Dances with Drones: Spatial Matching and Perceived Agency in Improvised Movements with Drone and Human Partners

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ABSTRACT

As drones become interwoven in human activities, increasingly taking on tasks interpreted as creative and performative, such as choreographed light shows, there is emerging interest in understanding how drones and humans can perform together. Humans have different habits when performing with partners as opposed to solo. How do people adapt their behaviors and perspectives when improvising with robotic partners? To explore these questions, we conducted a study investigating dancer-drone interactions using a system of micro aerial vehicles designed to facilitate improvised solo and partnered dances. Through solo and tandem dances with one or two robots, we analyzed the performers' perceived workflow from semi-structured interviews and quantified their movement patterns during the improvisation. We found that the dancers perceived drone movements through spatial metaphors like the ceiling and gravity, anthropomorphizing drones as props on a stage through position and generated sound. The dancers felt a greater connection in single-drone scenarios and showed heightened avoidance behavior in two-drone situations. Our work shows how a robotic system can energize human dancers to improvise individually and in pairs.

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CCS CONCEPTS

• **Human-centered computing → Empirical studies in collaborative and social computing**.

KEYWORDS

improvisational dancing, micro aerial vehicles, human-drone interactions

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1 INTRODUCTION

Improvisational dance is an intricate process characterized by spontaneous, unscripted movement, fostering open-ended, creative expressions. This complex interplay of interactions [27] leads dancers to engage their bodies expressively, often drawing upon all their intuition to rapidly create and prototype dance compositions, whether individually or in partnership.

In improvisational dance, the primary source material is the dancer's body and its inherent kinaesthetic creativity [63], which encompasses the creation of body movements. To enhance the exploration of our bodies, various technical artifacts have been integrated into dance performances, including visual projection [24], interactive sound installations [8], wearable costumes [18], and robots [17, 31].

Micro aerial vehicles (MAVs), commonly known as drones, have been used in recent years across domains such as aerial photography [41], cargo delivery [11, 60], and light shows [56]. With the growing presence of drones in shared spaces with humans, research into human-drone interaction has gained increased importance. Such research encompasses investigations into human perception [22, 54], user interfaces [3, 9], and new applications in landscape architecture and tour guide [7, 51]. However, there remain unanswered questions pertaining to how humans engage with drones within creative and performative contexts where improvisation depends on the perception of drones and the environment in which they act.

In contrast to wearable devices and terrestrial robots, aerial vehicles possess a distinctive attribute—an ability to move in three-dimensional space [43]. The small footprint of micro drones offers a unique opportunity for exploring close-proximity interactions with humans [57, 61]. Furthermore, the auditory component introduced by the propellers' sound and the airflow they generate add a multi-modal dimension to the experience of dancers sharing the space with drones. These inherent advantages of drones have the potential to engage the improvisation of dancers, shaping the spatial dynamics of their movements.

Human behaviors often vary when performing with partners compared to solo. In solo improvisation, dancers tend to focus more on individual themes, whereas when engaged in partner improvisation, their focus shifts to bodily communication [44]. Research suggests that transitioning from solo to partner dancing can spark creativity [37]. In the paired condition, creativity emerges not merely as an aggregation of individual efforts but rather through the nonverbal communication between partners, characterized by negotiation and collaboration between the dancers in a common purpose. However, there is limited exploration into how this transition from solo dance to partner dance extends to human-machine interactions, whether involving single or multiple devices.

As drones are increasingly involved in our daily life, especially in working scenarios, how we work with them in arts and design practices remains an open question. Thus, to develop an understanding of the human-drone interaction in an improvisation context, the following research questions are formulated:

RQ1: What are the performers' relationships with drones and each other during improvisational dance?

RQ2: How do performers spatially interact with the drones in an improvisational context?

RQ3: How are drones perceived as autonomous agents in the performance context, and what parameters affect that perception?

To answer the **RQ**s, we recruited 12 performers with various experiences for dance interventions and conducted semi-structured post-dance interviews. During the experiments, participants engaged in improvisational dance sessions accompanied by drones, either with a single drone, with two drones, or in pairs alongside a single drone or two drones, whose trajectories are pre-programmed. We collect both qualitative data through interviews and quantitative data through video analysis. The collocated interaction between drones and dancers reveals how performers perceive the drone and are activated by drone movements. Our study offers design insights for future interaction strategies that involve the incorporation of non-humanoid robots into performances.

2 BACKGROUND

2.1 Dance and creativity

Dance can be both an individual and a shared experience, serving as a powerful outlet for self-expression and personal exploration [46].

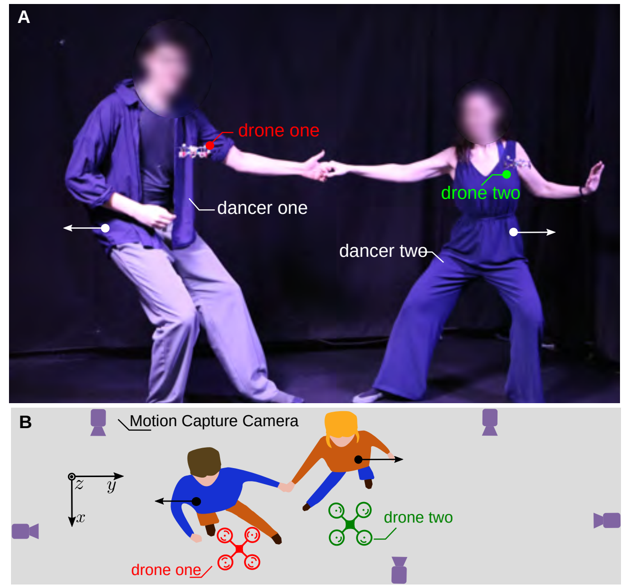

Figure 1: Overview of this research setting. A. Two dancers are dancing with two drones. B. Top view of the settings.

The central theme in dance research revolves around inspiring the creative use of the human body. Fogtmann et al. [14] proposed kinesthetic interaction as a comprehensive framework to explore the design aspects related to the body's potential. This framework encompasses three key themes: kinesthetic development,' which involves enhancing bodily skills through interaction; and kinesthetic means,' which focuses on achieving various objectives. And kinesthetic disorder,' which challenges the kinesthetic sense to transform the experience. One example of kinesthetic development is enhancing kinesthetic awareness [8], which is the perception of one's body position and movement. Further exploration of the body's capacity to discover new possibilities through abstract motion led to the formulation of the term 'kinaesthetic creativity' [24]. In partner dance, collaboration and negotiation are integral components, offering dancers opportunities to either support or challenge each other's ideas. This collaborative aspect not only enriches the dance experience but also has the potential to foster creativity [37].

2.2 Dance as multi-sensory experience

Dance is a multi-sensory experience. In addition to vision and sound, which are crucial channels for our experience of the environment, dance has been used to stimulate participants to reflect on the internal mechanisms of their bodies and foster innovative expression. Dancers possess the ability to differentiate movement dynamics by sound. For instance, swooping sounds result from circular movements, whereas monotone sounds correspond to inactive movements, according to [1]. The introduction of an external stimulus for the dancers to improvise with or against enhances their expressiveness and the way they regulate their attention [13]. The dancers' use of the metaphor may benefit from the alignment of sound and movement, providing an artificial experience [8]. The motor sound of drones was identified as a useful feedback modality with a constructive function [32]. The drones' auditory and vibratory effects were used to expand the movement beyond the physical confines of the body [29].

2.3 Technology in dance

Technology in dance serves various purposes, including performances [2, 26], recreation [46, 64], and fostering improvisation [28, 36]. The integration of technology profoundly impacts performers physically and emotionally. Karpashevich et al. [28] designed an interactive costume restricting lower body movements while responding to arm movements through LED lighting. This design heightens body awareness, and the limitations imposed by the costume stimulate previously unthought movements. In a participatory performance created by Alaoui et al. [2], participants are guided by instructions sent through mobile phones, using both text and gestures. This experience elicited a sense of being controlled by an unseen authority, prompting unintentional actions for some participants, while others embraced it as a means for engagement and exploration.

2.4 Drones perception and interaction

Compared to other robots, the agility and ability to operate at altitude make drones well-suited for human-robot collaboration scenarios [58]. For human performers, the acceptance of the drone is determined by its factors such as size [21], speed [59], morphology [61], and direction [39]. For example, the drone comes in the front direction and goes straight towards the participants with moderate speed (0.5 m), a preferable setting discovered in the previous research [59]. Interpersonal distances of humans can be divided into four levels: intimate space (<0.45 m), personal space (<1.2 m), social space (<3.6 m), and public space (<7.6 m) [20]. Humans are inclined to physically interact with the miniature quad-rotor (like 92 mm wheelbase), allowing it to enter the personal space, even the intimate space [39]. However, the distance between the drone and people is affected by the drone's velocity, which significantly impacts people's perceived level of safety [54].

