, which featured a broad range of possible scenarios. To validate our findings with further insights from the dancers' reflections on their experience with the MR mirror better grounded in their realistic daily practice of dance making, we conducted a follow-up survey with the same participants four months after the workshops. We asked if they had new thoughts about the MR mirror while using mirrors and digital technologies in dance studios, or generic ideas and suggestions for using the MR mirror in dance.

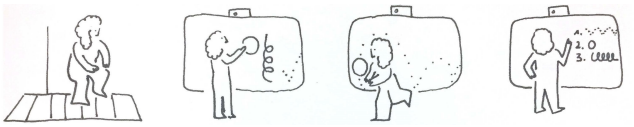

**Figure 9: Understanding movement quality through physical simulation in the mirror: (1) Nola is working on the energy of bouncing; (2) She uses the MR mirror to define a formal vocabulary made up of physical simulations rendered in the reflection, such as a bouncing ball and a spring; (3) She is able to follow the visualisation to better understand the quality of bounce; (4) She can create custom-made exercises using combinations of those visualisations.**

## 3.4 Follow-up Expert Interviews

While all participants in the workshops had varying levels of professional experience and expertise from diverse dance backgrounds, we conducted a follow-up improvisation and interview session with one of them who has extensive and diverse professional experiences as a dancer, choreographer, rehearsal director, and educator working with international dance companies and artists around the world. Inspired by similar methodology adopted in previous work for preserving the authentic first-person embodied experience of the dancer [15, 25], we present her own writing based on the interview discussion to provide an intimate perspective from someone who usually acts as the leader in studio sessions covering a diverse range of styles and philosophies, for future directions of the integration of the MR mirror in dance studios. We also consulted an award-winning choreographer and digital media dance artist using a live demo of the prototype, to gain further insights into the potentials of the MR mirror for artistic practices closely related to dance.

## 3.5 Participants

We recruited 12 participants (8 women / 4 men) with a mean age of 21.9 years ($Min = 19, Max = 29, SD = 3.6$), and one expert participant (woman, 35) from the Victorian College of the Arts at The University of Melbourne. All participants were professional dancers and/or pursuing tertiary education in dance at the university, among which nine were professional dancers, seven were university dance students, and one was a choreographer. Our expert participant is a professional dancer, choreographer, educator, and rehearsal director with extensive experience in contemporary dance, theatre, TV & film, and other performing arts. All other participants had background in contemporary dance, while 6 had training background in ballet, 4 in street dance, 3 in jazz, 2 in choreography, and 2 in circus and gymnastics. We conducted the workshops with all 13 participants in six groups, and a follow-up interview session with the expert participant only.

## 3.6 Procedure

We conducted the study with the 13 participants in six groups of 1 to 3, depending on their availability and different professional backgrounds in dance. One researcher (woman) with a dance background led the workshop sessions [15]. Upon arrival, participants were informed of the purpose of the study and asked to sign a consent form. For each group, we started with the technology probe workshop,

| Group | NO. of Dancers | Professional Background |
|---|---|---|
| 1 | 2 | Dance artist/educator and Student dancer with professional exp. |
| 2 | 2 | Student dancers with professional exp. |
| 3 | 1 | Student dancer with professional background in choreography |
| 4 | 3 | Student dancers with professional exp. |
| 5 | 2 | Professional dancers with theatre, circus, and gymnastics backgrounds |
| 6 | 3 | Professional dancers with background in street dance |

**Table 1: Number of participants and their professional backgrounds in dance in different groups.**

where the researcher briefly explained how to use each visualisation function before participants started improvising in front of them. Figure 10 shows one session with a group of three participants improvising in front of the MR mirror using PL and AD. Participants improvised with each function for unlimited time, while thinking aloud.

After the technology probe workshop, participants were led to the room next door, where the experimenter conducted the speed dating workshop while sitting with each group around a large table. For each of the eight storyboards, the experimenter read through the illustrated scenario, and then engaged in an open discussion with the participants for their reflections on their daily practice, and for their feedback on the role that the MR mirror could play in the future. Finally, we gave participants art supplies for them to illustrate their designs of future technologies to assist dance improvisation. The two workshops lasted approximately two hours combined on average for each group, with a $40 gift card compensation for each participant. We video-recorded all workshop sessions for later analysis.

One week later, we invited back the expert participant who had previously participated in the workshop with the other dancers, for a follow-up improvisation and interview session. We asked the expert participant to improvise in front of the MR mirror using the four visualisation functions again. With the refreshed experience, we then conducted an open interview with the expert participant. Together, we reflected on the workshops conducted one week earlier, and discussed our initial observations and thoughts. The expert participant further elaborated on her feedback during the workshops and on her reflections over the past week regarding the potentials of the MR mirror's applicability in dance. We video-recorded her improvisation with the MR mirror, and transcribed her feedback from the interview.

