Supporting Perception of Spatiality in Dance in Augmented Reality

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ABSTRACT

We present how we co-designed with a connoisseur a system that visualizes a star-like ribbon joining at the solar plexus and animated it from motion capture data to perform Isadora Duncan's dances. Additionally, the system visualizes the trace of the solar plexus and specific keyframes of the choreography as key poses placed in the 3D space. We display the visualization in a Hololens headset and provide features that allow to manipulate it in order to understand and learn Duncan's qualities and choreographic style. Through a workshop with dancers, we ran a structured observation where we compared qualitatively how the dancers were able to perceive Duncan's qualities and embody them using the system set according to two different conditions: displaying all the future keyframes or displaying a limited number of keyframes. We discuss the results of our workshop and the use of augmented reality in the studio for pedagogical purposes.

CCS CONCEPTS

• **Human-centered computing → Visualization**; **HCI theory, concepts and models**.

KEYWORDS

Dance, Dance notation, Interactive Visualisation, Physical Models, Augmented Reality, systems for supporting creativity

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1 INTRODUCTION

In dance, most practitioners have their unique way of documenting and archiving movement, whether it is through drawings, words, or videotaping [9]. In addition to that, there are general notation systems that allow describing dance using language and symbols. In the 1920s and 1950s, Rudolf Laban and respectively Rudolf Benesh created two notation systems for writing dance based on abstract symbols. Another movement notation system that emerged in the 1970s is called Sutton. This system is based on representing the position of the human body using stick figures. While it is less used in practice than Laban or Benesh, Sutton sparked our interest as it relies on explicit visualization of the body in space, just like 3D bodily visualizations do in the literature on dance research in HCI and graphics [13].

In a previous study on designing systems to support the transmission of Isadora Duncan's repertoire, we co-designed with a connoisseur a star-like ribbon made of five flexible ribbons joining at the solar plexus and animated it from motion capture data using tailored optimization-based algorithm to represent Duncan's qualities of fluidity and wave-like movement that initiates from the solar plexus [32]. Isadora Duncan is one of the pioneers of today's modern and contemporary dance. Her work revolutionized dance because it sought to move away from the rigid technique imposed by ballet to uncover what she described as "the natural movement". The main characteristic of Duncan's movement is fluidity which characterizes how the body is in perpetual motion. Another characteristic of Duncan is that movement is initiated from the solar plexus and propagates along the dancer's body like a wave.

In this paper, we present how we co-designed with a Duncan connoisseur a system that allows the visualization of the dancing body in 3D space. We chose to represent the body as stick figures. We based the design of the stick figures on the star-like ribbon joining at the solar plexus that we developed previously in [32]. We added to the ribbon model a visualization of the trace of the solar plexus. Additionally, we co-designed keyframes that visualize several star-like ribbons that represent key moments of impulse in the choreography. These keyframes were inspired by the stick figures drawn in space used in Sutton's notation. Just like in the notation, we placed these keyframes in the 3D space, displaying the future ones as a feedforward meant to guide the dancers into Duncan's choreography. We displayed the system in an augmented reality (AR) Hololens 2 headset and shared it with dancers with the goal of supporting their understanding and learning of the spatiality in Duncan's choreography.

Through a workshop with dancers, we ran a structured observation where we compared qualitatively how they were guided to perform the dance and to perceive Duncan's spatiality in the

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choreography, using the system set according to three different conditions: 1) displaying all the future keyframes or 2) displaying only one future keyframe and 3) displaying the three future keyframes. We discuss the results of our workshop and, more generally, the use of AR in the dance studio for pedagogical purposes.

We summarize our contributions hereafter:

- We present the co-design with an Isadora Duncan connoisseur of a system inspired by Sutton notation that aims at supporting dancers' understanding of the spatiality of Duncan's dance.
- We present the results of a structured observation of dancers using the system in an AR headset, according to three conditions with various numbers of keyframes in space. The aim is to compare how the number of keyframes affects their experience and perception of spatiality in Duncan's dance.

2 PREVIOUS WORKS

2.1 Dance notations and augmented dance notations

There are two available popular ways of archiving dance. One of them is through videotaping. The other one is through using dance notation systems. Videotaping, while being accessible, suffers from omitting many aspects of the movement and choreography. Notation systems have been created to provide a more exhaustive way through language and symbols to keep a written trace of movement and choreographic structures. One of the most well-known notation systems is the Laban Notation introduced by Rudolf Laban [21, 22]. The idea of this notation system is to write, through abstract symbols, the positions of each body part in the 3D space, which Laban discretized into what he called a kineshere. Another well-known notation system is the Benesh notation introduced by Rudolf Benesh [3]. The Benesh notation focuses more on the trajectories the body parts leave in space. Another dance notation was introduced later by Valerie Sutton [29], where she represents the position of the human body using stick figures on a horizontal stave. One of the main problems with these notations is that they are hard to write for beginners. To make them more accessible, researchers have developed various software systems in order to visualize the dance that has been notated or notate a dance that has been described. For instance, in [35] and [34], the LabanWriter software enables a user to translate choreography explained in words into a Laban notation and vice-versa. The LabanDancer software interprets the generated files and animates a human mannequin which follows the choreography. In [24], the team used basic ballet poses in order to animate a figure dancing a choreography written in the Benesh notation. In [7], they automatically generate Laban notation from motion-captured data.

In this work, we are inspired by the Sutton dance notation, which is particularly suitable for representing the body. We create a 3D system that spatializes the choreography by placing animated stick figures in 3D space. The goal is to help users understand the spatiality of the choreography, as well as its temporality. We motivate the design of a 3D representation of dance movements by the results of the study in [12]. They compared Benesh and Laban notations in a 2D and a 3D animation and found that the 3D animation did not disrupt the dancers and stimulated their creativity, and supported their understanding of the movement better than the 2D animation.

2.2 Representing a dancing body

One of the historical ways of representing a dancing body is to do so using humanoids. In the DanceForms software [5], the digital dancer is represented as an animated humanoid. Hachimura et al. studied how to augment the human-like avatar for dance education in virtual reality (VR) [18]. They found that each visualization (wireframe, solid, solid with wireframe, and solid with texture) suits a different learning modality. In [31], Tsampounaris et al. studied how augmented human-like avatars can augment learning and understanding of dance movement. They augmented the avatars using particles emitted from the hands and feet and displayed motion trails.

