

1 **A Constructed Response: Designing and Choreographing Robot Arm**
2 **Movements in Collaborative Dance Improvisation**
3

4 **ANONYMOUS AUTHOR(S)**
5

6 In dance, performers improvise and choreograph with each other, prototyping movement designs with each other. These interactions
7 extend into collaboration with technology to enhance the creative process. We want to understand how performers design and
8 improvise movements together in the case of working with a robotic arm, which serves as an instrument in the stage space capable of
9 non-humanoid movements. We engaged and observed dancers in a workshop to co-create movements with robots in one-human-to-
10 one-robot and three-human-to-one-robot settings. We found that dancers produced more fluid movements in one-to-one scenarios,
11 experiencing a stronger sense of connection and presence with the robot as a co-performer. Conversely, in three-to-one scenarios,
12 the dancers divided their attention between the human performers and the robot, resulting in increased perceived use of space and
13 more stop-and-go movements, perceiving the robot as part of the stage background. This work highlights how technologies can drive
14 creativity in movement artists as they adapt to new ways of working with instruments, extending prior research on dancing with
15 inanimate objects by exploring how robotic arms influence creative collaboration. We contribute insights into designing systems that
16 support improvisational processes and artistic collaborations with non-humanoid agents.
17
18

19 CCS Concepts: • **Human-centered computing: Computer System Organization → Robotics.**
20

21 Additional Key Words and Phrases: robot dance, improvisation, choreography, human-robot collaboration, human-robot interaction.
22

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26

27 **1 INTRODUCTION**
28

29 Dance is an inherently collaborative art form where performers engage in improvisation and choreography, both
30 individually and in groups[61][44]. These interactions are fundamental to the creative process, allowing dancers to
31 prototype movement designs and refine their performances through continuous feedback and cooperation[43][22][57].
32 Understanding how dancers work with each other and with technology provides insights into the evolving dynamics of
33 creative expression in the performing arts.
34

35 Novel interactions derived from technological advancements offer creative possibilities for performers[46][37].
36 Dancers have long engaged with inanimate objects and props, using them to expand creative expression and explore
37 the relational dynamics between movement and materiality[5]. This interaction forms the basis for integrating more
38 advanced tools, such as robotic systems, into choreographic practices. The integration of robotic systems into dance
39 introduces new modes of collaboration, prompting dancers to adapt their traditional practices to incorporate these
40 technological elements[27][33] [31]. Previous CSCW studies have explored dance, design collaboration and technology,
41 such as the study Rivière et al.[48] introducing a technology probe for dancers to decompose movements, demonstrating
42 the role of technology in dance education and practice but not focusing on collaborative or design aspects. Hsueh et
43
44

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Fig. 1. Examples of Dancer-Robot Interactions in Improvisational Dance. One human-one robot improvisation sessions (Top, middle). Multiple humans-one robot sessions from different groups (Bottom).

al.[30] investigate the collaborative dynamics between creators and performers in contemporary music and dance. It examines how composers and choreographers interact with performers through shifting roles and how artifacts mediate these interactions, with role transitions fostering new creative pathways without addressing the integration of robotics or technology in the creative process. LC et al.[39] examines how performers adapt to virtual performance paradigms. It highlights strategies such as using technological and time constraints as creative tools and adapting rehearsal workflows to remote interactions. This study focuses on remote interactions and virtual settings but does not address collaborative or design processes, while our work investigates in-person collaboration and creative processes with non-humanoid robots. Kwon et al.[38] exploring human-AI design collaboration, while our work investigates creative collaboration between humans and non-humanoid robots in embodied practices like dance. Research has extensively examined dancers' learning processes and documentation practices, but few studies have examined how robotic systems affect collaboration dynamics and movement qualities in solo and group settings. This gap highlights our novel approach to studying how non-humanoid robots affect creative processes in individual and group dance.

This study focuses on non-humanoid robotic arms, explores how non-humanoid robot presence influences performers' improvisational dance, focusing on both individual and group dynamics. Besides, this study also explores how improvisation and choreography foster self-expression in solo and group settings, highlighting how individual creativity intersects with group collaboration and shared artistic goals. As shown in Figure 1, the examples highlight one human-one robot improvisation sessions (top, middle) and multiple humans-one robot sessions from different groups (bottom). We designed a series of workshops to explore how dancers interact with a non-humanoid robotic arm under various conditions: one dancer with one robot (1-1), and three dancers with one robot (3-1). These workshops aimed to investigate both improvisational and choreographed settings, providing a comprehensive understanding of how dancers design and perform movements with robotic systems. By qualitatively analyzing these interactions, we sought to uncover the nuances of human-robot collaboration in dance.