Drones can interact with people in various ways, influencing their perceptions and how they connect with them. For example, a drone with a "face" creates a space for interpretation, narrative, and showing empathy for humans beyond just recognition [22]. Humans can accurately associate a drone's movements and behavior to its inner emotional state, such as happy, sad, afraid, and sleepy [10]. Drone Chi [32] has the participants interact with a somesthetic-designed drone and find a flux between mental spaces. The interactions with drones can be categorized based on the level of responsiveness and autonomy of drones, which will influence the performer's perception [43]. According to [9], performers may use metaphors depicting drones as animate beings such as a person, a group of people, or a pet. Bodily interconnection is also formed between humans and drones. For example, motions approaching or retreating encouraged following; lateral motions signaled restriction; and altitude changes prompted observation, while complex paths led to avoidance [5]. In [58], the authors explored the collaboration between humans and drones through physical contact, in which the drone can sense the force and momentum exerted by the dancer and thus adjust its motions, therefore designing the drone responses. In [12], the choreographer used imitation to explore the drones' affordances and find creative opportunities. Adjusting their own movements and somesthetic cues, they skillfully direct the motion of drones, thereby shaping their expressivity.

Table 1: Dancers in this Work

Dancer	Gender	Age	Dancing Experience	Place of Birth
P1	female	18-25 years old	advanced	Indonesia
P2	female	18-25 years old	advanced	Hong Kong
P3	male	36-50 years old	expert	Spain
P4	female	36-50 years old	expert	Hong Kong
P5	female	26-35 years old	advanced	Mainland China
P6	male	26-35 years old	advanced	Japan
P7	female	26-35 years old	advanced	Mainland China
P8	female	26-35 years old	moderate	Mainland China
P9	female	26-35 years old	advanced	Mainland China
P10	female	18-25 years old	moderate	Mainland China
P11	male	36-50 years old	expert	Hong Kong
P12	female	26-35 years old	expert	France

Moderate: dancing experience < 2 years, advanced: dancing experience < 5 years, expert: dancing experience > 5 years

As drones become more pervasive in human activities, how performers perceive and adapt to them will be key for creative improvisation. Although previous studies have probed how people understand and interact with drones [12, 29, 43], none have explored the perception of drones in a performative context and how the presence of drones alters the dancers' improvisation. Additionally, as humans improvise differently in solo and partner dance, how these adaptations translate to human-drone interaction remains unexplored. We aim to address these gaps in our research. To achieve this, unlike the responsive drones in [12, 32, 57], we make the trajectories of the drones pre-programmed as part of a choreography. The details will be provided in Sec. 3.

3 METHODS

3.1 Participating dancers

We conducted the study with 12 participants, consisting of nine females and three males with a range of ages and varied levels of dancing experience as summarized in Table 1. The participants were grouped into pairs, and each pair engaged in six distinct dancing experiments. These include individual dancers performing with one drone, an individual dancer interacting with two drones, two dancers participating with a single drone, and finally, two dancers collaborating with two drones simultaneously. Each of these scenarios was given at least one practice run and then executed at least once after the practice. The study was approved by our institutional review board for human subject testing. Subjects signed a consent form to participate. They were informed that all data collected are anonymously analyzed and they can stop participating at any time for any reason.

3.2 Technological implementation

3.2.1 Platform and flight arena. We opted for Crazyflies (Bitcraze) as our drone platform due to their favorably compact size [54] and user-friendliness. The small size helps mitigate any perceived threat to the dancers, especially during close drone interactions. Our experiments were conducted within a laboratory environment equipped with a motion capture system (MoCap) (OptiTrack Prime

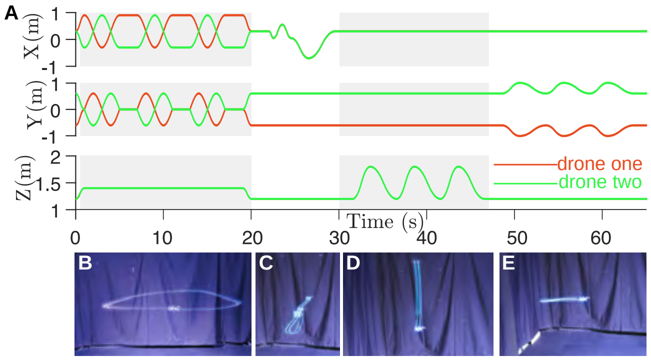

Figure 2: Trajectory of the programmed drones. A. The desired positions of the drones, divided into four distinct phases: circling motion, forward-backward motion, up-down motion, and left-right motion. The trajectories of the two drones exhibit symmetry. B ∼ E showcase the long exposure photos of the four trajectory phases.

13W). This provided real-time feedback on the drones' positions, enabling us to control and execute planned trajectories precisely for the drones. The indoor flight arena measured 2 m × 2 m × 2 m in size, providing ample space for both the planned drone movements and the dancers' choreographed routines.

3.2.2 The trajectory of the drones. To specifically investigate how the spatial movements of the drones influence the dancers' responses, we meticulously crafted the trajectories of the two drones to be symmetrical. These trajectories were structured into four distinct stages, as illustrated in Fig.2: (1) Circling Motion (2) Forward/Backward Motion (along the X-axis) (3) Up/Down Motion (along the Z-axis) (4) Left/Right Motion (along the Y-axis). This design allowed us to observe and analyze how dancers responded to these specific drone movements.

3.3 Data acquisition and analysis

3.3.1 Semi-structured interview and survey. Following the completion of the dances with drones, the dancers participated in semi-structured interviews conducted by the researchers. These interviews were designed to align with the **RQ**s outlined in Sec. 1, focusing on their experiences and feelings while dancing with the drones, highlighting the distinctions between dancing with a human partner and a robotic one, and gauging how dancers interpreted the drone's role in the intervention. Video recordings of the dance experiments were made for subsequent video coding and quantitative analysis. Additionally, the dancers were presented with a survey (questions presented in Fig.10) to quantitatively evaluate their subjective experiences and feelings during the dance interactions with the drones. The transcripts of the interviews received an initial coding by each researcher, who then discussed the themes together with each member of the research team [6, 50]. The organization and analyses of the codes into themes are repeated until agreement is reached and results are presented in Sec. 4.

3.3.2 Video observation. We conducted the analysis of the video data through two distinct approaches:

(1) **Computer Vision Analysis:** This method involved extracting dancer movement data, such as variations in head height, hand height, and foot accelerations during dancing. To achieve this, we employed 3D pose estimation techniques [19] to infer the positions of various body joints in the videos, including the head, hands, pelvis, and feet, in the world coordinates shown in Fig.3. Furthermore, we annotated the positions of both the drones and the dancers in the video using Faster-RCNN [48] for drones and RTMpose [25] for dancers.
(2) **Video coding Analysis:** We utilized video coding techniques to identify specific actions performed by the dancers and document noteworthy behaviors among them [47, 52]. The identification is based on body movements, including the arms, hands, trunk, and legs, and the relative positions of the dancers and drones.
The detailed video coding procedure is as follows: Two researchers independently observed and coded dancers' movements during solo dance scenarios involving one or two drones using a shared codebook developed collaboratively. Each coded movement in the codebook was effectively tallied. We opted for an 8-second timeframe to code each video, producing action sequences for different body parts in 8-second windows. If there is more than one action occurring in the 8-second window, they are all included in the coding. Each coded action for a particular time window is considered in agreement if it occurs in both of the researcher's codes for that window. The two researchers individually coded one video, and the coherence across all time windows between the two researchers' codes resulted in a Cohen's kappa coefficient of 0.75. Due to the high agreement in the common code, all subsequent videos are coded separately by each researcher.

For the quantitative computer vision data, we focused on scenarios involving a single dancer dancing with either one drone or two drones. as the algorithms only support 3D pose estimation for a solo dancer. To accurately track the positions and movements of dancers using motion capture, we would require them to wear reflective markers akin to those used on drones. However, this would impact the dancers' experience, consequently affecting the outcome of our research.