# 4 RESULTS

The technology probe workshop, the speed dating workshop, and the follow-up session with the expert participants generated around 13 hours of video recording in total, 13 low-tech prototyping designs made by participants, and the writing of the expert participant. Two


**Figure 10: A group of three participants improvising in the technology probe workshop using (a) Point-point-Line and (b) Air Drawing.**

researchers, including the workshop lead, carried out a general inductive analysis of the data, using independent parallel coding to categorise notable participant behaviours and comments during the technology probe workshop, notable comments as quotes from the speed dating workshop, and notable themes in the low-tech prototyping designs [66]. This was followed by collaborative tagging and discussion around the findings on a Miro board [3]. The analytic process led us to a shared understanding of the different types of dance behaviours and technological exploration behaviours performed by the participants, and regarding their comments on the effects of the MR mirror on their presence, visualisation, the creative process, and their existing custom and practice. After the initial analysis, we validated our findings with the expert participant to avoid any potential misunderstandings [25].

## 4.1 Technology Probe

We categorised the behaviours and comments with the technology probe into themes under three categories: Dancing with the Mirror, Exploring the Technology, and Reflection on the Creative Process.

*4.1.1 Dancing with the Mirror.* We observed various ways in which participants danced with the visualisations in the MR mirror, and how the visualisations changed the participants' movement style and quality. We categorise these findings as: **Embodying the Reflected Space**, **Dancing with the Reflection**, and **Defamiliarisation**.

**Embodying the Reflected Space**: Many participants used PL in the same way as intended in Forsythe's Improvisation Technologies. They created lines in space and then improvised while aligning their body parts to them: "*It's like Forsythe's video but a live version.* (3A)", "*It lets you know how your body can create imagery.* (4A)", "*It makes me think about the space between my limbs, quantifies the space, and grounds the perception of space within my body.* (4B)" Many participants also created different shapes and styles of images using PL and AD to visualise their movement traces, such as creating gradual patterns using PL that visualise the trajectory of the space between their hands, and drawing symmetrical shapes using the drawing hand which led the movement of the whole body (Figure 10).

[3]https://miro.com/

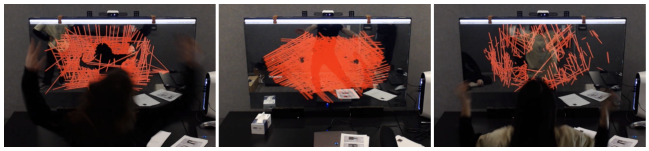

**Figure 11: Examples of participants exploring the depth occlusion feature by creating and moving through a "wall" of lines.**

Realising that the visualisations rendered in the MR mirror are registered in the space around them, participants tried to get a better sense of embodiment over the reflected space in different ways through the visualisations collocated with their reflected bodies in the mirror. Many participants commented that they liked the fact that they were able to occlude the lines that are behind their reflected bodies in the mirror, and that this occlusion effect gave them a better sense of where they were relative to the visualisations in the space. "*It allowed me to visualise the space by occluding the lines.* (4C)" Some participants even created walls of lines using PL and AD. They used different parts of their bodies, such as the head, the hands, and the torso, to extrude the "wall", as if breaking out from a confined space (Figure 11). Some participants also created cocoon-like structures using AD around their bodies while turning in circles.

**Dancing with the Reflection**: One common theme that emerged in participants' behaviour was the use of visualisations as dance materials or partners during the improvisation. Most notably using DP, most participants danced with the delayed capture of their own reflection as if it was a partner. They created symmetrical patterns with the delayed images of themselves, performed repetitive and synchronised movements, and slowed down at times for them to catch up. "*Even though I knew the amount of the delay, I still wanted to play catch with the delayed capture, and there were moments of repetition and unison.* (4C)".

**Defamiliarisation**: The effect of defamiliarisation can be observed and inferred from participants' comments, most notably through EE. By dancing with the avatar masking their reflected bodies in the mirror, participants experienced the improvisation from the perspective of a different body: "*I was able to objectively watch myself like someone else.* (3A)".

An interesting consequence of the limitation in the Field-of-View (FoV) of the Kinect sensor and the technical limitations in the tracking algorithm (unable to track occluded joints), was that there were glitches, in which the avatar appeared to be floating in mid-air when participants' legs were not tracked correctly (e.g. when they stood on one leg with the other leg raised up) (Figure 12). This effect, along with the avatar's visual appearance, gave them a sense of "weightlessness." Some participants notably jumped around in front of the mirror while improvising using EE more than when improvising using the other visualisations: "*Because it was not my body, and for that character (avatar) you don't see the musculature and the human qualities, I didn't feel the weight of my leg as much, and felt very easy to put my leg up.* (4B)"; "*Its (the avatar) movement so informed my movement, because of the difference in the specificity (of our bodies), its otherness, its non-human appearance, and even the limitations of the camera (the floating effect).* (5B)" Some participants also performed robot-like movements after seeing the robotic appearance of the avatar.

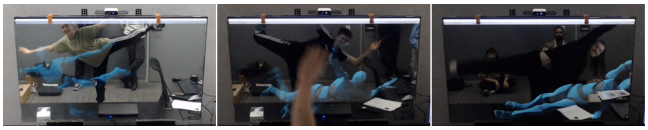

**Figure 12: Examples of participants trying to create the floating effect of the avatar by tricking the tracking algorithm.**

*4.1.2 Exploring the Technology.* Participants exhibited intriguing ways in how they explored the novel technology of MR mirror. We categorised these behaviours into **Criticising**, **Suggesting**, **Repurposing**, **Testing the Limits**.