Our research questions (RQs) guide this exploration:

105 **RQ1:** How does a non-humanoid robot affect the way performers create body movements during improvisation with
106 the robot?

107 **RQ2:** How do performers work in teams to collaboratively improvise and choreograph movements with a non-
108 humanoid robot?

109 **RQ3:** How do performers and choreographers design movements for a non-humanoid robot to facilitate and prototype
110 movement-based performances?

111 In these workshops, we probed the dancers' experiences and perceptions through semi-structured interviews,
112 observations, and qualitative data analysis. Our findings revealed that dancers produced more fluid movements and felt
113 a stronger connection with the robot in one-to-one scenarios, while group settings led to increased spatial use and more
114 segmented movements, with the robot often perceived as part of the stage background. Our findings highlight how
115 robotic systems can serve as tools for advancing creative choreography and as platforms for end-user development and
116 programming through demonstration, providing actionable frameworks for applications in movement-based learning,
117 interactive education, and collaborative workflows across diverse domains.

118 The research provides valuable insights into how dancers adapt to and integrate non-humanoid robotic arms into
119 their creative processes, illustrating how technology can drive innovation in movement and performance. By comparing
120 individual and group interactions with the robotic arm, the study highlights significant differences in movement quality
121 and performer engagement, offering essential information for designing robotic systems that support artistic expression.
122 Additionally, this research emphasizes the importance of interdisciplinary collaboration, demonstrating how knowledge
123 transfer between dance and robotics can pave the way for novel creative possibilities and augment human creativity in
124 new and transformative ways[28][53].

130 131 2 RELATED WORK

132 2.1 Collaboration in Dance

133 Previous researchers have extensively explored the dynamics of collaboration in dance, including collaborative choreo-
134 graphy, co-improvement in dance dance-making process, and collective improvisation.

135 Various studies have noticed the collaborative nature of choreography as dancers and choreographers closely work
136 together to create dance pieces. Rowell [52] noted an emerging new status for dance as a collaborative art through an
137 analysis of contemporary dance in Europe and the UK. Klien [35] also stated that dancers in the current political context
138 have to balance their individual freedom and personal experiences within a larger group instead of simply being hired
139 to perform. In the similar context of UK's contemporary dance, Butterworth [13] identified five distinct collaborative
140 processes between choreographers and dancers, and introduced the *Didactic-Democratic Spectrum* framework, which
141 outlines varying levels of collaboration between dance artists. As Gibbons [26] later described, choreographers and
142 dancers collaborate to generate materials and inspire each other, especially in the "editing process". In this dance making
143 process, the choreographer can be viewed as a "curator" who organizes, compiles, and arranges choreographic objects,
144 movement material and structures. Carroll et al. [16] demonstrated how the choreographer collaborated with dancers
145 using *Choreographer's Notebook* during the dance production process. The hierarchical nature of this collaboration was
146 also revealed, as only choreographers provided feedback on dancers' videos, while dancers did not correct each other.
147 Recently, Ciolfi Felice et al. [25] presented a deployment of a creativity-support tool Knotation in a long-term study to
148 explore the collaborative process and shifting roles between choreographers and dancers in dance making.

Dance often consists of following an internal (the dancer's own feelings and emotions) or external rhythm (movements of the partner or a group), as well as coordination with the space [45]. In many dance styles, dancers must practice interpersonal coordination, managing time and space, and varying their movements to synchronize or contrast with their partners. For example, when performing contact improvisation, which involves two dancers maintaining physical contact and responding to each other's movements [12], the dancer acquires kinesthetic interconnectivity to sense the partner's body and the ground [34]. They respond to the very moment naturally through specific skills like "listening", and creating with the moving body to the largest extent. In this process, dancers learn to track their partner's attention and even decide the direction of movements based on tactility, weight distribution, gaze, and temperature sensed by their partners. Historically, dancers have also worked with inanimate objects or props[21][5], to enhance creative expression and explore spatial dynamics. These interactions serve as precursors to understanding the performer-object relationship, offering valuable insights into how technology like non-humanoid robots could further enrich collaborative and creative practices in dance.

Prior studies offer related but distinct insights into the intersections of dance, collaboration, and technology. Hsueh et al.[30] examined collaborative relationships between creators and performers in contemporary music and dance, emphasizing role transitions but not addressing robotic or technological integration. Rivière et al.[48] introduced a technology probe to assist dancers in decomposing movements, highlighting the role of technology in dance education and practice without focusing on collaborative or design dynamics. Our study bridges these gaps by examining how non-humanoid robotic systems influence creative processes in dance, emphasizing embodied interaction, kinaesthetic creativity, and collaborative choreography. By exploring in-person, real-time dance collaboration dynamics with robotic technologies, our work expands the understanding of how humans co-create with non-humanoid robots in performance-driven contexts.