4 FINDINGS

To gain insights into how the spatial movements of the drones influence the reactions and shape the perceptions of the dancers, we conducted interviews with the dancers and analyzed their responses to answer the **RQ**s listed in Sec. 1. We explored the impact of varying the number of drones or dance partners, delved into their perspectives on the role drones play, how the dancers distributed their attention, and highlighted distinctive attributes that set drones apart from human partners. In addition to the qualitative insights gathered through interviews, the quantitative results obtained via computer vision analysis based on 3D pose estimation, video coding analysis, and survey are detailed in this section. All the dancers involved in this study are experienced in social dance but had

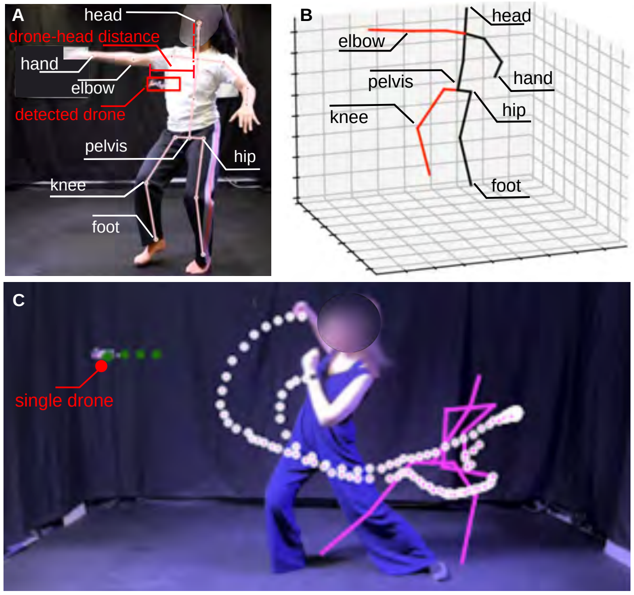

Figure 3: The detected drone and joints of the dancer acquired from 3D pose estimation techniques. A. Snapshot of the detected drone and joints of the dancer captured from one video. B. 3D-reconstructed skeleton corresponding to A. C. Snapshot of a dancer co-move with the single drone horizontally. The skeleton indicates the end position of the body, the white dots show the trajectory of moving joints, and the green dots show the trajectory of the drone.

limited exposure to aerial robots and were not provided with prior information regarding the trajectory of the drones.

4.1 Relationships with drones and human partners

In investigating the performers' relationship with other dancers and drones (**RQ**1), our findings revealed that dancers commonly perceive themselves as followers in interactions with drones, in contrast to the sense of equal partnership with a human counterpart. This distinction may arise from the pre-programmed trajectories of the drones, resulting in a predominantly one-way interaction. In contrast, dancing with a human partner typically involves reciprocal responses, creating a dynamic exchange. However, even though drones cannot directly respond to the dancers, they still serve as sources of inspiration through their movements. Dancers draw creative influence from the drones' actions despite the absence of immediate feedback or interaction. Our findings also shed light on how dancers allocate their attention during performances, whether with machines or humans, in various approaches.

4.1.1 Following the lead of drones. When asked about their roles in relation to the drones, participants predominantly positioned themselves as followers. P3 conceptualized the drones as extensions of his own body, offering directional cues that guided his movements. P4 shared this perspective, describing her approach as one of constant improvisation, simulating the role of a drone in response to their unpredictable trajectories, saying, *"I improvise a lot to see how to be a drone as the movement of the drones is unpredictable. Thus, I have to follow"*. P11 and P12 also mentioned they followed the drones without hesitation, with P11 explaining, *"... When the drone goes forward and back, our movement goes forward and back; when they go left and right, our movements mirror that as well. So we're copying that way"*. The drones' movements also prompted unique patterns within the dancers' performances. For instance, the drones' circular trajectories led P2, P8, P9, and P10 to execute coordinated circular motions. Furthermore, when the drones ascended, the dancers mimicked catching motions, prompting upward movements. P7, P9, and P10 highlighted this phenomenon. P9 and P10 also emphasized mirroring the drones' movement speed, with P9 stating, *"... when it's fast, you want to do some fast moves, and when it's slow, you want to do some slow moves."*

The quantitative results from computer vision analysis align with the outcomes from the interviews. As we analyzed the dancers' motion in multiple phases based on the four drone trajectory segments as illustrated in Fig.2, considering the X, Y, and Z coordinates in both single-drone and two-drone dance scenarios. One example of the dancers' co-movement is provided in Fig.3C. The results in Fig.4 show that during the forward/backward drone movement (along the X-axis), the dancers exhibited the highest median velocity along the forward/backward directions compared to other drone motions. We also observed that the dancers reached the greatest hand height when the drones moved vertically (along the Z-axis), regardless of the number of drones. This is demonstrated by a significant p-value of 0.0068 for hand height during the two-drone dance (determined through a one-way repeated measures ANOVA across four phases of the drone's trajectory). We further conducted a post-hoc Tukey test to determine the specific differences among the four stages. The test revealed significant differences between the circling and up/down stages, yielding a p-value of 0.041. However, the p-values for X and Y velocities in both one and two-drone scenarios and hand heights in one-drone scenarios are insignificant, with values over 0.15. These results indicate a synchronized pattern between the dancers and the drones, suggesting that the dancers followed the drones. .

4.1.2 Connection to the drone is one-way giving. Despite the dancers' limited familiarity with drones and their operational principles, a consistent observation emerged among the participants during this study. It was noted that the drone's movements followed a pre-programmed trajectory, devoid of any real-time responsiveness to the dancers' motions. This observation drove them to contemplate the potential impact of the interaction between themselves and the drones. P2 perceived the drones as non-living entities, leading to a perception of the dance experiences with drones as being unidirectional in nature, saying: *"The conversation with the drone, it's just like a one way giving. ... whatever you do, it will do the same thing..."*. P3 elaborated on this perspective, stating, *"... this is a program that is set, I don't think the drone is interacting with me. I am interacting with the drone. It will be different if the drone also interacts with me and reacts with my movement."* Similarly, P4 noted, *"I don't think the drone is reacting to me; if I give some emotion to a human, he will give me something back, but a drone cannot."* In her view, dancing with drones seemed akin to a one-way performance with drones as

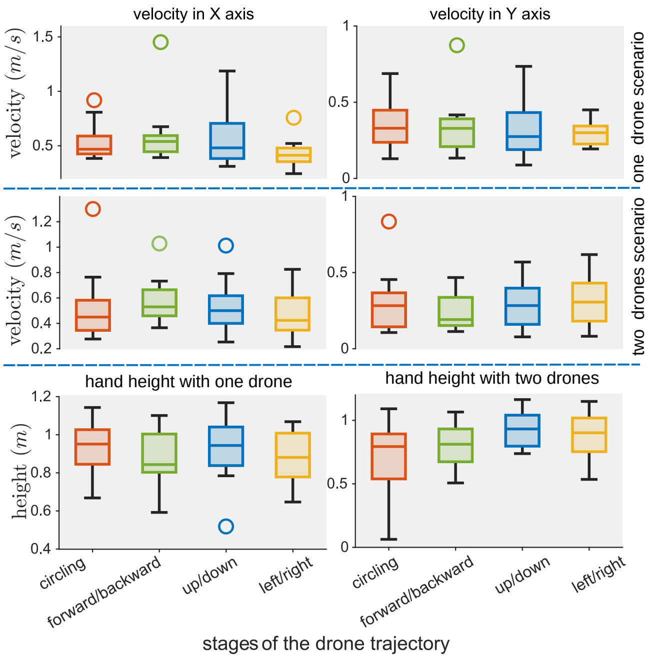

Figure 4: The velocity in X, Y axes and the hand height of dancers during different drone trajectory phases in the single and two-drone scenarios.

props. P5 expressed a desire for the drones to engage more substantively beyond mere position changes. Echoing this sentiment, P7 and P8 shared the belief that interpersonal communication played a pivotal role when dancing with human partners, but is impossible when dancing with drones. P11 mentioned his wish for greater drone flexibility, as he noted the drone's fixed behavior, stating, *"... because the drone is set, so we are adapting to the drone, not the other way around."* The notion of a one-way performance emerged as a recurring theme, signifying a distinctive characteristic of dancing with drones in our particular setup.

4.1.3 Drones as source of inspiration. Drones can serve as sources of improvisational inspiration in diverse contexts. P1 and P2 underscored the absence of physical objects often makes them rely on imagination for improvisation. However, dancing with drones introduced a source of physicality that facilitated interactive engagement, as P1 said *"in class we don't usually have the object, we are just using our imagination. And this time we actually have it in front of us. And we got the chance to actually interact with it"*. After her initial experience dancing with drones, P12 expressed a desire to integrate this technology into her teaching, acknowledging the potential benefits it could offer to students. *"It would be wonderful to train students with that"*, as she said. Additionally, she attributed her comfort level to the presence of drones, as they diverted her attention from the camera, which typically made her shy during filming.

The movements of the drones also proved inspiring for the dancers. Beyond guiding their motions and fostering creative responses, the drones' position also offered a spatial affordance. P11 noted that the drones' forward and backward motions effectively created a corridor-like space where he could dance, saying *"I think position of the drones was definitely helping us. ... they're going forwards and backwards, it created like a corridor that we could that we'd used to dance in."*. Additionally, P1 perceived the up-down motion of the drones as resembling 'ceiling falling,' eliciting a sense of tension. The dancers perceived this spatial arrangement as a creative constraint that shaped their choreography.

The dancers regarded the drones' motions as akin to a form of music. P7 equated the drones' trajectories to auditory stimuli, which directed her choreographic choices akin to composing a dance with music. Both P9 and P10 embraced the idea of drone movements mirroring rhythmical patterns or melodic compositions, thus embracing the concept of danceable songs, saying *"I would feel like it's like a rhythm, and I would think about a lyric, and I will dance to the lyric that I imagine"*. P11 and P12 added that their typical choreographic practice centered around rhythm in relation to music. However, in the presence of drones, the constraints they posed shifted dancers' focus to body movement and positioning in relation to the drones' motions instead of the music. P12 explained, *"Here the movement of our body had to have the priority because we have to adapt to the drone. That's how we got inspired."*

It's noteworthy that partners can harbor contrasting interpretations of the drones yet incorporate drones into their routines. For example, P11 viewed drones as mere obstacles to avoid, while P12 saw them as dancing companions or "fairies." Despite these differing viewpoints, P11 and P12 collaborated on choreography and improvisation, incorporating drones into their routines despite varying interpretations.