Choosing to represent the dancing body abstractly (beyond humanoids) has also been a topic of interest for both choreographers and researchers and has shown a lot of potential in dance. In 1999, in collaboration with choreographer Merce Cunningham, Downie and Kaiser created a model displaying strokes of color representing dance motion in the dance piece *Biped* [20]. In [14], Fdili Alaoui et al. studied how different behaviors of mass-spring systems suggest the movement qualities of the choreographer Emio Grecco. Their study shows the suitability of abstract visuals to represent movement qualities for dancers. This echoes the study of Leach e,t al., where they emphasize the need for an abstract body representation in dance [23]. They based their findings on a collaboration with Marc Downie and Wayne MacGregor. In [30], Poulin and Epoque represented dance movement using a flow of particles animated from motion capture of the dancers' movement of Stravinsky's piece Rite of Spring. Hsueh et al. represented movement using multiple abstract visualizations (particles, springs, blobby form, Fluid body, and trails). They showed how these visualizations support dancers in creating new movement material [19]. In [15], movement qualities based on Emio Greco's style were translated into an abstract moving light spot to support the user's exploratory and expressive use of the system. Valuing a plurality of representation is at the heart of the Digital Body project of choreographer Alexander Whitley [33]. The project explores multiple representations of the body based on motion capture data, going from abstract to more literal visualizations.

In [32], we introduced a model which consists of 5 flexible ribbons joined together at the solar plexus. This model has been co-designed with an expert connoisseur of Isadora Duncan's repertoire and has been perceived by dancers to convey Duncan's quality despite – or because of– its abstract representation. We base the current study on that model and add a visualization of the spatiality of the choreography in 3D.

2.3 Augmented ways to learn movement

Multiple experiments in HCI have designed new technologies to help students learn dance movements. In [26], a video editing system was introduced based on how students and teachers usually learn new choreography. Anderson et al. created an AR mirror to guide dancers through learning and to allow them to reflect on their movements and correct them. In order to explore the three-dimensionalities of dance, researchers have used VR and AR to have better spatial visualization. Chan et al. experimented with real-time motion capture to teach dance in VR [6] and found that feedback in VR helped students learn movement better than a demonstration with no feedback. More recently, Sra et al. created a VR social system allowing students to participate in dance lessons remotely [28]. They found that VR facilitated such a social way to learn dance remotely.

In [25], Raheb et al. surveyed how 3D visualization based on motion capture data can improve learning and teaching dance. They highlight how three-dimensionality has something to bring to dance education. Following that study, the authors used AR in [10] to teach dance in the studio.

In this work, we build on previous works and display our system in AR via Hololens 2 headset. The goal is to have dancers experience movement in space, as spatiality is central to choreography, especially that of Isadora Duncan.

3 DESIGNING THE SYSTEM

3.1 Co-design with an expert

For over a year, we worked in close collaboration with Elisabeth Schwartz, an expert connoisseur [27] in Isadora Duncan's Dance, who is also the fourth author of the paper. Throughout the paper, we will name her E.S.. We followed a co-design [17] process, having the expert involved in all stages of the design and taking into account her feedback. The collaboration consisted of various meetings and conversations that took place in person, in E.S.'s apartment, or through calls and e-mails. It also consisted of the first and the second authors of the paper taking classes with E.S. regularly over a six month period. During the classes, E.S. taught pieces of Duncan's repertoire and transmitted the history and philosophy behind Isadora Duncan's work. These classes and conversations were a way for the authors to understand Isadora Duncan's qualities of movement in an embodied way and to use that knowledge directly in the design of the system. Throughout the design process of the system, we showed videos of the prototypes to E.S. and had discussions with her through video calls (see Figure 1) and in-person meetings.

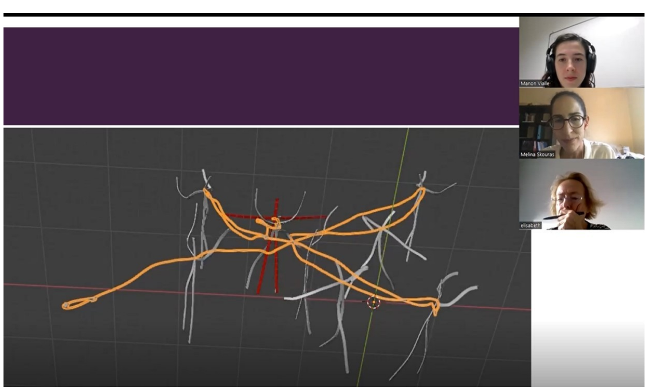


Figure 1: Zoom meeting with E.S. to discuss the second prototype.

3.2 Inspiration from Sutton dance notation

We took inspiration from the Sutton dance notation to create our prototypes.

In Sutton dance notation, the human body is simplified into stick figures. The notation represents the dance through a written score showing the displacement of the stick figures in space. Figure 2 shows the Sutton notation of the Prélude dance.

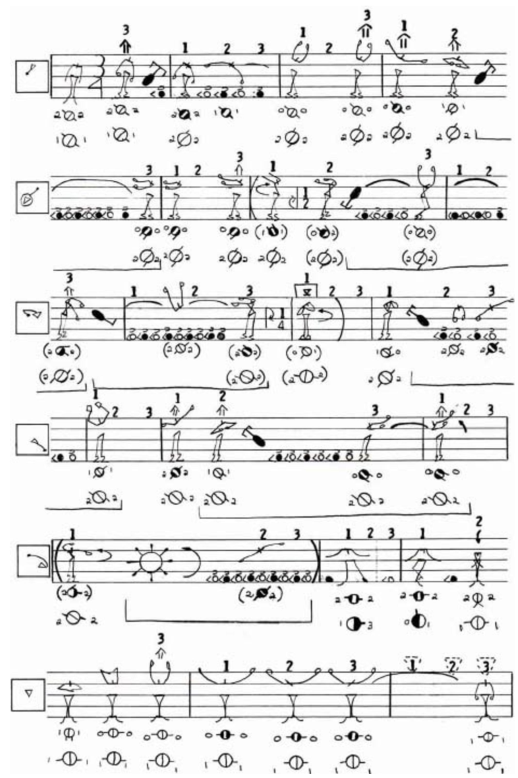


Figure 2: Sutton notation of the Prélude dance choreographed by Isadora Duncan (image source: www.dancewriting.org, CC BY-SA 3.0).

To represent the body as stick figures, we chose a ribbon model that we developped in our previous work [32]. This model was tailored to the style of Isadora Duncan. We assessed this model in a study with dancers where we showed that it represents the movement qualities of Isadora Duncan faithfully, more so through its simplicity and abstract representation of the body [32]. The model is made of 5 flexible ribbons joining at the solar plexus. These flexible ribbons move according to the recorded dance and emphasize how the movement propagates fluidly through the body in a wave-like motion. To render the dance's spatiality, we wanted to design a system that visualizes the trace of the body's position in space. Since we are working on a ribbon model [32] that is centered around the solar plexus, our first idea was to display the trace that the solar plexus leaves in space. This would emphasize the centrality of the solar plexus. Moreover, the trace displayed in time would help dancers understand the temporality of movement and its spatiality.