**Criticising**: Participants made critical comments about the MR mirror due to its limitations and the novelty effect of some functions. Some participants pointed out that due to the limited range of FoV of the tracking camera, there was not much use of the legs in AD, PL, and DP. 3A also mentioned that the fact that she had to look at the mirror to see the visualisations is a compromise of the freedom of movement, which is crucial to improvisation. 4A and 4C commented on the disorienting feeling that they got with DP, where the delayed capture of themselves confused them of where in time and space they really were: "*I tried to ignore it (the disorienting feeling) and get used to the delayed capture collocating with my real reflection. It got better after a while.* (4A)"

**Suggesting**: Participants made several interesting suggestions for how they thought the technology could be improved. Some participants wanted more interaction affordances with the lines in PL. They asked for the ability to rotate the lines created, to shoot lines out of single hands as arm extensions, to colour the lines differently, and to change the lengths of the lines by holding a button, etc.. 6A and 6B also suggested that there could be more functions like DP that are not dependent on motion tracking, because of the better sense of freedom in dancing with them. 3A suggested a more anatomical appearance of the avatar in EE to better see the details of their poses and movements.

**Repurposing**: Participants appropriated the visualisation functions and used them in ways that were not intended by their designs. 3A suggested that apart from improvisation, PL would be very useful for teaching and demonstrating as in the Forsythe lecture, and that DP would be great to add to a performance setting as a stage effect. Some participants used PL exclusively to create a wall of lines to explore the depth occlusion effect, and found it to be the most promising visualisation, even though it was never intended as an individual feature. Many participants tried to confuse the motion tracking to create the effect of the avatar floating in mid-air with EE by standing on one leg and lift the other leg up high. For instance, when 6B tried it and achieved that effect, 6A and 6C in the same group excitedly yelled: "*Glitch! Glitch!*" Because detailed hand movements were not tracked by the Kinect sensor, many participants noticed it and adapted to the movement style of the avatar's hands in EE, consciously or subconsciously. They improvised with their hands extended flat and waved them like fans.

**Testing the Limits**: One common type of behaviour observed in the participants was testing the limits of the technology. Beginning with AD, participants tested the range of the motion tracking function by getting really close to the mirror, and by drawing lines with their hands hidden behind their back from the tracking camera.

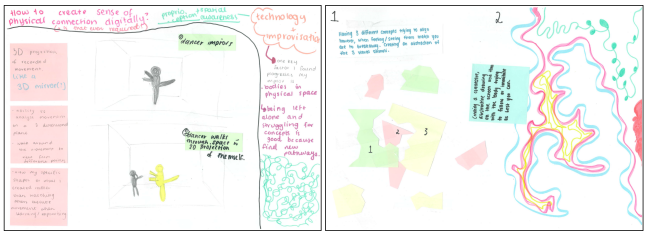

**Figure 13: Examples designs made by participants from the low-tech prototyping session.**

These types of behaviours happened the most with EE where participants were intrigued by the full-body motion tracking provided with the avatar, and wanted to push the limit of the tracking. This testing behaviour elicited playful dance phrases from participants during their improvisation. They moved their bodies in humorous and twisted positions, or jumped around a lot more while observing how the avatar responded. The testing also evoked new ideas in their improvisation: "*I found myself trying to confuse it (the tracking), which served as start of new ideas for improvisation.* (5A)"; "*It was very playful. I was in a different head space when this (EE) is on, comparing to dancing by myself.* (6C)"

*4.1.3 Reflection on the Creative Process.* During the technology probe workshop, participants made many insightful comments on how the MR mirror and its visualisation features may affect their existing practice and customs in dance. One common reflection is the demand of attention for using the visualisations rendered in the mirror. 3A mentioned that the demand of visual attention caused a compromise in the freedom of moving the body towards any direction during improvisation. Participants also mentioned attention while commenting on AD: "*I was not sure if I should focus on the dance or the drawing.* (4C)" Participants that did not usually practice improvisation with a mirror thought that the mirror itself is a distraction for improvisation: "*I was distracted by myself.* (1B)"; "*(Especially the young) Dancers tend to get fixated on themselves using the mirror.* (6C)" Some participants also pointed out that the visualisations from the MR mirror might not be enough as instructions or cues for improvisation, and that more context would be useful.

## 4.2 Speed Dating

During low-tech prototyping, participants have mostly written down or sketched out the ideas that they had just mentioned during the storyboard discussions. For this reason, we summarise results from these two parts of the speed dating workshop together, and categorise them into three topics: **Presence in the Mirror**, **Visualisation**, **Creativity**. We present two sketches in Figure 13 as examples, and include all 13 in the supplementary materials.

*4.2.1 Presence in the Mirror.* Participants commented on the MR mirror's effect on their sense of presence in the space through their reflections. We categorise these discussions into **Self Presence** and **Spatial Presence**.