4.1.4 Allocation of attention in multi-agent dancing scenarios. The complexities inherent in dance scenarios involving multiple drones and dancers pose challenges as performers' attention is divided among multiple agents. This study aims to illuminate the dynamics of attention allocation—specifically, whether dancers prioritize their focus on human partners or robotic counterparts.

P3 articulated a strategic approach, alternating his focus between drones, stating, *"some parts of my body will move with one drone, some parts will move with the other drone. Sometimes all my body is with one drone, and sometimes my body is with two drones, sometimes it's with the other drone—my body switches."* P4 mirrored this selective engagement,saying *"I would like to play with this one sometimes and sometimes the other one, sometimes both as well."* This trend extended to their interaction with human partners as well. Similarly, P6 and P1 exhibited congruence in their attention-shifting pattern when dancing with two drones, a reflection of P4's approach. However, P5 adhered to a distinct strategy, consistently focusing on one drone even in dual-drone scenarios, exploiting the symmetric nature of drone trajectories to anticipate the position of the other drone, thus mitigating divided attention.

Conversely, P7 attested to allocating heightened attention to the drone proximal to her, a strategy that grew increasingly arduous with the introduction of multiple drones, thereby unsettling her focus on her own movements. P8 shared P7's sentiments, acknowledging the diversion of her attention due to the interplay of movements executed by the two drones. Notably, in P5 and

P6's joint exploration involving two drones, their attention allocation strategy shifted from initially shared focus to bifurcation, prioritizing either the partner or the drones as the task's intricacy heightened. P10 admitted to experiencing a sense of disorientation amidst the proliferation of partners. However, P9 embraced a distinctive approach, electing to engage primarily with the entity in closest proximity, whether it was a drone or human partner. P9 elucidated, *"... when its position has some distance, we are more inclined to dance with my partner as we have more space. When we both perceive the drone approaching, we instinctively shift aside, resuming independent dancing or engaging with the drone ..."*. As dancers tend to engage more intensively with either the drone or their human partner, these diverse attention allocation strategies reflect how dancing with drones can stimulate and inspire dancers in nuanced, often less perceptible ways.

4.2 Spatial interactions with drones

RQ2 asks in short, how do dancers' spatial movements match with the drones, and how does this interaction differ from spatial dynamics with humans? Through the dancing experiments described in Sec. 3, we observed that dancers displayed a preference for dancing with multiple agents. They found the complexity and the induced spatial constraints to be motivating factors for exploration. Furthermore, our observations revealed that dancing with drones necessitates frequent adjustments of position. In contrast, when dancing with a human partner, a dancer's movements often involve pose and gesture changes. Additionally, some of the movements observed while dancing with drones were driven by the need to avoid collisions, leading dancers to lower their bodies and explore lower space.

4.2.1 More drones motivated the dancers to explore space to a greater extent. Many participating dancers exhibited a preference for engaging in dance performances with two drones, despite the spatial limitations introduced by their simultaneous presence. P6's viewpoint provides insights into this phenomenon, *"I would try to use more space because those drones are using a larger area"*. He likened this experience to navigating within a bustling ballroom during a social event, wherein adept maneuvering is essential to avoid collisions. He elaborated further, *"The more constrained the space, the more motivated one is to exploit it... In a party's dance setting, one is attuned to fellow dancers. Similarly, with two drones, a panoramic perspective is gained"*. Correspondingly, P3 observed that while dancing with two drones introduced heightened complexity, it also provided a "360° vision" due to the necessity of simultaneously tracking both drones. P7 shared this sentiment, noting that the presence of two drones facilitated her exploration of both upper and lower spatial dimensions. P1 and others also concurred, asserting that focusing on two drones actually opened up more space for their creative movements. This sentiment was echoed by P11 and P12, the latter of whom explained, *"... the more drones, the more we have to adapt and the more we actually do new things ... it's constraining you so you have to adapt so it's making you move more,... the more you move, the more you actually pushed outside of your comfort zone, the more inspiring"*. Collectively, dancers perceived the drones not as constraints but rather as stimuli for spatial exploration, with an increased drone count prompting a corresponding expansion of their spatial investigations. Nevertheless, certain dancers, like P9 and P10, expressed a preference for solo engagement with a single drone due to concerns related to safety considerations.

4.2.2 Dancing with drones: exploring frequent positional changes. When queried about the principal contrast between dancing alongside drones and dancing alongside humans, many dancers highlighted the need for frequent spatial repositioning while engaged with drones, compared to dancing with human partners. In the context of drone-companion dance, P4 articulated her inclination towards dynamically maneuvering through space by consistently altering her positions relative to the drones. P5 and P6 corroborated this observation, attesting to their proclivity for altering their spatial location instead of markedly modifying their movements or gestures. P6 expressed this sentiment, *"In normal social dance or party, people try to improvise by using steps or arms or legs. But don't try to move the position. Changing the position is more important when dancing with drones."*. Fig.5 showed the snapshots of P4 and P6 from their videos, showing their dynamic movements in a short period for positional change when they are dancing with drones.

4.2.3 Navigating potential hazards by dance movements. In addition to the dance interactions between the performers and drones, certain movements exhibited by the dancers are driven by their need to avert potential dangers posed by the drones, such as collision. P3 noted that his decision to descend in altitude at times was a preemptive response to the drone's accelerated movements, driven by his desire to prevent any physical contact. Conversely, when the drones adopted a more steady motion with lower speed, P3 felt more confident of elevating his movements and exploring the upper spatial realm, quoting: *"...Sometimes because I don't want to touch it, I go lower...But when the drone is faster, it's better to be lower because you don't know the direction and you don't want to be touching it. So when I feel it's moving faster, I will be lower. When I feel it's more steady and slower, I feel more capable of staying up."* Particularly evident are P5 and P6, whose inclination was to venture into lower space to minimize the risk of collision with the drones, a reflection of their safety concerns. P6 intuitively adjusted his positioning to a lower stance and arched his back when he lost visual contact with the drone. In a scenario involving two drones, P8 deployed a similar tactic, adeptly maneuvering her body and executing wave-like motions beneath both drones to forestall any potential collisions. . The synchronized movements of the two drones also compelled P9 to exercise greater caution in coordinating her dance steps. P10 demonstrated a propensity to maintain a line of sight with the drone, rapidly pivoting to face it when it moved behind her, a behavior indicative of her fear of collision, noting: *"when I turn back to the drone, I would like to quickly turn towards it to see where it is because I'm afraid it would hit me"*. Fig.8 demonstrates the tactical movements of P3, P6, and P8 to avoid the drones' potential danger when dancing with them. This kind of movement motivated them to explore the lower spatial areas more than usual.

Quantitatively, the computer vision analysis approximated the heights of the dancers' heads, hands, and pelvis via the 3D pose estimation. We then compared the results of dancing with a single drone and with two drones, as illustrated in Fig.6. The data shows that when dancing with two drones, the body parts are consistently and noticeably lower than when dancing with one drone, suggesting

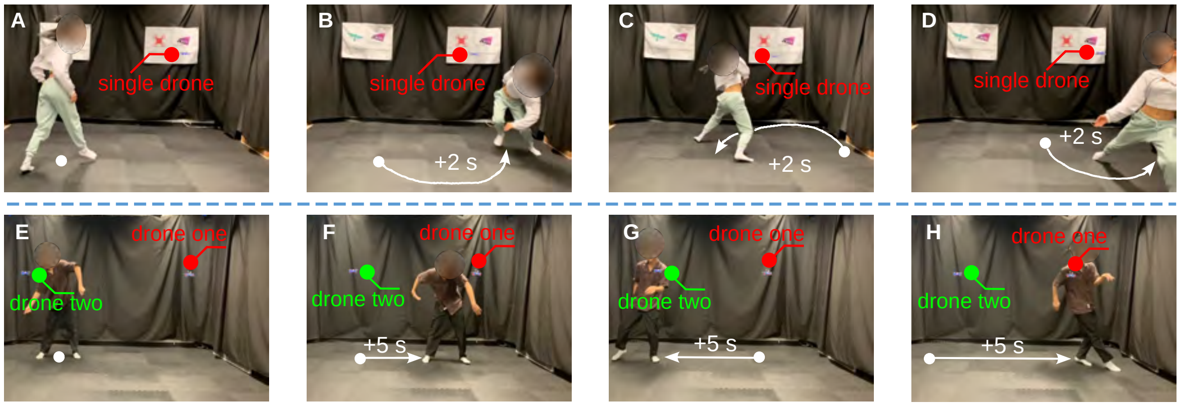

Figure 5: Frequent positional movements of the dancers when the drones are relatively stationary. A ∼ D are snapshots from one video with the camera's view fixed, depicting P4's dynamic movements over a 6-second duration as she traverses from the central-left region of the flight arena to the right side, following a circular path. E ∼ H are snapshots from another video with the camera's view fixed, demonstrating the path of P6 in 15 seconds, in which he makes two transitions from the left to the right side of the arena. Notably, the drones' positional movements remain limited in contrast to the dancers' dynamic performances.

that dancers tend to lower their bodies when two drones are present. This may result from the attempt to avoid drones. A paired t-test between the one-drone and two-drone scenarios verifies that hand and pelvis heights are both significantly lower in the two-drone scenario (p=0.0385 and p=0.02832, respectively, the p-value for the head height is 0.0743, which is not significant).