2.2 Technology-mediated Movement Interactions

Integrating technology into dance has been proven to influence movement creation, teaching, and performance. For example, Motion capture (MoCap) systems, provide dancers with real-time feedback, allowing them to visualize and refine their movements dynamically during rehearsals[15][56]. Moreover, Virtual reality (VR) creates immersive environments, enabling novel forms of dance expression and audience interaction[2][9]. These technologies enhance dancers' engagement with the art, fostering deeper connections with dancers' movements and audience.

Robotic systems in dance move beyond tools to become active collaborators in performances[17]. Research on co-creative processes between humans and robots in contemporary dance shows how robots bring unique capabilities and challenges to the performance space[63][7]. Our study extends existing research on end-user development and programming through demonstration, particularly in the context of human-robot collaboration, where users interactively design and adapt robotic behaviors. Similar to the methods employed in prior works[21][2], our workshops involved choreographers programming robotic arm movements through demonstration, enabling a collaborative environment that fosters creativity, learning, and adaptation. This approach aligns with interdisciplinary applications of robotic systems in educational settings and creative industries, where users actively engage in shaping the technology to support their artistic and functional objectives. This study highlights how dancers and choreographers adapt their practices, using the robot's distinct physicality and movement patterns to inspire new choreographic ideas[17].

Robotic arms represent a fascinating blend of precision and versatility in dance[51][50]. Dancers adapt their choreography to the mechanical properties of robotic arms, exploring the creative potential that arises from this interaction[33]. Unlike human dancers, robotic arms provide consistent, repeatable movements, enabling intricate synchronization and

209 complex patterns that enhance the visual and emotional impact of performances. This consistency pushes dancers to
210 innovate within the robot's capabilities, finding new ways to express their artistry.
211

212 Research on the integration of robotics and interactive technologies in dance has shown how these robots can
213 enhance collaborative creativity[62]. Studies have also explored how haptic feedback and interactive lighting syn-
214 chronized with robotic movements create multi-sensory dance experiences[40]. These advancements illustrate the
215 evolving dynamics of creative expression in the performing arts, emphasizing the importance of understanding how
216 dancers work with new instruments to enrich the art. Our study builds on prior work in end-user development and
217 programming through demonstration, emphasizing human-robot collaboration in creative settings. Similar to methods
218 explored in prior studies[21][2], choreographers in our workshops programmed robotic arm movements through
219 direct demonstration. This enabled a collaborative process that supports creativity, iterative learning, and adaptation,
220 aligning with interdisciplinary applications in educational and creative industries. Furthermore, while existing research
221 predominantly focuses on tools like MoCap, VR, and humanoid robots, the role of non-humanoid robotic systems
222 remains underexplored. By integrating robotic arms with unique movement capabilities, our work examines how such
223 technologies challenge traditional collaboration paradigms and inspire dancers to innovate their creative workflows.
224

225 **2.3 Perception and Interaction with Non-humanoid Robots**

226 Non-humanoid robots, designed without mimicking human form, play functional and task-specific roles in various
227 domains[6][50][18], including the performing arts. Unlike humanoid robots, which aim to replicate human behaviours
228 and interactions[24][41], non-humanoid robots like robotic arms offer unique opportunities and challenges in perfor-
229 mance settings.

230 Non-humanoid robots, designed for specific functions, influence how humans perceive and interact with them.
231 Their distinct forms and movements shape these interactions, with smoother, and more predictable motions enhancing
232 comfort and acceptance[59]. This predictability is crucial for performers, as it facilitates better collaboration and
233 understanding, allowing dancers to anticipate and synchronize with robotic movements[23]. The interaction with
234 non-humanoid robots, therefore, is faster more intuitive and engaging collaborations.

235 In performance arts, non-humanoid robots like robotic arms offer novel forms of artistic expression[7], enable
236 complex choreographies that challenge traditional dance boundaries[1]. These robots provide consistent, repeatable
237 movements, pushing dancers to innovate within the robot's capabilities. Existing research has primarily emphasized
238 the practical and aesthetic contributions of humanoid robots to performance arts, often overlooking the creative and
239 collaborative dynamics of non-humanoid systems. This work bridges that gap by focusing on non-humanoid robotic
240 arms and their potential to act as co-creators in dance. Our work highlights how the lack of anthropomorphism in
241 robotic systems encourages dancers to explore alternative movement vocabularies, fostering unique choreographic
242 approaches and expanding the scope of artistic expression.