In dance, notation consists of translating something continuous (dance) into something discrete (a finite number of symbols written onto paper). Inspired by Sutton's notation, we decided to use key poses, also known as keyframes in computer graphics, which would be placed along the line of the solar plexus. These keyframes would visualize key moments of the choreography placed in a 3D space. While discretizing the choreography seems to contradict Isadora Duncan's philosophy of continuous and fluid movement, it corresponds to how E.S. teaches it. Because it is difficult to learn the choreography from start to finish, E.S. segments it into "sequences" that she demonstrates one after the other. In our system, the discrete keyframes serve as visual and spatial prompts that indicate the main movement in each sequence that forms the choreography.

A question that emerged is how to choose which keyframe is important to be displayed. In other words, how to determine which moment of the dance is important to be shown?

According to the connoisseur, key moments in the choreography relate to when the dance is quick or sustained or when it is changing orientation. We used the ribbon model's energy as a reference to identify those moments. We interpreted the moments where the energy was the highest to be the moments with the most interest. The idea was to display those key moments as stick figures shown in 3D space and connected through the trace of the solar plexus.

Along with the connoisseur, we wanted a visualization that would help dancers to engage with the dance in an embodied way. We decided to add a red ribbon that would "perform" the dance along the line of the solar plexus and go through each keyframe when it is performing that specific movement. Having a red ribbon would serve as a guide for users to be able to follow the dance. The keyframes displayed in white would help users know what will happen next in the dance. They would provide a *feedforward* that gives information to the dancers on the key future moments of the dance that the red ribbon would be performing.

We also discussed with E.S. the choice of the dance to work on. We decided to work on the Prélude dance because its displacement in space is central to the dance. E.S. said "*Yes, here it is really good because we really see the construction in space, for prelude it is in a star shape. It is clear in the four diagonals.*" As shown in Figure 3, the spatiality of the trajectory forms a cross-like pattern that can be visualized easily.

3.3 First iteration of the design

Following these first design choices, we developed a first prototype. We shared it with E.S. on video and discussed with her her experience of the system.

She pointed out that having static poses was counterintuitive to the idea of continuous movement in Duncan's style: "*When it comes to Duncan, as you may have understood, the question of sequencing is complex because she doesn't conceive movement by sequence or cutting unlike other choreographers.*"(E.S.). Indeed in Duncan's philosophy of movement, the movement is always in a continuous curve. It is propagated in a wave-like motion. Impulse in movement is what makes a wave continue expanding and retreating, and so on. To address this issue, we decided to display small animations for a few seconds instead of static poses. These animations correspond to the impulse moments that "pick up the dance as it continues" (E.S.). For the dancers to perceive these animated impulse keyframes throughout the dance, we decided to loop them. In the rest of the paper, we will call these small animations *moments of impulse*.

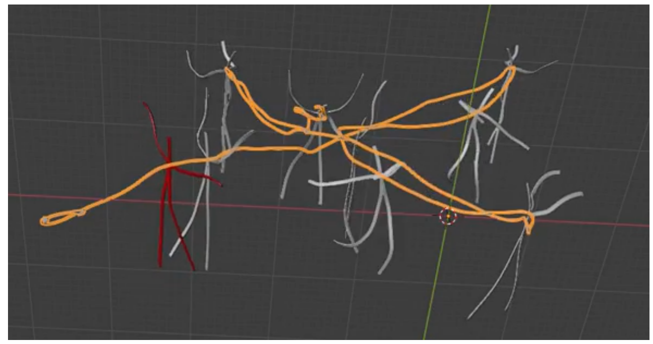


Figure 3: The first prototype displaying the keyframes in white, the line of the solar plexus, and the red ribbon that "performs" the dance.

3.4 Second iteration of the prototypes

The resulting prototype of this iteration is shown in Figure 3. After sharing it with E.S., we discussed with her what could be improved in the new prototype.

We discussed with E.S. how many moments of impulse are needed to be displayed at the same time. One thing that stuck out was that the moments of impulse needed to disappear when the red ribbon entered them because afterward, they were not relevant to the rest of the choreography. Moreover, displaying past moments of impulse would make the space crowded, making the rest of the dance hard to decipher.

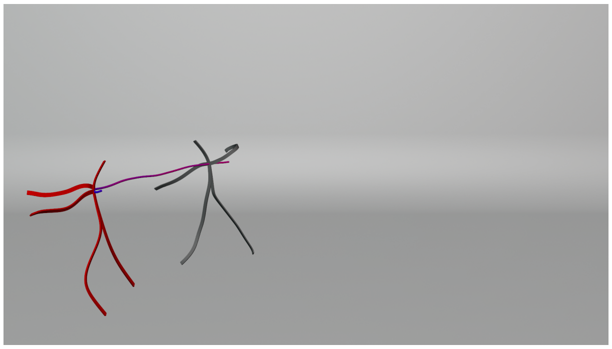
This also led us to question whether it was necessary to show all the moments of impulse or a limited number of them since we cannot focus on all of them at the same time. Therefore, we decided to develop two new versions of the prototype. One version would display solely one future moment of impulse, and another version would display all the future moments of impulse.

We shared those two versions with E.S.. Seeing them led her to question the visibility of the line of the solar plexus. We decided to try two versions: the first one would display the entire line of the solar plexus, and the second one would display only the part of the line leading to the next moment of impulse.

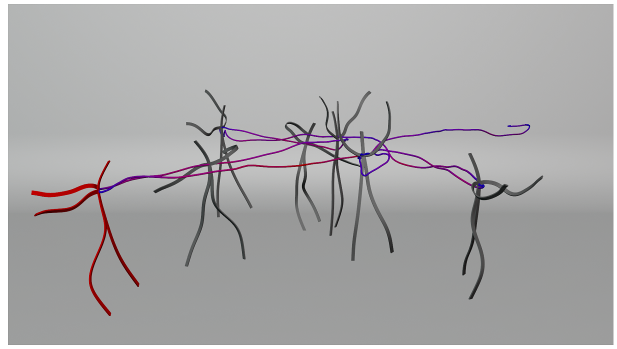
To enhance visibility, we also added color to the line of the solar plexus. The color corresponds to the speed at that particular instant: the slowest the movement, the closer the color to blue, and the fastest the movement, the redder the line.

3.5 The final prototypes

We showed E.S. the prototypes and discussed them with her. We discovered that the color of the solar plexus line was irrelevant to



(a) The first version displays only the next moment of impulse, the red ribbon, and the colored plexus line connecting the previous moment of impulse and the next moment of impulse.



(b) The second version displays all the future moments of impulse, the red ribbon, and the entire colored plexus line from start to finish.

her, as it was not obvious to her that it mapped to speed. She also thought that not displaying information about the speed was a good way of giving freedom to users to appropriate the choreography's dynamics and make them their own.