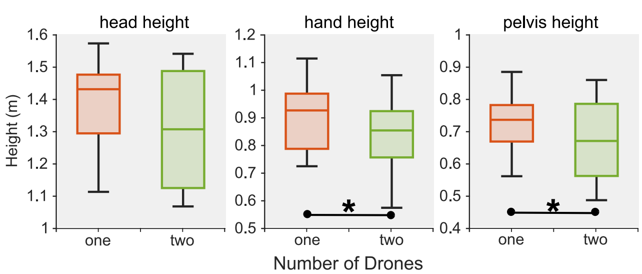

Figure 6: The head height, hand height, and pelvis height of the dancers in the single or two-drone scenarios

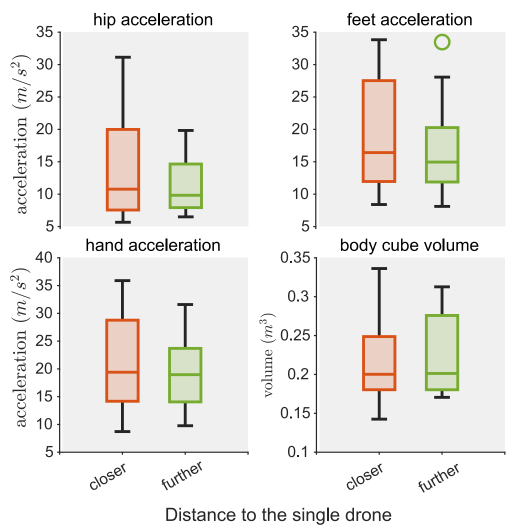

Figure 7: The feet, hand and feet acceleration and bounding volume in closer and further human-drone-distance

4.2.4 Effect of different proximity to the drone. The spatial interaction is also influenced by the relative distance between the dancers and drones. Using the median head-to-drone horizontal pixel distance as a threshold, we categorize the human-drone distance as either 'closer' or 'further'. In the 'closer' category, the majority of cases featured the drone and dancers on the same side from the audience's perspective, while the opposite was true for the 'further' category. As depicted in Fig.7, although we can observe that in the 'closer' scenario, the acceleration in the movements of the hips, feet, and hands tend to be higher. Conversely, in the 'further' scenario, the bounding volume encompassing the end-effector joints defined in [4], was greater. Nevertheless, the p-values obtained from a paired t-test are deemed insignificant, with the p-values over 0.3 for the accelerations of the hip, feet, hand, and bounding volume.

4.2.5 Dancer spatial behavior can depend on the number of drones present. The results of video coding are presented in Table 2, listing the overall occurrence of each movement among the 12 dancers. The total count of each movement is the sum of these movements counted in each flight phase of the drones, unveiling differences in dancers' behavior between the one-drone and two-drone conditions. The comparison reveals that the frequency of 'avoidance' actions is higher in interactions involving two drones ($N = 60/12 = 5$) compared to interactions with a single drone ($N = 25/12 \approx 2$), where N is the average number of actions per dancer. Likewise, dancers are more inclined to 'approach' the drone in one-on-one interactions ($N = 70/12 \approx 6$) than interactions with two drones

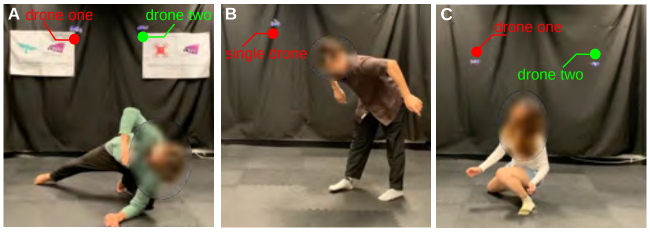

Figure 8: Navigating Potential Hazards by Dance Movements. A. P3 lowers his body to avoid being hit by the drone. B. P6 arches his back when he loses visual contact with the drone. C. P8 lowers her body to avoid hazards in the two-drone-dancing scenario.

($N = 21/12 \approx 2$). This discrepancy suggests that the presence of two drones may instill a greater sense of caution in the dancers, aligning with the conclusion of Sec. 4.2.3.

However, certain actions such as 'rotate' ($N = 30/12 \approx 3$) and 'crouch' ($N = 30/12 \approx 3$) exhibit similar frequencies regardless of the involvement of one or two drones. This implies that, while these actions are prevalent among dancers, the specific frequency varies among individuals and is not significantly affected by the drone count. Conversely, actions like 'embrace' ($N < 1$), 'pointing' ($N < 1$), 'pushing' ($N < 1$), and 'falling to the knees' ($N < 1$) were observed in only one or two dancers, suggesting a preference for these actions by specific individuals rather than a common occurrence across the entire group.

4.3 Dancers' perception towards the drones

To answer **RQ**3 regarding the perception of the drones in a performance context, our findings revealed a notable shift in dancer perceptions, which is initially marked by avoidance and fear. This gradually evolved into confident and closer interactions with the drones. Unlike human partners who rely on gestures and movements to influence their dance partners, dancers primarily attributed the drones' speed and sound to their impact on the dance. Interestingly, although most dancers still considered drones as stage props rather than human partners, they recognized and appreciated the unique attributes of drones that inspired their dance improvisations.

4.3.1 Change in dancer's perceptions towards drones. With increasing exposure to the drones and their motions, the dancers' perceptions transitioned from initial apprehension due to unfamiliarity to a more familiar and comfortable disposition (P1 and P2). P6, after participating in several dance sequences, began actively devising new movements and, intriguingly, attempting to assume a leading role in guiding the drones instead of adhering to their motions. As familiarity deepened, P7's sentiments also shifted toward a heightened sense of comfort. Gradually, the drones evolved from being perceived as potential threats to inspiring agents. P7 reported that her initial response was avoidance, driven by fear, which eventually gave way to a more nuanced understanding of movement in relation to the drones. She discerned when to lower her stance or make ground contact, synchronizing with specific drone motions, effectively harnessing the drones as catalysts for her own creativity instead of evading them. *"... sometimes I try to escape it, but actually it gives me more thoughts on how I should move, ... it's more about just to escape from them"* (P7).

This effect was found in P8 as well, whose perception shifted from cautious restraint to treating the drones as collaborative partners. This transition occurred in tandem with growing familiarity with the drones' trajectories. P7 postulated that the relinquishment of perceiving drones as threats, particularly when engaging with a single drone, fostered an affinity akin to partnering. P9 also had initial anxiety that gave way to a realization that the drone's motion exhibited a pace markedly slower than her anticipation. This distinct tempo offered by the drones led her to decelerate her movements, yielding a dance style she had not tried before. *"... It moves slower than I expected, so when I am dancing with it, I have to slow down my moves and change to another dance style which I never tried before ..." (P9).*

Fig.9 illustrates the dancers' movements which reflect their change in perception. The first trials involved dancing with a single drone, in which they preferred to dance at a longer distance with the drones. By contrast, after several trials, they get more comfortable with the drones and are confident to engage with them at a much closer proximity, even though the space is more crowded in the presence of more drones and their partners. For instance, Fig.9D captured P8 and P7 circled the drones at a close distance using their held hands. In Fig.9F, P9 improvised movements, seemingly striking the drones, showcasing her willingness to engage closely with them.

Upon re-examining the height data obtained through the 3D pose estimation (Sec. 4.2.3), we temporally partitioned the data from each trial into two segments. The objective was to evaluate whether dancers became more comfortable with drones over time, as shown in Table 3. The initial trial, involving dancing with a single drone, exhibited minimal variance in average joint heights. Conversely, during the second trial with two drones, a discernible increase in height was observed from the first to the second half of the trial. The elevation in hand, head, and pelvis heights indicated a gradual ascent during dancing with two drones, reflecting the dancers' growing confidence and reduced fear. Moreover, the heights recorded in the first half of dancing with two drones were lower than those observed in the single-drone scenario. However, the two scenarios converged to similar heights in the second half. These quantitative results align with the qualitative findings presented in Sec. 4.2.3 and Sec. 4.3.1.