**Self Presence**: Some participants were intrigued by the mirror's unique capability of revealing and confronting the dancer's creative and expressive identity by augmenting their reflections: "*When you*

*look in the mirror, you are confronting your personal self, your dancer self, your artist self, your choreographer self ... It's a lot of you, and your body is your canvas.* (1A)" They felt that this reflection raised their self awareness during the improvisation: "*There is a vulnerability in it. It's not someone else's movement. You are putting yourself forward.* (5B)" While the avatar in EE masked the reflections of the participants' bodies, its presence also provoked them to think about their own bodies, as they discuss Storyboard 5 (Figure 7): "*I feel that a lot of ideas (movement quality) have to come from within.* (2B)" Many participants also felt self-conscious reacting to the illustrated scenarios where their movement would be recorded. They commented on this topic while relating to their experience with the MR mirror in the technology probe workshop, and to their daily training and creation practice: "*When I improvise, I prefer no mirror, no camera, in a closed off space, so that I can (better) feel it.* (2A)" Participants also questioned the authenticity of their body movement under recording: "*Something subconsciously happens when you start recording. It's not as authentic.* (6C)"; "*There is some tension added when recording.* (2A)" However, other participants also mentioned that they like to use recordings to analyse their own movement while they improvise to create a choreography.

**Spatial Presence**: Participants elaborated on how the MR mirror may help them visualise and embody the space around them better, and on how they have been trying to achieve that in their existing practice: "*I need to think about lines in my body and in the space between different body parts to help me do the movement.* (4B)"; "*One thing you learn without being taught is the kinaesthetic awareness of where everyone else is in space* (5A)." Participants liked the function of visualising the volumes of space occupied by the movement: "It is cool to track what space is unoccupied and that's questioning if I want to leave this space blank intentionally. (4C)" They also found the scenario about visualising a virtual space interesting: "*We have never really visualised the space internally. This would be a good way to immerse yourself in the space.* (2A)"

*4.2.2 Visualisation.* One important theme of the discussions was the effect of different types of visualisations on dancers' **Mental Imagery** for intended movement qualities, **Sense of Embodiment** over the augmented body and space in the reflection, and the lack of **Multimodal Stimuli**.

**Mental Imagery**: Participants mentioned that creating mental imagery is an important skill in dance, for them to visualise movement qualities and forms described by the choreographer. They described their existing practice for creating mental imagery as using verbal descriptions of textures: "*Coming from a contemporary background, I play with a lot of textures like honey, fairy, sticky ... and you try to interpret that in your body.* (6B)" Participants described recent experiences of the difficulty in creating mental imagery: "*We found it really difficult because it's a piece from so many years ago and we couldn't embody the movement particularly* (2B)" Speaking of the same project: "*We just couldn't pick up the details. It's definitely a mental element other than a physical one, so you definitely need a strong visualisation.* (2A)" Participants commented on the MR mirror's potential for assisting imagery: "*In practice, sometimes you can't get in there because you don't have the visual capacities to create image in your brain ... that's why I found the mirror useful, especially the lines* (PL). (4B)"

**Sense of Embodiment**: Some participants gave detailed comments about their experience on embodying a different body, energy, or movement quality through the MR mirror: "*I felt my body was different because I was looking at something different. My body felt lighter when the character jumps, it was really like no energy, no weight. That's why I think it (MR mirror) may be useful.* (4B)" They also elaborated their ideas for future use of the MR mirror's capability of inducing sense of embodiment over movement qualities: "*You can visualise a snail and mimic it and move like a snail ... It is an advancement of just filming yourself ... I can embody something a bit further.* (6C)"; "*You can imagine that you are holding a ball, but if you actually see the ball in your hands in the mirror, it's going to make you think differently until you (are inspired to) create the imagery yourself. I felt that with the screen (MR mirror).* (4B)"

**Multimodal Stimuli**: Many participants pointed out that the exclusively visual information rendered by the MR mirror should not be the only tool in the creative process, and mentioned the use of mutimodal stimuli in their daily training and creation process: "*It can be limiting if you only think about visuals rather than sensory and qualitative (information) or tensions.* (5B)" Some participants sketched ideas around verbal and textual feedback provided by the MR mirror to aid their practice and improvisation. Many participants elaborated on the lack of tactile feedback, and how that is important in their practice: "*I need the teacher to tell me how to do it and preferably actually put me in the right position. I function with physical promps a lot.* (4A)" Some participants specified that the bodily contact is especially important in partnering: "*When I'm improvising with someone I don't know, we just connect with each other and try to breath together ... bringing in touch slowly and just gently feeling each other's bodies. So you give some information but also receive some information ... just with hand connections.* (1B)"

*4.2.3 Creativity.* Other than commenting on the features of the MR mirror, participants also reflected upon their daily creative process related to the storyboards. Many of them mentioned the importance of exploring new movements through improvisation: "*It's testing the boundaries of your practice, seeing what potential can be reached.* (6C)"; "*I think the main role of improvisation is to constantly break habits and to keep pushing for difference.* (2A)"

Many participants mentioned that apart from improvisation, the MR mirror can also be applied for learning and training because of its capability of visualising alignments and movement qualities. Some participants exhibited a negative sentiment towards using technology in dance, especially 4C: "*I don't think machines can gauge energy in the same way that human can. How does the machine know?*" Participants frequently mentioned and sketched ideas around using the MR mirror in performances, which could benefit from the novel visualisations. These include rooms built with mirrors, ways of visualising movement traces, abstract patterns rendered in the mirror for dancers to interpret, and playing back dance recordings through 3D projections or holograms (Figure 13).