In addition to that, E.S. thought that the loop animations were "too harsh" and that we needed to add a pause after each animation to make the looping appear more smooth. This would be more coherent with Duncan's qualities and general style that favor smooth and continuous movements. Through testing with E.S., we decided on a duration of 0.8 seconds for each moment of impulse.

We felt like the number of visible moments of impulse was a critical parameter of the system that we were creating. Therefore we decided to create a third prototype that would be a compromise between the two previous prototypes. It would display the next three visible moments of impulse. In the following, we will call the first prototype that displays all the moments of impulse "Prototype all keyframes ". We will call the second prototype that visualizes solely the future moment of impulse "Prototype next keyframe ". We will call the third prototype that visualizes the three future moments of impulse "Prototype three keyframes ".

When testing the system, we observed that because the red ribbon was performing the dance, it led us to simply watch rather than engage with it. We wanted to see if removing the red ribbon could help dancers engage physically with the prototype by following the feedforward and dancing toward the future moments of impulse with their bodies. After a few tests with E.S., we realized that when we removed the red ribbon, she lacked information about where she was at in the choreography. It did not achieve the original goal of engaging the dancers more with the prototypes. Instead, it led to more confusion. To fix this issue, we decided to have the trace of the solar plexus disappear as the red ribbon would have entered into the moment of impulse. This way, the dancers could still see the red ribbon in space while having the solar plexus trace disappear to indicate where they could follow the model and dance with it. An overview of the features of each prototype is summarised in Table 1.

In order to share the 3D prototypes with dancers, we decided to use a Hololens 2 headset, which is an augmented reality headset. The headset lets the users see the room they are in and the added 3D visuals. It lets the users move in the room freely and see the 3D prototypes from any point of view in the room. We chose to use a Hololens 2 augmented reality headset because it is a portable device that can be easily set up in a dance studio [25]. Figure 5 shows a view of each prototype seen through the Hololens 2 headset.

Following the design process, we became interested to see how the number of moments of impulse impacted the dancers' understanding and perception of Duncan's choreography in space.

3.6 Implementation

We followed the implementation of [32] to animate the ribbon model. We then extracted the keyframes based on the moments of maximum impulse. To do so, we looked at the bending energy curve of the ribbon model with respect to time. From that, we used a peak extraction algorithm to get the moment where each impulse was located. This gave us the specific time when our moments of impulse were located. To display the trajectory of the solar plexus, we displayed a 3D curve composed of all the positions of the plexus with respect to time, using a tube-like mesh to make it more visible. The tube was sectioned in smaller tubes in between moments of impulse, to be able to make them appaear and disapear for Prototype next keyframe. Moreover for Prototype three keyframes, to be able to have the solar plexus line disappear as the red ribbon would have entered it, we sectioned the line into small cylinders between two time frames, and made them p at time goes by. We used the Blender software [11] to generate the prototypes. To create the AR visualization, we used Unity and Microsoft MRTK.

4 SHARING THE SYSTEM WITH DANCERS

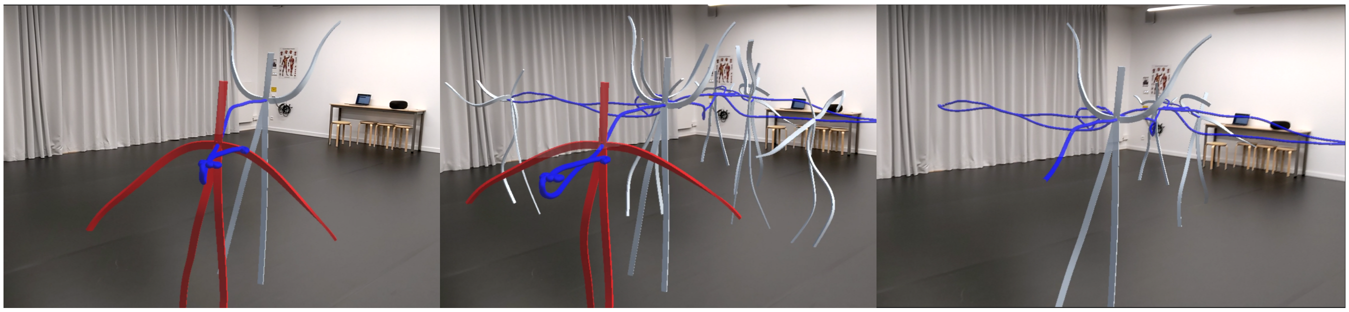
4.1 Method

We organized a workshop aimed at understanding how dancers perceive the three prototypes we co-designed and how the different attributes affect their learning and perception of Isadora Duncan's spatiality. To do so, we run a structured observation [16] comparing qualitatively how dancers experience each prototype.

4.1.1 Procedure. The workshop took place in a local dance studio. First, E.S. led a 30 minutes warm-up session with the participants to invite them to warm up to the style of Isadora Duncan. Then E.S. taught the participants the Prélude dance for 15 minutes. Participants were then asked to fill in body maps to represent how

	Prototype next keyframe	Prototype all keyframes	Prototype three keyframes
Number of visible moment of impulse	Next	All	Three next
Visibility of the trajectory of the solar plexus (blue line)	Just the line between current and next moment of impulse	All of it	All of it and it disappears as the red ribbon animation would have entered it
Red ribbon presence	Yes	Yes	No

Table 1: Features of each prototype.



(a) Prototype next keyframe **(b) Prototype all keyframes** **(c) Prototype three keyframes**

Figure 5: View of each prototype in the Hololens 2 headset.

Figure 6: Participants performing the Prélude dance during the teaching process with E.S.

they felt after that learning process. We then introduced how the Hololens 2 headset worked and showed participants a video of how to use the menu of the headset. Participants, as well as E.S. and the second author, were then split into two groups: group A and group B, as shown in Table 3. In the first part of the workshop, each group was introduced to one of the two prototypes. Each group member had 10 minutes with the Hololens 2 headset to explore the prototype. After that, participants filled in body maps to document their embodied experiences of the prototype. We then held a group discussion for approximately 15 minutes, in which we asked them to verbalize their experience. In the second part of the workshop, we switched prototypes among the groups. Again each dancer had 10 min with the headset, filled out a body map, and participated in the following group discussion. Lastly, all participants were introduced to the last prototype in the Hololens 2 headset, each participant having 10 minutes to experiment with it. We finished the workshop with a group discussion. Table 2 shows the prototypes that each group experienced in each part of the workshop. During the group discussions, all participants, along with E.S., the first and second authors, sat on the floor to discuss the differences in the perception and experiences of the prototypes (see Figure 7).