Although dancers are cautioned against touching the drones due to the fast propeller, some unintentional collisions occurred (e.g., P2, P4, P7, p8, and P10). Surprisingly, these undesired collisions made dancers realize the collision was less intimidating than expected, bolstering their confidence in dancing with them The trajectories of the dancers' attitudes toward drones shows the shift from fear to inspiration and from avoidance to creative exploration. *"At the beginning, I was kind of afraid that I would clash with the drone. But later on, when you feel that it's safe, you kind of want to explore how the drone will interact with you" (P5).*

4.3.2 Impact of drone speed on dancer experience. Apart from the position change the drone speed also plays a pivotal role in shaping the dancers' perception. P3 recognized the drones' speed as a catalyst for heightened stimuli, expressing, *"It makes everything*

Table 2: Dancers' movements in response to one and two drone movements observed through dancing experiment videos

dancer movements		count with one drone	count with two drones
hand movements	pointing	8=(2+0+2+2)	5=(0+ 1+ 3+ 1)
arm movements	embrace	10=(4+3+2+1)	10=(2+1+3+4)
	pushing	13=(2+1+6 +4)	7=(1+1+4 +1)
	pressing	12=(1+1+6+4)	4=(0+0+2+2)
	catching	8=(2+2+1+3)	9=(0+0+6+3)
	swing	2=(1+1+0+0)	0=(0+0+0+0)
trunk movements	crouch	40 = (21+5+5+9)	38=(16+4+11+7)
	rotate	30 = (16+10 +3+1)	30=(13+5+4+8)
	swing	56=(11+12+25+8)	21=(1+6+14+0)
	somersault	15=(2+2+8+3)	11=(3+7+1+0)
	avoidance	25=(8+7+5+5)	60=(14+14+19+13)
	approach	70 = (14+18+19+19)	21=(13+3+1+4)
leg movements	raise one leg	6 = (1+0+3+2)	1=(0+0+1+0)
	falling to the knees	1 = (0+0+1+0)	3=(1+0+2+0)

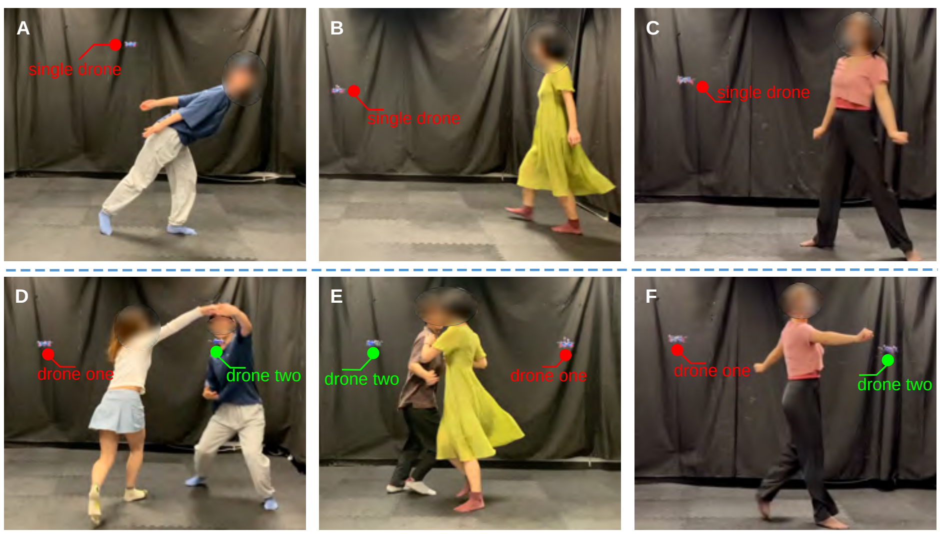

Figure 9: The movements of the dancers reflect their change in perception towards the drones. A ∼ C show the dancers P7, P5, and P9's dance with the drone for the first time, respectively. In which they prefer a longer distance between the drones, reflecting their initial apprehension and fear towards the drones. In contrast, D ∼ F capture their movements after several trials, where they confidently engage with the drones at a much closer proximity, even though the space is more crowded with two drones and their partners.

Table 3: Average joints' heights in the first half and second half of each trial

average height of joints	one drone		two drones	
	first half	second half	first half	second half
average hand height (m)	0.90	0.90	0.77	0.91
average head height (m)	1.41	1.38	1.11	1.36
average pelvis height (m)	0.73	0.73	0.62	0.72

speed up in the brain. I would say everything works way more like adrenaline." P6, on the other hand, highlighted the significance of drone speed in guiding his movements, stating, *"Speed changing is important when you dance… also, if the drone's speed is changing, I adjust to the drones' speed."*

On one hand, P9 concurred with the necessity of adapting to the drone's speed like P6 and P2's opinions, as she put it, *"So when it's fast, you want to do some fast moves, and when it's slow, you want to do some slow moves."* On the other hand, both she and her partner P10, also connected the drone's speed to their comfort level, favoring slower drone movements. *"It moves slower, and there is more space for me, so I think I can dance more freely and feel more comfortable" (P10).*

Given the fixed trajectories and speeds of the drones during their flights, certain dancers recognized this limitation and expressed a desire for variability in drone speed. P12, for example, pointed out, *"Could be interesting if there was some change of speed in the way it's moving, that would definitely have impacted the way we're moving* *as well."*, showing the functionality of the drones' speed in shifting the dancers' movements. Thus, the drones' speed emerges as a parameter contributing not only to heightened cognitive responses and movement alignments but also to the dancers' comfort.

4.3.3 Impact of drone sound on dancer experience. For some dancers, the sound of the drones becomes intertwined with their perception of the drones' characteristics. The presence of sound led P2 to perceive the drones as if they were alive, , *"The sound made me think of flies. The sound it creates and then the airflow, I guess for us, we also use it as some kind of stimulus, so if it's a very silent drone, it is maybe different."* Conversely, P9 discerned the drones from human partners through the sound of their motors, equating it to that of air conditioners or dryers, reasoning, *"No, it's still a machine, like air condition or a dryer, because I can hear the motor."*

The sound of the drones appears to serve as a positional indicator. P3 used the wind and noise generated by the drones' propellers to gauge their position, relying on this auditory feedback to position himself. He even indicated that he could discern the drones' movements through sound alone, stating, *"I still can feel them by the noise... there are moments when I don't see them but I know where they are and I hear maybe where it's moving and I can position it in my brain."* This sentiment was shared by P8, who found the sound helpful in locating the drone even when it's out of sight. P9 and P10 associated the volume of the drone's sound with distance, enabling them to adjust their dancing movements accordingly. *"When you get closer to it, you hear a louder sound, based on the distance of the sound, the louder or lower, you can change your dancing movements" (P9).* P11 also noted that *"...you could identify where it was without looking."*

The sound of the drones also indicates their speeds. P4 connected the sound of the motors to the drones' speed, providing an alternative form of perception beyond the visual. *"... Not only by the eyes' observation because the sound I will link up with the speed... and also the wind is like a kind of interaction ... , so it's giving me some body sensation other than just a look at it" (P4).* P6 concurred that speed changes are accompanied by corresponding sound alterations, noting *"And sometimes if the speed is changed, the sound also changes. So accidentally, it matches with the sound"*. Despite limited drone experience, they identified that higher motor sounds corresponded to higher drone speeds during their dance interactions.

However, the noise of the drones also has an adverse impact on the dancers. P5 found the noises unsettling, associating them with the sound of helicopters. P7 preferred lower drone sounds. , and P10 regarded the drone's noise as a source of disturbances. In conclusion, the sonic attributes of the drones wield a diverse influence on the dancers' perceptions, offering cues for position, speed, and disturbance.

4.3.4 Drones as stage props. The perception of drones as theatrical props emerged as a prevailing sentiment among the participants. One potential reason for this perception is the drones' size and movement, which can reduce them to mere dots moving at high speed. In contrast, human dancers possess a complex array of limbs and joints that facilitate intricate movements, as P3 articulated, *"... so I have arms, head, hips, knees, arms, fingers, everything. Every joint is a part that can move. A drone doesn't have the joints, so it's different, I would say it's like a tool that it can guide you to have some movements in the space"*. P4 agreed that drone is *"a prop, basically we have arms and legs, the drone is only a point"*. The inherent limitations in drones' movements and spatial dynamics reinforce the idea that drones function as guiding instruments, enabling spatial exploration rather than co-dancing. *"I think it's more like a prop because it cannot change with my dance, I can only change with its moves, its trajectory is unchanged" (P9).*

Another reason for dancers perceiving drones as props instead of human partners stems from the nature of interaction being one-way, as described in Sec. 4.1.2.For instance, P4 and P5's perspectives delve into the emotional dimension of human interaction, contrasting drones' lack of emotional reciprocity with the expected responsiveness from human partners. P5 noted, *"most of the time I feel that it's only a robot . Dancing with a human is more interactive"*. P6 agreed, *"when you dance with a human, you can see the emotions from the partner"*. *"For me, it was still a prop because there's no interaction the other way between me and the drone" (P11).* The limited hovering time of the drone in the trajectory of this study (Fig.2) may contribute to the perception as well, since previous work indicated that a longer hovering time makes the dancer perceive the drone more as a partner [58].