## 4.3 Follow-up Survey

Four months later, participants provided feedback on the occasions where they were reminded of the MR mirror experience during their use of studio mirrors and other technologies during dance making and practice, and suggested potential applicability of the MR mirror in dance based on their reflections. We consolidate common

themes in their responses into **Documentation**, **Visualisation**, and **Performance and audience engagement**.

*4.3.1 Documentation.* Six participants mentioned that they wished they could use the MR mirror for documenting and demonstrating dance movements while they practised in front of studio mirrors and while video-recording their movements for creating new pieces. Participant 2B specified the reasons as "recording what space was used", and "in real time" (2B). Two participants mentioned that the 3D motion capture and rendering in the mirror could enable them to better capture the intricacies of the movements with the ability to look at it from different angles (5A,6C).

*4.3.2 Visualisation.* Five participants further envisioned the use of different visualisations in the MR mirror. While participant 1A reiterated her appreciation of the co-presence between the past and the present bodies of the dancer afforded by the MR mirror, other participants mentioned possibilities of using it to help dance partners learn each other's moves, to render visual cues for different dynamics and textures, to create and render digital terrains in the mirror around the dancer's reflected bodies, and to render abstract visual guides to direct dancers across the space.

*4.3.3 Performance and audience engagement.* Six participants commented that they wish to see the MR mirror used in future performance settings and other scenarios such as art installations to engage general audience with dance. For instance, they suggested that the MR mirror could promote interactions between dancers and dance audiences, potentially by playing back dance performances in mirrors to enable bodily engagement from the audience, while making dance more accessible. They also illustrated scenarios where the MR mirror could be adapted into art installations, such as walls of interactive mirrors in gallery spaces and art festivals (1A,2B,4C).

## 4.4 Follow-up Expert Interviews

*4.4.1 Feedback from expert participant.* We give voice to the expert participant (1A) from the follow-up interview, where she gave her feedback on the MR mirror, and reflected on its affordances and potential for integration in different aspects of dance. While 1A liked the potential of PL in pushing the exploration of physical limits, she was very interested in DP for enabling the dancer in the present to "*dance with the delayed digital self ... which opened many exciting possibilities for creative exploration.*" She especially appreciated the opportunity to manipulate time, perception and presence with DP, which encourages creative exploration of different movement dynamics and thematic ideas through "*a playful improvisation with different states of presence in relation to the body.*"

Through her experience working with different collaborators, 1A's practice "*consists of using both the conscious and the subconscious in an embodied focus ... including (1) myself in my body while in motion or stillness; (2) myself and my body moving in space; (3) myself in relation to other dancers/bodies; (4) myself in relation to an audience*", depending on the physical arrangement of the performance space. By combining the conscious and the subconscious, she is "*present in the moment with an embodied focus ... but also riding the creative, subconscious stream of free flow.*" To this end, 1A commented that "*DP encourages the use of the embodied focus ... while dancing with (different) versions of the self*", including "the past self" rendered in the mirror with the delayed capture, "the present self" in the corporeal presence, and "the future self" representing movement possibilities in the next moment. Additionally, 1A liked how EE could be used to visually articulate imagined qualities and dynamics which are often necessary to be conveyed to dancers.

To conclude, 1A considered the MR mirror "*a useful tool for choreography and improvisation in introducing new ideas of how we perceive ourselves, our bodies in space with digital images rather than only imagined in the mind's eye ... This technology can support the creative process in stimulating and exploring ideas for a new choreographic work as well as an educational instrument for demonstrating the choreographic process through improvisational approaches.*"

*4.4.2 Feedback from Digital Media Dance Artist.* After experiencing a live demo and watching a video demo of the prototype, the artist provided feedback from the perspective of a choreographer with extensive experience in digital media dance practice. She suggested that the MR mirror would be useful to program arm phrases to teach choreography to dancers and dance students, which is especially valuable in comparison to video recordings while benefiting from the 3D reconstruction capabilities. She also appreciated the potential value of the MR mirror as an interactive mixed reality installation for gallery spaces, especially with DP and EE, for better engagement with dance audiences. She also suggested that the MR mirror could be integrated on dance stages depending on the concept of the work.

# 5 DISCUSSION

Through the technology probe workshop, the speed dating workshop featuring story boards and low-tech prototyping, the follow-up surveys, and the expert interviews, we collected a rich set of valuable feedback from participants and experts with diverse backgrounds and professional experience in dance. In this section, we discuss common themes emerged from the results in different parts of the study grouped into subsections.