4.1.2 Participants. We recruited four participants with previous experience with the Duncanian style through classes they took with E.S.. We name them $P1$ through $P4$, as shown in Table 3. E.S. led the warm-up and the teaching of the Prélude dance. Then she participated in the experiment with the prototypes as other participants did.

The first author, who is a researcher and a dancer trained in ballet and contemporary dance, designed and developed the prototypes. She did not participate in the experiment. Instead, she introduced the prototypes, set up the headsets, and took pictures and videos. The first author's work was supervised by the second author, who is a researcher and a choreographer. The second author also took part in the workshop, like other participants. She will be referred to as $A2$. The first and second authors led the group discussions and participated in them in an organic way sharing their own experiences and observations with the other dancers.

4.1.3 Data collection. We analyzed the body maps that the participants filled out. We also recorded the group discussion that happened after each exploration of the prototypes. We took pictures and videos of the participants. We also took personal note of interesting events and striking discussions.

	Prototype 1	Prototype 2	Prototype 3
Group A	Prototype next keyframe	Prototype all keyframes	Prototype three keyframes
Group B	Prototype all keyframes	Prototype next keyframe	Prototype three keyframes

Table 2: Order of which groups of participants experienced which prototype.

Group name	Participant number
Group A	P1, P2, A2
Group B	P3, P4, E.S.

Table 3: Participants distribution in groups.

4.1.4 Data analysis. The first and second authors analyzed the data. They transcribed the audio recording and analyzed the videos and pictures, as well as the handwritten notes and the body maps. The transcribed data was then analyzed using a thematic analysis approach: they tagged concepts using codes (open coding) and then reorganized them into themes (axial coding) [4].

Figure 7: Participants discussing their feelings during a group discussion.

5 FINDINGS

5.1 Different systems for different perceptions

5.1.1 Perceiving Duncan's qualities. Participants discussed how the different prototypes (Prototype next keyframe, Prototype all keyframes, and Prototype three keyframes) let them perceive the qualities of Duncan's dance differently. For example, they mentioned that they perceived the initiation of the movement from the solar plexus differently in each prototype that they experienced. They also perceived the relationship to gravity differently in each prototype.

For *P*4, the initiation from the solar plexus was visible in all three prototypes: "*For the plexus, it is really good we feel it really well*" (P4). Indeed the blue line tracing the trajectory of the solar plexus was enough for them to see how central this part of the body is in the style of Isadora Duncan. However, participant P1 perceived the initiation from the solar plexus mainly in Prototype three keyframes. This was due to the fact that the red ribbon was not vizualized but also to the fact that the blue line disappeared as the dance was performed. This puts emphasis on P1's relationship to her own solar plexus, encouraging her to move as the blue line disappeared with time: "*For me it was really different, I really felt, [...] how to have the movement coming from the solar plexus, and there it is really motivated by here (pointing to her plexus)*"(P1). She compared it to the other two prototypes (Prototype next keyframe and Prototype all keyframes), and described how only Prototype three keyframes let her feel how the plexus is the source that leads the movement "*I told myself I was going to follow the blue line. And then I really felt it, the movement motivation. Yeah. With the other ones, I didn't have that at all.*"(P1).

Participant P2, on the other hand, thought that in Prototype three keyframes, she did not see the movement of the solar plexus as she did in the other prototypes through the articulated motion of the red ribbon. Instead, in Prototype three keyframes, she saw the displacement and the trace of the movement as visualized through the disappearing blue line of the plexus: "*It's almost the opposite for me because I find that the progress of the plexus is so strong on the first and the second one [referring to Prototype next keyframe and Prototype all keyframes], that here [referring to Prototype three keyframes] I mainly felt the displacement, and way less the movement of the body, the trace in fact, the displacement in the trace on the ground.*"(P2).

However, dancers reported that all the prototypes did not let them see the grounding of the feet, creating a fracture between the upper body and the lower body: "*This is maybe what bothers me the most, we have the feeling that they are weightless, whereas when we dance we are looking for grounding, and that inconvenience that I was feeling is really [because of] that. There's a fracture between the two, between that weightlessness that we see or feel through vision and this need that we have to be grounded. I don't know, I am a bit lost with that.*"(P2). This was a problem in the original model of the ribbons that was reported in the study of [32]. It is not surprising that the dancers mentioned it again. This limitation echoes what was found in the literature as the relationship to the ground remains a problem in computer graphics when displaying an animation reconstructed from motion capture[2].

5.1.2 Perceiving Spatiality. Participants had different perceptions of the augmented space in each of the prototypes that they experienced.

After her first experience with the headset (with Prototype all keyframes), participant P3 pointed out that she felt more aware of the general space, as shown on their Body map in Figure 8 where she wrote "*We are more aware of space*"(P3). She wrote it next to the eye area, which she also highlighted in color. This shows how the perception of space in the system was mostly visual.

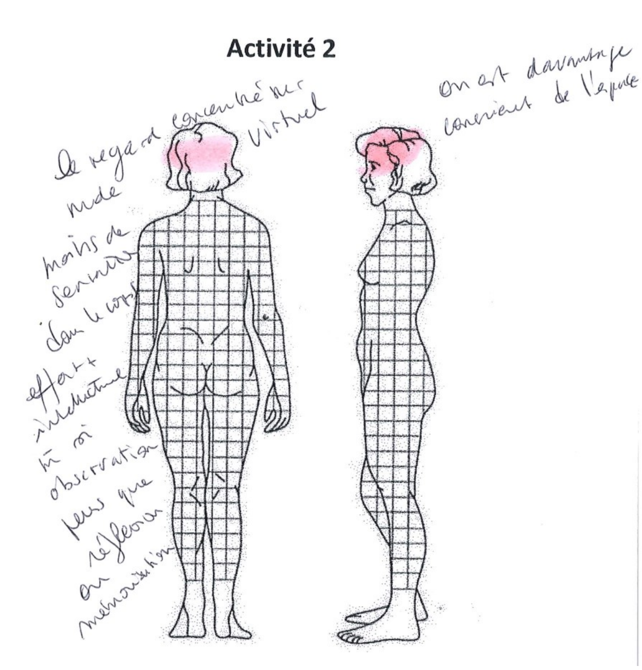


Figure 8: Body Map filled by P3 for their experience of Prototype all keyframes. Participant highlighted the eye area and wrote "we are more aware of space".

Participant P2 felt like Prototype all keyframes helped her see the depth of space more than Prototype next keyframe: "*What I really like with the second one, but maybe it's because I saw it in second, is there is all this depth of space, whereas the first one flattened space. We are just in the space of the moment. I think that with Duncan, there is a momentum really far away. And it's there where we have all this projection [referring to all the keyframes in space], and I think we can enter it without stumbling*"(P2). Seeing all the keyframes placed in space until the end of the choreography helped P2 comprehend how the choreography was articulated in space, letting her "enter" the keyframes without "stumbling", as opposed to Prototype next keyframe where only the next keyframe is displayed along with the next section of the trajectory of the solar plexus. E.S. also pointed out how Prototype all keyframes let her see the "globality" of the movement and the duration of displacements:"*And so I felt better the duration of the displacement. Which I never felt through the previous steps. I think we end up tasting, for someone who would like to learn the dance, to have a taste of the displacements*"(E.S.).