While the majority of dancers perceived drones as stage props, there were some who held different views. P2 recognized drones more as partners than mere props, as drones inspired and guided her during the dance. She shared, *"This to me is more than just an object because it has a lot of movement that inspires or guides us in a way for how we move. I think the reason why I feel like the drone is like the partner is because sometimes the drone can give me imagination."* In contrast, P12 found the categorizations of stage props or partners insufficient. Instead, she saw herself dancing with "small fairies," and her experience became playful when dancing solo. She remarked, *"Drones are not human but small fairies, playful characters when solo"*. Divergent perceptions of the drones serve as motivation for the dancers to engage in a variety of improvisational interactions with these aerial devices.

4.3.5 Distinctive attributes of drones in dance interactions. Drones possess distinct attributes that contribute to their uniqueness in the dance context, which inspires the dancers. One characteristic is the agility of drones and their ability to maintain stability. P6 highlighted the challenges humans face in stopping properly and maintaining stability for extended periods, emphasizing that these skills, while requiring practice for dancers, come naturally to drones. He also used the stopping of drones as signs for his movements. *"Being stable is difficult for humans. The drone's stopping is unique. It can stop easily. Yeah, and then really natural. That's something difficult for humans. A lot of dancers can't stop properly. It requires technique and skill. The drone can stop well. (We can learn) from watching the drone" (P6).*

The agility of drones was noted by P8, who observed, *"...if the dancer is on your right side, he cannot suddenly be on your left side, but for the drone, this part is quite different ..."*. The capacity for stability and agility did not go unnoticed by P9 either, as she noted, *"I think because only a drone can stay in the air for such a long time but human beings cannot do that."*. P10 added, *"Also, sometimes human beings cannot change their position so fast, like a drone. I also think the speed. Even for a dancer, it's difficult to get that speed ..."*.

Height alteration was another distinct characteristic noted by the dancers. P5 perceived changes in height as a unique aspect when dancing with drones, a movement not frequently encountered when dancing with human partners in social dance. She explained, *"For me, it's the height of the drone. For humans, for dancing, social dancing, we don't really change our height. But for drones, we can move there above and then lower. "*. The issue of height was also acknowledged by P7 and P9, who noted, *"Because a human being has a certain height, but a drone can fly higher or lower. If it does, it can get higher than a human being."*. The unique attributes of drones, including their agility, stability, and ability to change height, set them apart from human partners, shaping the dancers' perception of these machines.

4.3.6 Perceptions from the survey. After completing the dancing experiments with drones, the dancers were asked to participate in a survey. We collected ten valid responses from a total of 12 dancers (Fig.10). An analysis of Likert scale responses revealed several noteworthy findings:

(1) The scenario involving a single drone outperformed the scenario with two drones in terms of connection and comfort level. Specifically, 60% of the dancers gave high scores for their sense of connection in the single-drone scenario, compared to only 40% in the multiple-drone scenario. Similarly, 80% of the dancers rated their comfort level highly in the single-drone scenario, while only 30% did so in the multiple-drone scenario. This difference in perception might be attributed to the single drone providing more space for the dancer and making it easier to maintain focus, aligning with the results from Sec. 4.1.4.

(2) The scenario with two drones appeared to activate a greater sense of spatial exploration among some dancers and left them with an impression of being more competent. Notably, 20% of the dancers assigned the highest scores for space exploration to the two-drone scenario, whereas 60% of the dancers gave high scores for connection in the single-drone scenario, in contrast to the 40% who did so in the multiple-drone scenario. These findings align with the insights from our interviews, as discussed in Section 4.2.1. We conducted paired Wilcox tests between the one-drone and two-drone scenarios, yielding p-values 0.0340 for comfort. The p-values for connection, space, and competence are 0.8675, 0.0340, 0.4903, and 0.0583, respectively, which are not significant.

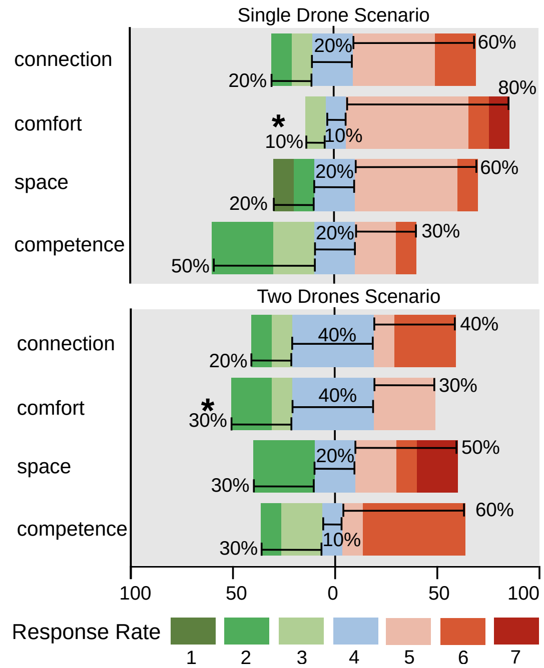

Figure 10: Quantitative dancer evaluation (options of 1 to 7, 7 is the highest) following the dancing with drones workshops. 'connection' refers to the question "How would you rate the level of the connection with the drone when dancing with a single drone/multiple drones?" 'comfort' refers to "How would you rate the level of comfort when dancing with a single drone/multiple drones?" 'space' refers to "How much the single drone/multiple drones invite you to explore the space of performance?" 'competence' refers to "How competent is the single drone/multiple drones during the performance?"

5 DISCUSSION

5.1 Integrating drones into performance art

Our findings lay open the possibility for integrating human-drone interactions into onstage performance art. Storytelling in stage work requires strong character development and narrative arcs, which can be expressed through both humans and their technological inventions like avatars, robots, and now drones. In particular, prior research has established that audiences can discern distinct 'characters' of drones based on parameters such as speed, height, and response time [10, 58], indicating that drones themselves can serve as narrative participants by varying their actions. This is exemplified in the drone-dancer opera by Eriksson et al. [12]. In this work, a drone's descent elicits a palpable sense of helplessness in the audience, who equates the descent with the emotion of losing control. Meanwhile, our study shows that dancers can have emotion-like perceptions of the drone during improvisation, just like the audience, showcasing the potential of drone movements to convey narrative elements. For example, in Sec. 4.1.3, we present evidence that the descending motion of drones, starting from above the dancer's head, mirrors the sensation of a 'ceiling dropping' utilizing the presumed fear of drones. Consequently, these drone movements could be employed, for example, in a 'catastrophe' scene to elicit emotional responses both as they interact with performers, and also to show this emotion to audiences. Furthermore, choreography incorporating sophisticated drone movements, such as speed changes influencing the dancers' pace (Sec. 4.3.2), could generate diverse tensions in narrative moments such as excitement, contentment, or fear during the performance.

In addition to choreographed movements for technical special effects [43], our study uncovers a more multifaceted role for drones in performances in their relationships with performers. As detailed in Sec. 4.1.3, they contribute to sources of inspiration that drive the dancers to try new moves, and, as elucidated in Sec. 4.3.4, they function as dynamic stage props and can be personified as fairies or other creatures. They also act as partners, synchronizing with performers' movements (e.g., Sec. 4.3.5). Beyond merely visualizing a dancer's stamping through simple vibrations, as demonstrated in the work of Kim et al. [29], our participants perceive drones as extensions of their bodies, enhancing and prolonging their movements (Sec. 4.1.1).

As a technical marvel, drones in art performance contexts may introduce heightened dynamics and interaction among the agents given their agility and speed, thereby infusing the show with increased vitality and vividness. The utilization of drones equipped with programmed lights, as exemplified by Waibel et al. [55], can further contribute to enhancing the technical prowess of the overall performance. Similar to work employing robot systems during performances with dancers [36], drones also provide a technical achievement that can be utilized with human partners to show stories of how people love, fear, and misunderstand state-of-the-art technology. In summary, drones can be integrated into performances in the form of storytelling characters, as support for performers, and to provide technical marvels.

5.2 Applications to kinesthetic development and dance education

Space exerts a profound influence on human perception [40], and the movements of drones can both create space to foster creativity (Sec. 4.1.3) and impose spatial constraints (Sec. 4.2.1) for dancers. In addition to shaping space, the unique motions of the drones inspire dancers to explore novel movements from diverse perspectives. We posit that the integration of drones holds educational value in dance and contributes to the kinesthetic development of students, irrespective of whether the dancer ultimately incorporates drones into their performances.