During the technology probe, participants had opportunities of freely exploring the visualisations in the MR mirror. Specifically, they gave feedback around their experience of embodying the reflected space through the lines and traces rendered in the mirror, which gave them sense of spatial presence in the mirror, as they commented in the speed dating workshop. Additionally, the visualisations reveal the temporal and spatial structures of their body postures and movements through the mirror reflection, which could also help create mental imagery which is often necessary in dance, as participants commented in the workshops and in the follow-up survey. Further, the altered visual appearances of the dancers' bodies in EE induced in them a sense of defamiliarisation with their own bodies, which was deemed helpful for nurturing novel dance movements as a response to the change. We discuss these topics regarding the direct effects of the visualisations on the dancers as **revealing, altering, and augmenting dance using the MR mirror**.

In the technology probe workshop, one of the common behaviours in exploring DP was using the delayed capture in the mirror as a dance partner in various temporal relationships with it. This was further elaborated by the expert participant as a way to encourage dancers to explore different levels of conscious and subconscious presence in space and time. Further, the bodily presence, as visually exposed by the mirror, induced different levels of self awareness

with different visualisations. We discuss these topics as the **multi-layered presence around the mirror**.

While exploring the MR mirror in the technology probe workshop, participants made positive and critical comments over the effects of the visualisations on their improvisation experience, and exhibited behaviour such as repurposing its functions and testing its technical limits. They also reflected on their creative process and suggested potential future uses of the MR mirror in the workshops and the follow-up surveys. We discuss these topics around their reception of the MR mirror as a novel technology in **freedom, resistance, glitches, and possible futures**.

Finally, we revisit the literature and discuss the significance of the MR mirror in the context of earlier works including *Improvisation Technologies*, for **Visualising movement, for dance**. We also discuss the **lessons for HCI** learned from the dancers' experience with the MR mirror for relevant research areas, especially in mixed reality.

## 5.1 Revealing, altering, and augmenting dance using the MR mirror

*5.1.1 Visualising dance movements in space and time.* By revealing visual traces and structures of movements in 3D, the MR mirror enriches dancers' temporal and spatial perception during improvisation. One challenge in dance is building mental imagery for movements and poses [63]. Similar to *Improvisation Technologies*, PL helps to visualise the otherwise invisible structure between dancers' body parts and their relationship with the surrounding space, formed at fleeting moments during improvisation [8]. At the same time, the straight lines are also traces of the dancers' past movement, as they remain displayed in mid-air at the locations they were created, as material for creating new movements [25].

Whereas AD visualises the continuous trajectory of the movement of the drawing hand or another body part, PL reveals an abstract trace of a moving structure between two parts of the dancing body. The lines in PL gave participants a better sense of the 3D space because they were created between two different points. This was appropriated by participants during the technology probe workshop, to create gradual patterns and abstract traces of their movement (Figure 10). Another appropriation of PL was to create "walls" of lines from which their body contours could emerge. This accidental feature of the MR mirror also helped them visualise the spatial relationship with the surrounding space charted by their own creation of abstract structures. These visualisations have potential in helping dancers understand their movement in real-time while they improvise, and in stimulating the creation of new movements, tapping into their kinaesthetic creativity [36, 58]. The advantage of the MR mirror over ordinary video screens for DP is that it places the dancer's moving body in the past directly over or next to their reflected body in the present. By sharing the reflection space in the mirror with their past self, dancers are able to approach, avoid, and move through them in real time. This serves both as a training tool for building awareness of their movement in time and space, and also as a visual stimulus for them to create improvisational movements that explore different relationships with their past selves.

*5.1.2 Creating dancers' lived experience through visualisations in the mirror.* Previous work have found that real-time interactive visusalisations as stage effects can alter the dancers' felt experience during their performance and change their movement quality [33, 42]. Visualisations in the forms of alternative representations or extensions of the dancers' bodies can alter the perceived body schema, which affects dancers' kinaesthetic creativity and changes how they perceive and execute their movements [5, 56]. With the MR mirror, similar visualisations can be rendered within the mirror reflection space while collocated with the reflection of the dancing body. Instead of seeing the visualisation around them from a first-person perspective, dancers see the visualisations directly augmenting their bodies and the surroundings in the MR mirror, from an exocentric perspective. This could lead to stronger defamiliarisation felt by the dancers with their bodies, and nudge them to move differently with a new freedom from the creativity fixation induced by their habits [11, 36]. This effect was found during the study, where participants internalised the weightless movement quality of the avatar through imitating and feeling its affordances and expressivity [25]. Similarly, the expectations of visualising anatomical body structures and energy simulations in participants' comments reflect their recognition of the benefit of being able to see themselves collocated with the rendered visualisations. This potential feature can help choreographers and rehearsal directors convey abstract concepts of body energies.

## 5.2 Multi-layered presence around the mirror

*5.2.1 The gaze through the mirror.* Participant feedback from the speed dating workshop echoed previous work that found that mirrors can create the negative experience of being observed [19, 23, 55]. However, previous work have also found that the presence of observers and cameras can cause dancers to raise the standards of their performance and exert higher effort, which may lead to a performance of higher quality [15]. Dancers are aware that dance as a performing art exists as poses and movements of their bodies, which is experienced through the gaze of the audience [15].