243 **2.4 Study on Choreographers and Dancers**

244 Movement-based collaboration with technology has been extensively examined, focusing on how these technologies
245 can enhance artistic expression and performance capabilities. This field investigates the collaborative dynamics be-
246 tween human performers and robotic systems, offering insights into the augmentation of traditional dance through
247 technological means.
248

249 Choreographers have increasingly viewed robotic technologies as tools that extend the boundaries of traditional
250 dance. These technologies facilitate the exploration of novel choreographic possibilities and enable the creation of
251

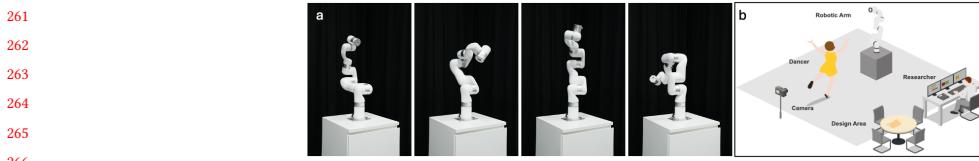


Fig. 2. Experimental Setup Overview: a) Non-humanoid robotic arm used in the workshops. b) Schematic of the experimental setup.

intricate and precise movement patterns. Previous research elucidates how digital performance technologies have revolutionized contemporary dance, opening new creative avenues[20]. And the collaborative potential between human performers and robots, highlighting the co-creation of dance performances[7]. For example, dancers adapt both physically and cognitively when working with robots. This adaptation involves understanding robotic movements and programming, thereby developing a hybrid skill set that integrates dance and technology. When dancers interact with robots[14], they use parts of their brain that help them observe actions and use their motor skills.

Robotic technologies enhance artistic expression and emotional engagement in dance performances. Robots can be programmed to execute movements that evoke specific emotions, thus adding depth to the performance. The aesthetic interplay between humans and machines has been discussed, creating unique artistic experiences that challenge conventional dance paradigms[36]. This technological-artistic fusion not only expands the scope of dance but also enriches the emotional and aesthetic experiences of both performers and audiences.

The integration of robots into dance and choreography poses challenges, including the necessity for technical proficiency and potential creative constraints due to technological limitations. The complexities of synthesizing self-organized dance with robots are mentioned, emphasizing the importance of interdisciplinary collaboration between artists and technologists[11]. However, these challenges also present opportunities for innovation, as the precision and reliability of robots can inspire new forms of movement and interaction, thereby pushing the boundaries of traditional dance [33].

Enhancing the collaborative dynamics between humans and robots in dance includes developing interfaces for programming robotic movements and exploring new interaction forms that leverage both human creativity and the robotic. Long-term studies on the impact of robotic integration on artistic practices will provide deeper insights into the evolving relationship between technology and art. Understanding how dancers and choreographers adapt to and innovate with robotic technologies will be crucial for advancing this interdisciplinary field.

However, little research has addressed how choreographers and dancers adapt their creative practices with non-humanoid robotic systems, especially in group settings[?][48]. Our study explores the collaborative dynamics and movement designs between one-on-one and group interactions with robotic arms. By focusing on how non-humanoid robots influence creative workflows, our work provides qualitative insights that contribute to interdisciplinary collaboration in performing arts and inform the design of robotic systems that support artistic innovation.

3 METHODS

3.1 Setup

Each session was conducted in a controlled laboratory environment. An xArm 6 robotic arm (UFactory, Shenzhen) was centrally placed on the floor. The robotic arm stood on a white platform with dimensions of 150 cm in height, 50 cm in length, and 50 cm in width, allowing dancers to move around it with a proximity ranging between 0.5 m and 1.5

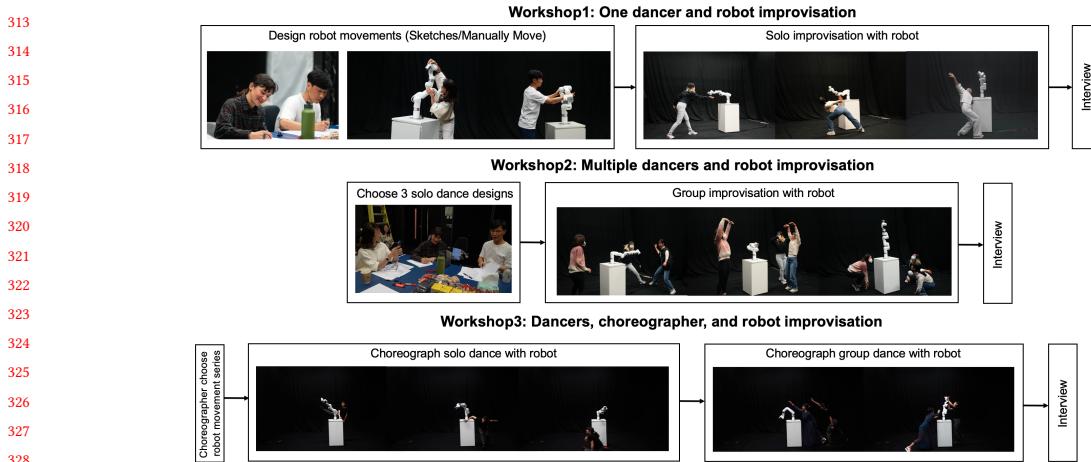


Fig. 3. Co-Designing Robot Arm Movements with Dancers. Top: Performers individually design and perform solo with robot movements. Middle: Group collaborates to synthesize individual designs and perform with the robot. Bottom: One choreographer creates a set of robot arm actions for a single dancer or two other dancers, who then perform with the robot.