After her experience with Prototype next keyframe, participant P4 pointed out how the direction and orientation of the dance were clearer than with the previous prototype (Prototype all keyframes). seeing fewer keyframes allowed her to focus on the directionality and orientation of the body rather than the general spatiality of the piece. In her body map shown in Figure 9, P4 scribbled the word "direction" as a significant element brought by her experience of Prototype next keyframe.

5.1.3 Less is more. Participants also pointed out that the less information they had, the better they could focus on Duncan movement qualities. For instance, E.S. preferred to start with Prototype next keyframe than with Prototype all keyframes because it had less information, letting her focus on one aspect of the dance: "*For us, it was complicated, the first time, to have all the complexity of the poses, the trajectories, in fact I think it's more simple when we use the second one [referring to Prototype next keyframe], that is only the next one*"(E.S.). Another participant pointed this out for the Prototype three keyframes compared to the first two prototypes. She said: "*There is also the fact of having less information on the third one [referring to Prototype three keyframes]. On the other two, I really had the feeling of having a lot of information at the same time, and it feels good to have a little bit less. To focus on one thing.*"(P1). Having less information enables dancers to focus on specific qualities. Too many keyframes displayed in space overwhelmed them with too much information that they did not need. This was particularly the case if the multiple keyframes prototype was the first that they experienced. The dancers needed to start with little information and build up layers of complexity as they progressed in the dance.

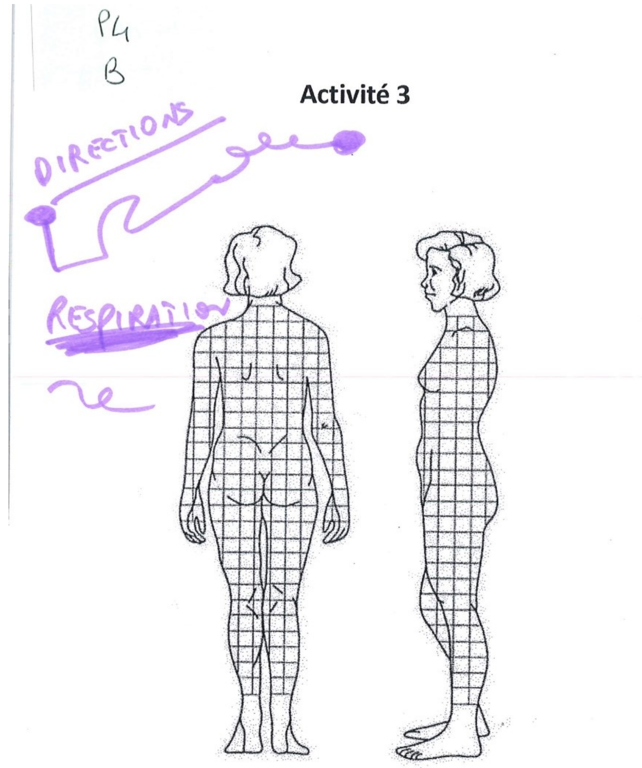


Figure 9: Body Map filled by P4 for their experience of Prototype next keyframe. Participant wrote "directions" as well as a doodle of a trajectory. They also wrote "breathing".

5.2 Different systems for different actions

The three systems that we proposed led to a variety of bodily responses from the dancers, ranging from observing to marking to improvising with the system.

5.2.1 The system as a way to engage users to observe. After exploring the two first prototypes (Prototype all keyframes and Prototype next keyframe), 3 participants agreed that they felt best when observing the system and not moving in space: "*If we don't enter the movement, we perceive the choreography really well, we feel it, we see how the body moves, it's surprising, with only three lines.*"(P3). Two out of four users expressed frustration because they wanted to engage with the system, but the visual information was "too much", particularly in Prototype all keyframes. "*My first reaction was it's really frustrating, to see it without accompanying it, what we want to do is to accompany it, to enter in its movement, yeah really to enter in its movement, but when we do that we lose it almost instantly, we get it only for a few moments*"(P2). Dancers refrained from moving because when they did, they lost track of the red ribbon and of the future keyframes displayed. This is partly due to the learning that participants had to go through to comprehend the technology of the headset and the way the system was designed in space. Moreover, this is also due to the fact that in both Prototype next keyframe and Prototype all keyframes, moments of impulse disappeared as the red ribbon entered them, causing the dancers to feel as if they lost track of the ribbon.

5.2.2 The system as a way to engage users to mark. One participant started marking the dance when exploring with Prototype next keyframe. When asked if she moved with it, she answered "*No, not really dancing but... I marked*"(P4). Marking consists of performing the movement in a less complete manner. We observed the dancers imitating the movement with one hand or performing it with the full body but with less energy. They marked with their bodies the movement while observing the ribbon enter the keyframes as a way to engage physically in the learning while keeping track of the system. Moreover, all dancers reported that they were encouraged to mark the movement because dancing it fully was not possible due to the cumbersomeness of the headset.

5.2.3 The system as a way to engage users to embody. Participants (3/4) noted that the third system (Prototype three keyframes) let them engage more significantly with the body in the dance than the two other prototypes:"*And the second time, because I did it twice, I told myself I was going to follow the blue line [...] With the other ones, I didn't have that at all.*"(P1). P3 also reported that Prototype three keyframes helped her engage more in the dancing than the two previous prototypes that she experienced before (Prototype next keyframe and Prototype all keyframes):"*We are more in the movement perception, more to do the movement than to observe it.*". Participant P3 also expressed that in her body map as shown in Figure 11. We can see how when experiencing with Prototype next keyframe, her experience was mainly to observe. In contrast, when using Prototype three keyframes, she reported how she followed the movement of the "blue line" with her own solar plexus. In this prototype, the blue line is more visible because no red ribbon is dancing in space. The body of the participants becomes the dancing ribbon. All participants mentioned that they tried to superpose their plexus's movement to the blue line in Prototype three keyframes as if their body produced it. They reported that doing that helped them engage in the dance and move with the blue line: "*For me, I really followed the blue line, and I really tried to follow it inside, to put myself in the spot of the figures, well of the red figure*"(P4).

Figure 10: One participant dancing with the headset on.