While participants expressed mixed feelings towards being tracked and recorded by the mirror, they also pointed out that improvisation is about bringing forward their creative self, and that it is important to get past the stage of self consciousness before becoming able to improvise freely. Whereas the mirror may induce the feeling of self consciousness from dancers, it may also intensify their urge of being creative. For this purpose, visualisations similar to EE may be good tools for training novice dancers to improvise with a playful and estranged body image, while providing an alternative vessel of expression.

*5.2.2 Creative use of the multi-layered presence.* DP was the visualisation function that excited our expert participant the most throughout the study. She interpreted it as a feature that enables the co-presence of the three dancers—the physical dancer, the reflected dancer, and the delayed 3D capture of the dancer rendered over the same space in the mirror. This multiplication enabled her to step outside of her physical self, which would have been the only focal point of her bodily awareness, and to establish connections to her other "selves" across space and time. An improvising dancer may perceive the delayed capture of themselves as a partner while they improvise and collaboratively create the space with it using their reflected body. They may also perceive it as a past extension of themselves that visualises the space occupied by their body and its movement, from which stems the future movement in the next split of a second.

The expert participant also stressed DP's potential in training dance improvisation and choreography. Dance improvisation is traditionally about "tapping the stream of the subconscious without intellectual censorship" through creating and acknowledging all "realities" by the dancers themselves [8]. For instance, the power of inward exploration is evident in Ohad Naharin's influential dance movement language *Gaga* , which focuses on the somatic experience and the body's power to create [4]. However, it also demands dancers (or non-dancers) to maintain "a constant awareness and activeness" that is never released [43]. With a similar philosophy, our expert participant discussed the importance of having "the freedom of the subconscious, and the clarity and presence of the conscious" at the same time. She proposed that MR mirror, especially DP, could be a great training tool for nurturing that multiplicity of awareness while benefiting from the multi-layered presence that it enables.

## 5.3 Freedom, resistance, glitches, and possible futures

Previous work recommended that technological integration in dance be aware of its existing customs and practices, which was reflected by participants' comments in our study [69]. Many of them raised the concern that the demand of visual attention to experience the MR mirror may hinder the freedom in the improvisation. Additionally, dancers may become fixated on themselves while seeing their reflections in the mirror during improvisation. Participants also mentioned the lack of tactile feedback. These are valuable lessons for future mirror-based tools for dance.

Many interesting behaviours of technological exploration occurred during the technology probe workshop. For instance, many participants appropriated PL—which was intended for revealing structures—for experiencing the depth occlusion effect. This unintended use of the feature was uncovered as they played and embodied the reflected space through the visualisations. EE also inspired participants to discover new movement qualities (e.g., weightless, robotic) by exploring the limits of the tracking technology. It also elicited playful movements and excitement towards the technology from the participants. These findings echo the literature of interaction design and dance, most notably the work by Hsueh et al. who proposed *indeterminacy, discoverability, appropriability, and correspondence* as goals for interaction design that considers kinaesthetic creativity [21, 36]. By designing indeterminant and appropriable interactive systems, future interaction design in dance can enable free exploration, and add another layer of creative possibilities in dancers' use and reuse of the functionality provided.

## 5.4 Visualising movement, for dance

Through rendering lines and traces in space, the MR mirror reveals the formation process of the dance movement. What it adds to the existing experience of the improvising dancer, and brings forward to their awareness, is the becoming of their dance movements. This visualisation or objectification of the unattainable form of body movement has been the pursuit of a group of technologists and innovators in the history of tools that aimed to visualise it. Étienne-Jules Marey's chronophotography and Eadweard Muybridge's animated films are the pioneers in this expedition of technological exploration. By animating sequences of still frames and highlighting the trajectories of human body joints, they revealed the becoming of movements in steps, which was previously impossible to demonstrate. These efforts instantiate Heidegger's claim that the essence of technology is in what it reveals [34]. Through revealing the knowledge of how a movement came to be, these technologies changed how we perceive movement, and then how we perform it.

However, in the context of dance, what needs to be revealed cannot only be the still frames of moving bodies or trajectories of body joints. Through *Trio A* and other works, Yvonne Rainer expressed her objection to "the photographic tendency" in dance, which fixates audience's attention on certain "unmoving centers of the dance phrases" [45, 57]. Rainer's concern with the "misrepresentation" of dance movement using still images echoes Bergson's account on Muybridge's works, that movement itself is missing from a succession of still images [20].

William Forsythe's *Improvisation Technologies* took one step further towards visualising movement for dance [28]. Whereas the technical difference is only in visual quality compared with the works of Marey and Muybridge, *Improvisation Technologies* not only reveals the simple trajectories of joints anymore. Rather, it reveals the dynamic forming process of the structures of the body space during dance movement. Different from trajectories, which convey the knowledge for studying movement, this representation of movement reveals abstract qualities and inspires dancers to use them as a vocabulary to create new dance movements. This pedagogical training enables dancers to quickly create and drop mental imagery of those structures during their improvisation.