Table 1. Dancers in this Work

Group	Dancer	Gender	Age	Dance Category	Dance Years
1	P1	Female	41-50	Swing	20
	P2	Female	31-40	Hip-hop	9
	P3	Female	21-30	Street Dance	7
2	P4	Female	51-60	Improvisation	40
	P5	Male	41-50	Ballet	35
	P6	Female	41-50	Contemporary Dance	30
3	P7	Female	21-30	Modern Dance	16
	P8	Female	21-30	Modern Dance	20
	P9	Female	21-30	Contemporary Dance	5

m. The experimental setup consisted of a non-humanoid robotic arm designed for improvisational dance studies and an arrangement tailored for three workshops. As shown in Figure 2, panel a illustrates the robotic arm, while panel b provides an overview of the setup layout.

3.2 Participants

To explore how dance practitioners interact with non-humanoid robots in both improvisational and choreographed dance of two situations: individual vs. group, we organized three separate participation sessions with three groups. We recruited nine professional dancers (eight female, one male; ages 21-60) from a local academic dance university to participate in half-day workshops. Nine dancers were divided into three groups randomly. Each group participated in 3 workshops. As detailed in Table 1, these dancers had between 5 and 40 years of experience in various dance styles, ranging from swing to contemporary dance. The dancers did not have prior experiences dancing with the robot or robotic arm, with 2 had prior experience with drones. All the dancers had prior experience dancing with inanimate objects like chairs. The workflow for these sessions is depicted in Fig. 3.

365 For Workshop 1, each dancer was asked to manually move the robotic arm first to become familiar with the robotic
 366 arm dynamics modes, so that they would not conflict with the movements of the robotic arm in future steps, ensuring
 367 their safety. Then each dancer did the movement design for the robotic arm, and then the researcher played the
 368 movement design recording for the dancer to do the solo improvisation.
 369

370 For Workshop 2, each group had a discussion first to choose the movement design in Workshop 1 and then did group
 371 improvisation with the robotic arm conducting chosen movement design.
 372

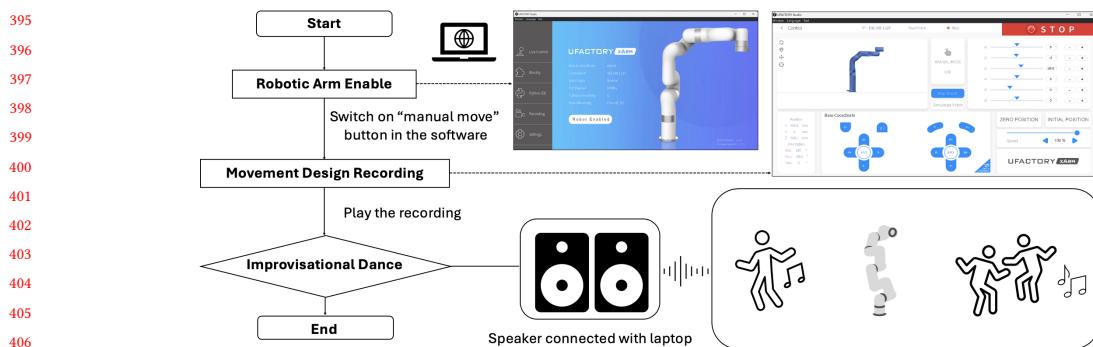
373 For Workshop 3, each group collaboratively decided to adopt the roles of one choreographer and two dancers for
 374 their work. The choreographer chose three movement designs in Workshop 1, which were then combined into new
 375 movement series by the researcher. The choreographer created a solo dance sequence for one of two dancers to perform
 376 with the robotic arm. And then two dancers performed together with the robotic arm following the choreographed duet
 377 performance sequence. This organization ensured that each group had a balance of creative direction and performance
 378 capabilities.
 379

380 These workshops were designed to let the participants think from sides of designing movements, choreographing
 381 movements and improvisation based on their interactions with the robotic arm.
 382