Prior studies have investigated enhancing kinesthetic creativity in technology-mediated movement improvisation [35]. One group proposed a taxonomy of interaction patterns with visualization systems and demonstrated how dancers invent new movements when constrained and motivated by the system [24]. Our study found that drones can activate dancers to gaze, follow, and interact with the drones, thus constructing novel movements and gestures. As shown in Sec. 4.2.1, the occupation of space by drones pushes dancers out of their comfort zones and inspires the exploration of body shapes and the use of more space. This mirrors the conclusions of Karpashevich et al. [28] and Hnoauer et al. [23], who found that although wearing the interactive costumes could constrain the lower body's movement of the dancer, the designed costumes balance and create tension between norms and technology, offering a new experience and inspire the dancers to perform unthinkable movements. Additionally, drones, with their ability to execute movements with high precision and consistency, serve as reliable references for dancers and guidance for movements (Sec. 4.3.5, 4.1.1) [30]. Drones could also sharpen dancers' awareness of their bodies and surroundings, as they require high body coordination while responding to external stimuli (Sec. 4.1.3). These advantages of drones would allow dancers, especially students, to brainstorm, experiment, and improvise with different movements, body shapes, levels, and choreographies.

The robot's presence can also transform traditional dance classes into more engaging experiences. Drones' accompaniment provides a space for imagination, adding meaning to bodily exercise [32]. As the dancers have things to interact with, it lessens shyness on stage, as P12 acknowledges in Sec.4.1.3. Previous work developed larger drones for the dancing performance [12, 29] and developed tactical drones to enable the physical instruction to the dancers [57, 58]. In our settings, we put tiny, autonomous drones into the dancing environment, inviting the dancers to explore the space.(e.g., Sec. 4.2.1) and interact closely with them. Consequently, the presence of drones could serve as dynamic flying markers, allowing the dancers to respond to the specific positions of the drones in space (Sec.4.1.1). The wide range of the movement of the drones could prompt the dancers to perform at different body levels, shapes, and movements, which will be beneficial in dancing education.

Finally, using drones and the creative new movements dancers make in response to them naturally has an aesthetic quality, telling a complex and nuanced story about the relationships between humans and drones within a creative framework. We posit that these interactions with drones not only contribute to kinesthetic development and dance education but also stand as a potentially distinctive and compelling performance in their own right.

5.3 Design implications

Based on our findings and results, we propose guidance for design, research, and practice in performing with mobile robotic devices like drones.

(1) For performers, we advocate incorporating regular drone dance practices into daily training to foster confidence in dancing with them and to establish a deeper connection with them. As highlighted in Sec. 4.3.1, our study reveals that repeated exposure through several trials effectively alleviates fear. Furthermore, Sec. 4.1.3 underscores that increased interaction with drones also catalyzes novel movements among dancers as a form of somatic practice.

(2) We propose utilizing drones in dance performances as guiding cues for dancers, particularly when the trajectories are controllable and repeatable. Audio feedback systems [15] and visual projection [13] are examples of interactive technology integration in dance that has improved spatial awareness and movement. The introduction of drones provides dancers with an object to follow, as detailed in Sec. 4.1.1, and incorporates audio feedback, as discussed in Sec. 4.3.3.

(3) Unlike traditional dancing, where the rhythm takes precedence [42, 53], the choreography of dancing with a drone emphasizes body movement in space, and the motion (including position and speed) of the drone itself is considered akin to rhythm, as discussed in Sec. 4.1.3. Notably, music is not regularly employed in this context, except for two dancers who found it indispensable for their performance. Conversely, other participants perceive the motion of drones as a rhythmic element akin to music that they can dance with.

(4) The movement of drones can serve as a visual representation of music. Previous work has attempted to use neural networks to translate music into drone motion [62]. Building upon our findings, we propose synchronizing the motion of drones with selected musical accompaniment during performances to enhance the vividness and versatility of the overall presentation.

(5) The heightened speed and relatively low altitude of drones, coupled with the presence of additional agents, whether they be drones or dancers, contribute to an increased sense of tension in the performance, as illustrated in Sec. 4.1.3 and Sec. 4.2.1. Consequently, we propose adapting the speed and quantity of drones in accordance with the type and desired tension of the performance. For example, many drones moving towards us slowly can signal impending doom, whereas two drones circling quickly over our heads may signal a type of curiosity or excitement.

(6) We recommend positioning the drones near the dancers whenever possible, as this near-distance arrangement has been observed to enhance interaction, as detailed in Section 4.1.4. With smaller drones, the collision causes no physical effects and appears not to be a major deterrent, as shown in Sec.4.3.1.

The insights gleaned from this study hold relevance for performative interactions with various types of anthropomorphic robots. Previous work shows that human performers can effectively collaborate with robots possessing diverse degrees of freedom, interpreting them as humanoid counterparts [49]. Additionally, interactions with a robot arm can serve as an example of how performers can draw inspiration from improvisational engagement with anthropomorphic robots [36]. Despite drones' non-humanoid structure and distinctive linear movements, we contend that robots in alternative formats, such as robotic arms or wheeled robots, can similarly inspire dancers [45]. For instance, dancers may adopt strategies like mimicking the movements of a robotic entity or contrasting actions in response, as evidenced in Sec. 4.1.1. Moreover, anthropomorphic robots, akin to drones, can shape the performance space for dancers, as discussed in Sec. 4.2.1. This makes our findings regarding spatial interaction and perception of the drones important also for robots outside the domain of unmanned aerial vehicles.

5.4 Limitations

5.4.1 Limitation of choreographed drone trajectory. We designed the trajectory consisting of four phases for the drones as described in Sec. 3.2.2. According to [32], the trajectories were comparatively straightforward and linear, which allowed the dancers to explore one dimension at a time. However, they differed from human performers as the drones appeared to be too predictable, maintaining almost stable speeds and repeating movements within the same interval.

One dancer preferred circling over the other movements that only moved along one axis. She suggested that adding diagonal or pathway movements could possibly make the drones more dynamic. When we asked the dancers about the human characteristics of the drones, they generally did not consider the drones this way and described their movement as not being alive. This echoes the findings of Alaoui [13], where the ambiguity in the behavior of artifacts can better trigger the interpretation of a partner by the dancers. It might be better if the dancers are incorporated into the process of drone movement creation and make the speed of the drone vary during the flight.

5.4.2 Limitation of interactivity for drones. In fact, introducing interactivity for the drones or granting the dancers the ability to manipulate the drones' trajectory to shape a narrative can significantly augment the performance. The dancers frequently expressed challenges in communicating with the drones, characterizing their interactions as one-way and lacking feedback. One potential avenue for improvement could involve tracking the dancers' joint positions and simultaneously autonomously controlling the drones' movements. For instance, the drones could be programmed to approach the dancers' bodies or respond to some gestures of the dancers, fostering a more dynamic and engaging interaction between the dancers and the drones. Such enhancements have the potential to elevate the overall interaction and synergy between the dancers and the drones.

5.4.3 Limitation of the background of the participating dancers. Another limitation of our research is that we did not account for the diverse range of dancing styles that participants may have brought to the study. While the dancers in this work previously concentrated on social dancing with limited prior experience interacting with anthropomorphic robots in other settings, different dancing styles often encompass distinct techniques, movements, and interactions, which could potentially impact how dancers react to the presence of drones, thus introducing nuances in the dynamics and interactions within the dance performances. Additionally, the difficulty in finding suitable participants limited the number of dancers involved in our research, which could limit the generalizability of our findings. Lastly, our study primarily took place in a studio-like environment designed for exploration rather than on a traditional stage. This setting may not entirely replicate the conditions and constraints that dancers typically encounter during live stage performances, potentially influencing how they engage with drones.

6 CONCLUSION

In this work, we investigated how individuals perceive and interact with autonomous drones within the creative context of dance. Our findings shed light on several intriguing aspects of this unique interplay.

Dancers primarily prioritize orchestrating the spatial aspects of their performance, often regarding the drones as obstacles within the environment. This spatial orchestration frequently leads to dancers aligning themselves with the drones, perceiving them more as elements of the stage setup rather than interactive partners, primarily due to the one-way nature of drone operation. Notably, the sensory experiences arising from the sound and airflow generated by the drones can be associated with the speed and dynamics of the drones and thus harnessed constructively to enhance the performance. When multiple drones are present, we observed that individuals tend to explore the space more expansively, engaging in increased avoidance maneuvers and adopting lower body positions. Conversely, in interactions with a single drone, a stronger and more intimate connection is established.

Moreover, our study unveiled intriguing insights into the nature of dances. Solo dances were often described as playful, while partner dances were characterized as more conversational. This distinction reflects a heightened level of interactivity and two-way communication possible in partner dances. Fascinatingly, even when two dancers held contrasting interpretations of the drones, they managed to collaborate effectively, highlighting the adaptability and creativity inherent in dance partnerships.

The incorporation of drones ignites the creative improvisation of both individual dancers and pairs, thus offering insights into the interaction between human dancers and drone movements in diverse contexts. This exploration not only enhances our comprehension of how dancers react spatially to drone motions but also illuminates the manner in which drones influence human perception. We believe that the HCI community can draw inspiration from the interactions and perceptions observed between dancers and drones in an improvisational context. This work also contributes insights into the design implications of dancing with drones and potentially anthropomorphic robots in other formats. Consequently, these findings hold promise for developing innovative strategies in dance choreography and the domain of human-machine interaction.

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