MR mirrors, as exemplified by the functions employed in our study, bring the revealing of movement further forward from augmented video recording to real-time, real-space, and interactive virtual object rendering. The lines, traces, and the ghost images of the dancers' past enable them to materialise their mental imagery of the spacing of their movement at any point in time. The created visualisations then remain around them as pieces of material representation of their past movement through a montage [20]. This representation of movement is of great importance to modern dance and choreography, where the essence of the movement is not what is presented on stage, but how dancers respond to what they see through their felt experience and kinaesthetic awareness [6, 25, 47]. Dancers and dance students today are taught to actively explore their bodies' kinaesthetic creativity, to investigate their own impulses to move and improvise, and to understand movement as malleable material that can be reshaped and reformed [6, 7, 43, 58]. Like music, the meaning of dance improvisation is given by the past moment kept in the *passing* present [64]. By seeing the "movement material" created by themselves rendered live next to their reflected bodies in the MR mirror, dancers are given a new opportunity to embody the *here and now* through the combination of an abstraction of their past and a true reflection of their moving body in the present. As our expert participant explicated, the training and the creation of new dance works could benefit greatly from this multi-layered presence in space and time enabled by the MR mirror.

## 5.5 Lessons for broader HCI research

The sense of presence and embodiment over the reflected space in the mirror, as mentioned by participants, makes it an interesting case

[4] https://www.gagapeople.com/en/

to examine the MR mirror experience in light of the sense of embodiment [22] and presence [59] widely discussed in HCI research, most notably in MR. Recent findings in cognitive science indicate that the reflected body is treated as "special" in the mind compared with other objects, with a closer relationship to the self [40, 41]. Users were found to be able to perceive the space around the reflected body using an egocentric frame of reference in the similar way to the real body [54]. While these works suggest benefits from seeing the body in the mirror as context, other evidence suggests that users may also be able to use the reflected body to perform input. In their recent studies, Mine et al. found that a disconnected hand avatar can be integrated into the peripersonal space which may represent the reference frame required for visuo-motor action using a specific body part [50, 51]. While it is widely known that tool embodiment could be achieved with appropriate training, it is plausible for us to perceive the reflected body as an intuitive tool for performing input during MR interaction with the mirror [10], and a medium through which users could embody the reflected space [22].

While improvising in front of the MR mirror, participants were able to perceive that they were "in" the mirror among the rendered lines and traces through the medium of their reflected bodies, which were tracked and represented by the Kinect sensor. These effects likely validate the previous work on the role of reflections in the sense of embodiment over external space. As tool embodiment has been studied extensively in psychology and in HCI [2, 10], it is plausible to regard the reflected bodies of the dancers in the mirror as among their most familiar "tools", which serve as convenient medium for them to embody the reflected space in the mirror, as they are more realistic than disconnected hand avatars in virtual reality [50]. In a similar way, William Forsythe tried to help dancers with *Improvisation Technologies* to establish a deeper awareness of their surrounding space through using their bodies, and to better use their bodies to create dance phrases by measuring the space through movement. This connection between body movement and the sense of spatial embodiment could inform broader HCI research in MR. While mirror metaphors have been explored in virtual reality research [46], future work could learn from the use of the MR mirror by dancers, and further explore possibilities of improving the sense of embodiment and presence in virtual environments by rendering users' body movement traces in them, either through a virtual mirror or from the first-person perspective. Conversely, the MR mirror could seek to investigate its effect on dancers' sense of presence while borrowing from its definition in MR research, by manipulating known factors such as *bodily engagement* and different *virtual body representations* [59].

### 5.6 Limitation and future work

Our observation, as echoed by the expert participant, was that dance students in earlier stage of their careers tended to exhibit more resistance towards the MR mirror, whereas more experienced dancers enjoyed the experience more, and offered more constructive feedback. The junior dancers may have been more fixated on the training they received through their curriculum, and were more reluctant to accept changes in their practice, whereas more experienced dancers were more open to explore new ways to create. Future works could explore differences in the acceptance of new technologies among dancers with different experience and backgrounds.

## 6 CONCLUSION

We investigated the potential of harnessing visualisations overlaid on dancers' reflections on an MR mirror for creating new movements in an improvisational context. We prompted participants' perspectives through four prototype visualisations as a technology probe. In a workshop, we elicited participants' dance and technological explorations as they improvised in front of the MR mirror. We used storyboards to illustrate future scenarios of MR mirrors in dance, and conducted a speed dating and ideation workshop around them. Through follow-up surveys and interviews with experts, we yielded deeper reflections on the potential impact of MR mirrors on dance-making from diverse perspectives.

We found that the MR mirror enables dancers to visualise their dance movement within the reflection space embodied by their present bodies in the mirror, and to connect with their past self to create new dance movements in the future. Our findings reveal the MR mirror's potential for altering the felt experience of dancers through its visualisations. The technological exploration behaviour observed in our study provides valuable insights into interaction design for appropriability, and suggest directions for integrating MR mirrors into dance practice in the future. We offer a discussion on the unique place of MR mirrors in the theoretical context of dance and performing arts, and in the history of technology for visually presenting body movement. Finally, we distil lessons from the study for broader HCI research.

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