383 Before the experiment, all participants signed a consent form, which explicitly granted permission for their faces
 384 to be shown in photographs, the use of their data, and for the publication of these images as part of the study. All
 385 procedures followed the ethical guidelines established by our Institutional Review Board (IRB).
 386

387 3.3 Technology Implementation

388 In our series of workshops, the Ufactory xArm 6 robotic arm was central to exploring the intersection of non-humanoid
 389 robotics and dance. The system comprised the robotic arm, Ufactory's control software, a laptop for recording movement
 390 design and the control, and an external speaker for music play. Each session utilized the same non-lyric music, "Mo
 391 Better Blues," to ensure a consistent auditory environment.
 392



408 Fig. 4. System Overview for Robot Control and Movement Recording: The robotic arm is controlled through Ufactory software
 409 connected to a laptop. The system enables movement design and recording by selecting "manual move" and then clicking "recording."
 410 The recorded movement is played back for dancers' improvisational performance, with music played through a connected speaker.
 411

412 The robotic arm was initialized using Ufactory's control software, ensuring it was accurately calibrated and ready
 413 for use. This involved checking all joints and movement axes for proper alignment and functionality, a crucial step to
 414 guarantee the precision required for the workshops. Then, dancers engaged with the robotic arm through the software's
 415 Manuscript submitted to ACM

"manual move" button. This mode allowed them to manipulate the arm physically, creating their movement sequences. Once dancers started their movement designs, the software's "recording" function was activated. This feature captured each movement, ensuring fidelity in playback. The recording process involved capturing the exact trajectory and timing of the movements, which were later used for both solo and group improvisational sessions. During the improvisational dance, multiple recorded sequences were played in a predefined order executed by the robotic arm in synchronization with the music (Fig. 4).

425 3.4 Data Acquisition

426 To systematically collect and analyze data, we implemented several approaches involving video recording, photography,
427 sketch scanning, note-taking, and semi-structured interviews. This data acquisition strategy was designed to capture a
428 wide range of qualitative data to address our RQs thoroughly.

429 A camera was placed on a tripod in front of the setup to capture the interactions between dancers and the robotic
430 arm (Fig.2b). Photographs were taken to document significant moments and details of the experimental setup and
431 participants' interactions. Participants' sketches, which were part of the movement design process, were scanned to
432 preserve the visual data for later analysis. Researchers also maintained detailed notes during each session to record
433 observations and spontaneous insights, providing a rich qualitative layer to complement the visual data.

434 In addition, semi-structured interviews were conducted after each workshop to align closely with the research
435 questions and gain insights into participants' experiences. The interview questions were tailored to the unique focus of
436 each workshop: **Workshop 1:** Questions explored participants' perceptions of their relationship with the robotic arm
437 (e.g., leader/follower roles), how the robotic arm influenced their movement decisions, and their creative interaction
438 process. **Workshop 2:** Questions examined participants' experiences in group improvisation (3-1) compared to solo
439 settings (1-1). Themes included: Perceptions of collaboration dynamics: "What are the major differences between 1-1
440 and 3-1 settings?" Spatial exploration: "When do you explore space more—1-1 or 3-1? Why?" Attention distribution:
441 "During 3-1, which do you pay more attention to, the robotic arm or your partner dancers? Why?" Connection with the
442 robotic arm: "Which case makes you feel more connected to the robotic arm?" Creative inspiration: "Did the robotic arm
443 inspire you during the dance?" These questions provided insights into how group settings influenced spatial dynamics,
444 attentional focus, and dancers' engagement with the robotic arm. **Workshop 3:** Questions centered on movement
445 generation and transformation, focusing on the rationale for selecting specific motifs, adapting choreography for the
446 robotic arm, and comparing human and robotic movement designs.

454 3.5 Data Analysis

455 Interview transcripts were subjected to an initial round of coding by each researcher independently, following the
456 guidelines of thematic analysis[10]. This initial coding phase involved identifying and categorizing significant statements
457 into preliminary codes. Researchers then collaboratively discussed these initial codes to refine and consolidate them into
458 themes. This iterative process of coding and discussion continued until a consensus was reached on the final themes,
459 ensuring the reliability and validity of the analysis. The organization and interpretation of these themes provided
460 insights into the dancers' experiences and perceptions, which are presented in detail in Section 4.

461 Video recordings were systematically coded to capture key moments of interaction, such as the use of space, changes
462 in attention, and movement quality. This analysis focused on identifying patterns in dancers' engagement with the
463 robotic arm, providing a visual context that complemented the thematic analysis of interviews.