5.2.4 The system as a way to engage users to improvise. One participant (P2) went further with the Prototype all keyframes: she started improvising with each moment of impulse, forgetting about the original choreography. One of the participants said while watching her: "*She's dancing with all the white ribbon. She's creating her own choreography*"(P1). Another participant commented afterward: "*you looked really appeased. You were all serein.[...] Just like the Prélude*"(P3). We observed that during the improvisation, P2 was improvising with her own movement but borrowing from the style of Isadora Duncan. When asked about what she was doing during that improvisation, the participant said "*I was following the blue line. To have more landmarks.*"(P2). She then further explained that she was having a duo with each one of the keyframes in space: "*I was thinking it might be really interesting to work on duos. Because in the duo we are in a relationship that exists by itself. And so we can interact and learn to interact with it. And see how we can interact with the one which exists by itself.*"(P2).

5.2.5 A plurality of systems for a plurality of experiences. At the end of the experiment, participants reflected with E.S. on how all the systems had something to teach. Indeed, rather than having one prototype that would fit all the needs, each prototype had something to bring in terms of their embodied experience: "*This is really complex, but this brings out the interest of having different "formulas" like we did today. Some very sober, very simple, it's good because we can say, "ok I'm going to look at movement, the trajectory of the plexus, how do you have people see the ripple of the plexus, horizontal with suspension, going down to the floor, etc." So you can learn something from each one of them.*"(E.S.).

5.3 Opportunities and limitations of AR

5.3.1 Learning effect. Bringing a new type of technology to a dance studio was challenging. All participants experienced a learning

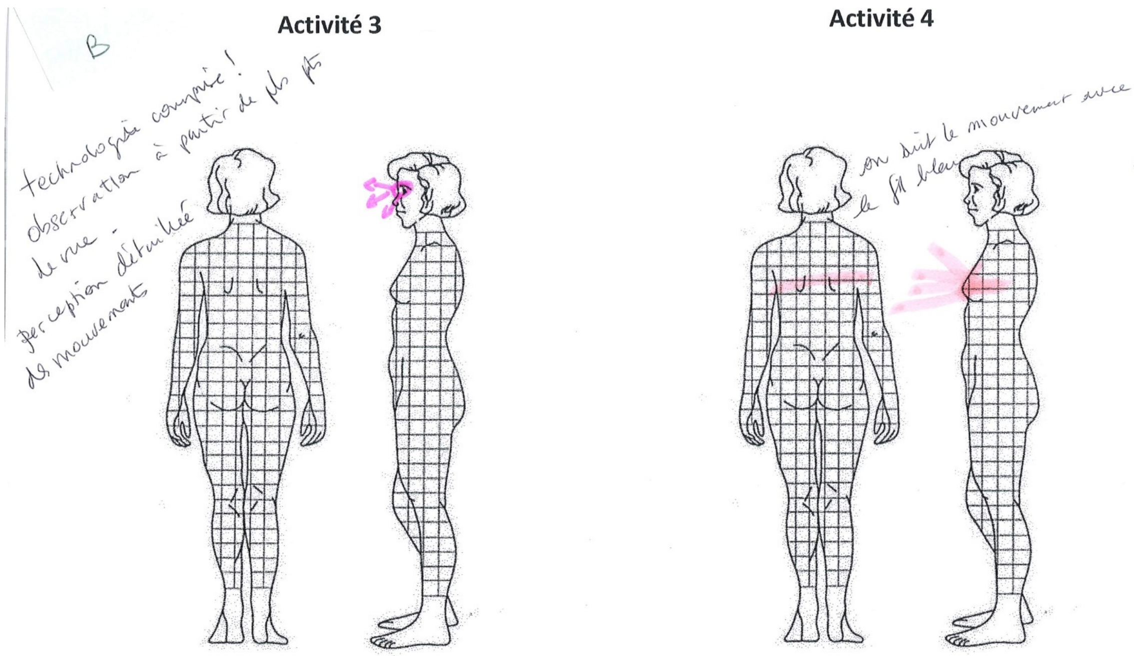


Figure 11: Body Map filled by P3, on the left experience with Prototype next keyframe, on the right with Prototype three keyframes. On the left, participant drew arrows coming from the eyes and going in different directions. On the right, they drew lines coming from the solar plexus and going in different directions.

Figure 12: One participant improvising with the moments of impulse.

effect that stopped them from truly experiencing the system's potential initially. "*[...]it gives a bit of a headache. I don't know why. Maybe it has something to do with habits. But it's true that we see well, but it demands such a high level of focus, I don't feel available to really follow it and to really be in it.*"(P2).

Understanding where the model was in space and how it worked was also a challenge, "*Yeah it is difficult for me to find the good position in space to see it in full because if I see only half of it is difficult*"(P1). To resolve this issue, E.S. explained that she took a step back from the space of the studio to understand the space that the system was taking: "*But in fact, looking at it a first time, well first there is the question of the technicality of the headset. I discovered that I had to take a few steps back to see better*"(E.S.). AR headsets are indeed technologies that not many have at home. In the context of our workshop, the dancers were unfamiliar with the device and the interface. It took them some time to familiarize themselves with it. They also discovered during their second experimentation with the headset that the space that the system was evolving in was fixed, meaning that if they moved their head around the ribbons, the ribbons would stay where they were in the studio space and not follow their gaze: "*And also I finally understood how the headset work. I thought that I was bringing it with me when I moved. But in fact, the figure exists in itself in space. I understand that I can turn, and I appreciate what I can do with it. And so I think I can really see the dance. From all side*"(E.S.). This understanding of the spatial independence of the model in 3D also led to them positioning themselves differently in space, walking around the ribbons, and seeing it from different angles and perspectives.

5.3.2 A tool to enhance the learning experience. Despite the difficulties in familiarizing themselves with AR, dancers reported that they could see the potential of such technology. E.S. discussed how the different systems were an excellent way to practice a dance individually: "*I like the trajectories etc. I think for someone who wants* *to learn it, they can look at it, then take off the headset; it's a different experience of the dance, a more autonomous one*". Another participant also pointed out that it is a good learning tool "*It's really good to learn, I think, the choreography. To incorporate it. To see it like that*"(P3).

Moreover, participants discussed the advantages of such a technology when learning. Participants noted that compared to a human body, the headset is more reliable in terms of energy and repeatability: "*Yes, I think that this is tremendous. And I was also telling A2, the fact that we can also do it an infinite number of times without relying on a human body, which can get tired, or who doesn't want to do it.*"(E.S.). The headset not being human means it does not have the same needs and can be used repeatedly without needing breaks. Participant P4 even called it "economical" "*It's clear that it is economical, it doesn't have to eat, to sleep*"(P4). However, they all outlined that the system cannot replace a human teacher. Participant P1 pointed out that when she is lost in the dance, she had an easier time finding back E.S. than the red ribbons in the headset: "*It is a bit like looking at E.S. when we dance when we turn, and we're all together and I don't see her anymore. It's normal but also it is easier to find her back than to find the red stick figure.*". Another participant stated that she could not learn from that system alone: "*For me I wouldn't be able to learn the choreography with only this.*"(P4). She all reported that the system would not replace a teacher but would complement the teaching by adding information. It also presented a potential for individual training beyond the class environment in the home.