469 Sketches created during the workshops were scanned and analyzed to understand participants' conceptualizations
 470 of movement design. These sketches were compared to interview narratives and video observations, highlighting
 471 connections between dancers' intentions and their embodied practices.
 472

473 Photographs, while primarily used for documentation, supplemented the video and sketch analysis by highlighting
 474 specific spatial configurations and notable interactions referenced during interviews.
 475

476 To integrate these diverse data sources, we employed an affinity diagram approach, organizing findings from
 477 interviews, videos, sketches, and photographs into thematic clusters[32][3]. Insights about dancers' attention distribution
 478 during group interactions from interviews were corroborated by video evidence and supported by spatial layouts
 479 depicted in sketches.
 480

481 Participants were asked if they had prior experience dancing with the robotic arm, and all participants reported no
 482 such experience.
 483

484 3.6 Workshop 1: Robotic Rhythms: One Dancer Exploring Dance Movements with One Robotic Arm

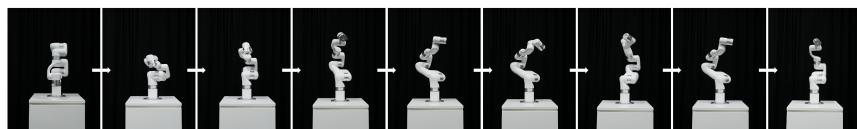
485 Workshop 1 focused on individual interactions between dancers and the robotic arm to explore movement design and
 486 improvisation. It aimed to examine how dancers interact with the robotic arm and adapt to its mechanical movements(see
 487 Fig.3).
 488

489 The workshop 1 was structured as follows:
 490

491 1. Demonstration of robotic arm dance: Participants observed a demonstration of the robotic arm performing a
 492 pre-defined dance sequence called "Born" movements (Fig. 4)[39]. This step provided an example of how the robotic
 493 arm moves in space.
 494

495 2. Movement Design: Each dancer was then tasked with designing three movement sequences. This process involved
 496 two steps: First, drawing sketches of the intended movements for design. Then, manually manipulating the robotic
 497 arm to execute and record the designed movements based on the sketches. Movement design sketches and the robotic
 498 arm movements are shown in Fig.5. To clarify the roles during this process, one dancer played the role of the robot
 499 programmer, designing the movement sequences for the robotic arm. The same dancer then served as the robot
 500 interactor, performing the dance while the robotic arm executed the pre-designed movements. A researcher acted as
 501 the robot executor, recording and playing back the designed movements for the dancer to interact with.
 502

503 Before engaging in the movement design process, the researcher explained that the robotic arm is hard and robust,
 504 emphasizing the importance of maintaining a safe distance during interaction. Through manually programming the
 505 arm's joints, participants became familiar with its movements and could intuitively establish safety precautions between
 506 the robotic arm and their bodies.
 507



508
 509 Fig. 5. Movement Design demonstration vignettes: "Born" movements series in [39].
 510
 511
 512
 513

514 3. Improvisational Dance: After recording the movement designs, each dancer conducted an improvisational dance
 515 interacting with the robotic arm performing the pre-designed movements. These sessions were conducted individually
 516 to capture unique interaction styles.
 517

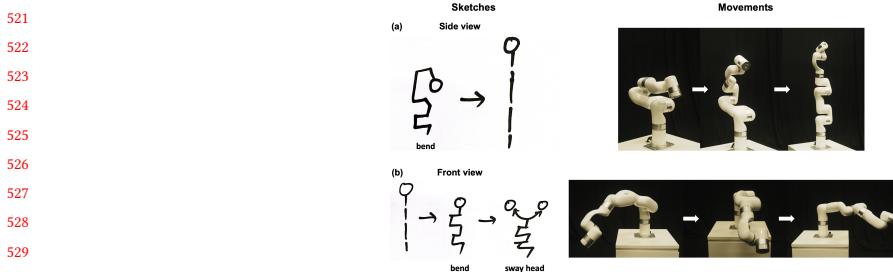


Fig. 6. Sketches and Programmed Movement Designs: Left: Movement designs created by professional dancers. Right: Recorded robot movements based on dancers' designs.

4. Post-Dance Interviews: Following the session, dancers participated in 20-40 minute semi-structured interviews to share their experiences and insights.

3.7 Workshop 2: Mechanical Motifs: Multiple Dancers Creating Dance Concepts with One Robotic Arm

The same nine professional dancers who participated in Workshop 1 were invited to participate in Workshop 2 (see Fig.3). Workshop 2 was structured to facilitate collaborative creation and interaction between multiple dancers and the robotic arm, following a similar engagement approach as outlined in the referenced study[30].

1. Group Formation and Discussion: The nine dancers were divided into three groups. Each group engaged in a 10-minute discussion to coordinate and select three movement designs from the nine movements generated in Workshop 1. This collaborative process allowed dancers to integrate their ideas and create a cohesive movement sequence.