6 DISCUSSION

6.1 Complementarity: beyond one system for all

Our findings showed that removing the red ribbon and making the blue line disappear with the progression of the dance in Prototype three keyframes made the dancers engage with the system in a more embodied way and perceive the displacement of the solar plexus more clearly. The gradual disappearance of the blue line emphasized the trajectory of their solar plexus as a source of the movement. Dancers used this disappearing line as a feedforward that guides their movements from their solar plexus, making it the motor of their motion in space. We also observed how they started dancing with the Prototype three keyframes, imagining their own body (in the place of the red ribbon) as what produces the blue line. **This suggests that creating a virtual alter ego displaying a body dancing is not necessarily desirable as it might hinder the dancers' embodied engagement. In contrast, erasing the bodily representation in the augmented world seems to hold great potential for the dancers to use their bodies creatively. Additionally, our results show the potential of feedforward to guide dancers in performing movements.**

In terms of the perception of space, dancers could perceive the dance's globality better and acquire a better awareness of the spatial structure of the dance in Prototype all keyframes that displayed all the future keyframes. In Prototype next keyframe, because only the next keyframe is displayed, they were able to focus better on the orientation of the body in space. These two prototypes encouraged observation or marking of the movement but not dancing with the system. The reason for that is the amount of information displayed and the presence of a dancing red ribbon that invited dancers to look at it carefully. We were able to see, however, how one of the dancers appropriated the Prototype all keyframes by improvising with all the future white keyframes as if they were characters in their own right.

Thus, the results of our study showed that there is no clear way to state that one prototype was better than another in fulfilling all the dancers' needs. Although Prototype three keyframes seemed to engage the dancers in more embodied ways than the other prototypes, Prototype all keyframes gave an idea of the overall duration and spatiality of the dance, and Prototype next keyframe provided minimal information that allowed the dancers to focus on one aspect of the dance as they progressed in their learning.

Offering a multitude of options to the dancers came up in our discussions with the dancers as something that can benefit them at different stages of their learning experience. This would allow them to experiment with various features according to their needs. Because learning is not a linear action, but rather an evolving experience that requires adapting and shifting one's strategies[26], **we see the value of designing systems that complement each other rather than one system that fits all needs and desires.** Complementarity can also allow for more gradual learning of the new technology. Dancers can start experimenting with a few features and later layer them with more complex ones as they become more familiar with the newly added ones.

6.2 Potential of AR in dance education

When choosing how to display our system to the dancers, an AR headset like the hololens 2 felt like a good option. Echoing the guidelines formalized by Raheb et al., we found that AR has good potential in dance education because it relies on portable headsets that can be brought to a dance studio. This allows the dancers to experiment with the technology in their familiar environment instead of in a non-ecological environment such as a lab [25]. Additionally, AR allows visualizing information in 3D, augmenting the regular space of the studio with additional feedback and guidance for the dancers. Finally, dancers reflected on the potential of using AR devices as learning support in addition to the human teacher. They identified the advantages of such technology in that it can be used repeatably without tiring and in various contexts, such as the home or outside. Thus, using AR brings a sense of independence to dancers who want to learn a new dance style on their own terms.

However, we found that bringing such a novel and unhabitual piece of technology to the dance studio is challenging. Dancers have been trained using the body solely for decades, and altering the body with a headset is cumbersome and difficult to adapt to. Moreover, the headset hasn't been designed for this kind of usage. When performing, dancers usually need to move their heads which is something they can not do easily with the headset. We observed how dancers feared letting the headset fall to the ground and adopted a more cautious embodied behavior. Moreover, the headset is not made to be used in a dance studio where the lighting is not ideal for the AR technology to work perfectly.

Overall, our findings do not suggest that AR technology can replace a human dance teacher. Instead, they highlight

how AR can support students in learning different aspects of dance without depending on official classes to have access to training. Additionally, using AR could be promising for non-dancers who do not dare to enter a dance studio to take a class. When trying it at the lab with different researchers, we saw how we could reach a wider audience, who, by testing the AR headset, ended up learning about the philosophy of Isadora Duncan and even trying to dance with it when they did not know of the dance in the first place.

6.3 The value of co-designing with a connoisseur

E.S. has been a collaborator and co-designer of the system from the beginning. She was curious about how technology could support the dancers' learning of Duncan's vocabulary. She expressed her interest and enthusiasm about augmenting the studio space with virtual elements representing the qualities of the movement and the spatiality of Isadora Duncan's work. Her knowledge of the dance was built over four decades of learning this repertoire and transmitting it to other dance artists. She dedicated all her carrier to building a deep understanding of Isadora Duncan's work. She used her knowledge in accompanying every step of the project. She infused ideas into the design of the keyframes. She gave feedback on the system at every stage of its design and development. She demonstrated the movements when necessary and tested the prototypes with her own body. She accompanied the design and organization of the workshop that we ran. Moreover, she taught the first and second authors the vocabulary of Isadora Duncan during multiple regular dance classes. **We believe that such collaboration putting at the center the expertise of a connoisseur is fundamental in the design of technologies to support dance and kinesthetic creativity[27]. Moreover, we value design approaches that dig into particular vocabularies in dance in a deep and committed way through collaborating with a connoisseur, avoiding generic and all-encompassing dance languages.** This echoes how [8] argues that designers should honor the diversity of each style and choreographic approach in dance, as they are an endless source of knowledge that can be generative to the design of technologies and particularly those targeting embodied, somatic, and kinesthetic activities [8, 36]. Having E.S. involved in every step of the design process led us to design a system that has been tailored to the philosophy of Isadora Duncan. Our system is not meant to accommodate other dance approaches. Our design is centered on Duncan's style and favors depth of knowledge and specificity over generalizability.

7 CONCLUSION

In this work, we presented how we co-designed with a connoisseur of Isadora Duncan, a system inspired by Sutton notation to support dancers' understanding of the relationship to space in Duncan's dances. The system displays a set of moments of impulse (animated keyframes) as well as the trajectory of the solar plexus (blue line) and a red ribbon performing the dance in a Hololens 2 headset. We led a structured observation where we assessed how different numbers of future visible moments of impulse and the presence or absence of a red ribbon affect dancers' perception of space and embodied engagement with the system. We discuss how the complementarity of the prototypes supports dancers' learning. We also discuss how AR, as a new technology, can be used in the dance studio for teaching purposes. Finally, we discuss how collaboration with a connoisseur was essential to co-designing a system that supports embodied engagement and perception of space in dance learning.

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