2. Group Improvisational Dance: Following the group discussion, each group performed an improvisational dance with the robotic arm. This stage of the workshop emphasized collective creativity and coordination, exploring how multiple dancers interact with and respond to the robotic arm's movements and how dancers interact with their human dancer partners. To clarify the roles during this process, one dancer served as the robot programmer, designing the movement sequence for the robotic arm. Another dancer acted as the robot interactor, performing the dance while the robotic arm executed the pre-designed movements. A researcher played the role of the robot executor, recording and playing back the designed movements for the dancers to interact with.

3. Post-Dance Interviews: After the group improvisational dance, participants were asked to explain their perceptions and experiences of dancing with the robotic arm in a group setting. They discussed why they chose specific movements and how they perceived the robotic arm's role in their performance. This discussion was facilitated using the same semi-structured interview technique employed in Workshop 1, ensuring consistency in data collection.

3.8 Workshop 3: Automated Artistry: Generating Dance Movements with Robotic Arms

Workshop 3 aimed to explore the creation and execution of choreographed dance movements involving human dancers and a robotic arm (see Fig.3). This included both solo and duet performances with the non-humanoid robotic arm, providing a comparative perspective on different interaction dynamics.

1. Movement Series Creation: Each choreographer was asked to select three movement designs from the nine generated in Workshop 1. These selected movements were then combined into a new and cohesive movement series.

2. Solo Performance Choreography: The choreographer first created a dance sequence for one dancer to perform with the robotic arm.

⁵⁷³ 3. Duet Performance Choreography: Following the solo performance, the choreographer then developed a duet dance
⁵⁷⁴ sequence involving two dancers and the robotic arm. To clarify the roles during this process, one dancer served as the
⁵⁷⁵ robot programmer, designing the movement sequence for the robotic arm. Another dancer was the robot interactor,
⁵⁷⁶ performing the movements while the robotic arm executed the pre-designed sequences. A researcher played the role of
⁵⁷⁷ the robot executor, recording and playing back the choreographed movements for the dancers to perform with.
⁵⁷⁸

⁵⁷⁹ 4. Post-Dance Interviews: After completing both the solo and duet performances, the choreographer and dancers
⁵⁸⁰ participated in a semi-structured group interview. They were asked to discuss their perceptions and experiences
⁵⁸¹ of dancing with the robotic arm in a choreographed setting compared to the improvisational settings explored in
⁵⁸² Workshops 1 and 2. The interview focused on understanding how the role of the robotic arm was perceived in the
⁵⁸³ context of structured choreography and how this influenced their creative process and performance dynamics.
⁵⁸⁴

⁵⁸⁵ 4 RESULTS

⁵⁸⁶ We explored the impact of varying numbers of dancer partners, delved into their perspectives on the role the robotic
⁵⁸⁷ arm plays, how the dancers distributed their attention, spatial interactions and explorations, and highlighted distinctive
⁵⁸⁸ attributes that set the robotic arm apart from human partners. In addition to individual and group dance, we explored
⁵⁸⁹ how the non-humanoid robotic arm influenced the choreographer's movement generation and the dancer's perceptions
⁵⁹⁰ in choreographed vs. improvisational dance. Qualitative insights are detailed in this section.
⁵⁹¹

⁵⁹² 4.1 Spatial Kinematics and Interactive Dynamics with Robotic Arm

⁵⁹³ The study explores how a non-humanoid robot affects dancers' creativity (**RQ1**) and choreographic group collaboration
⁵⁹⁴ (**RQ2**). Observations showed that solo dancers led the robotic arm in continuous movements, while group sessions
⁵⁹⁵ involved discontinuous movements. Dancers felt free and predictable in solo sessions but experienced spatial constraints
⁵⁹⁶ and spontaneity in group settings. Across all workshops, spatial awareness and exploration, navigation hazards, visual
⁵⁹⁷ balance, and stage utilization were key considerations.
⁵⁹⁸

⁵⁹⁹ *4.1.1 Distinct Movement Improvisations in Individual vs. Group Human-led Performance.* The dynamics of leading
⁶⁰⁰ and following between dancers and the robotic arm and among human dancers revealed distinct patterns during the
⁶⁰¹ improvisational dance sessions. In individual improvisation with the robotic arm, dancers experienced a clear sense of
⁶⁰² control and leadership over the robotic arm's movements. When asked about the lead or following relationship between
⁶⁰³ the robotic arm and dancers, P5 described this as "a toy, an object" with "higher intimacy" in the one-on-one setting. P3
⁶⁰⁴ supported this by stating, "Lead, because I need to interact with the robotic arm, and I need to do the performance
⁶⁰⁵ with it and consider the visual effects." This sense of manipulation allowed dancers to feel as if they were leading the
⁶⁰⁶ interaction, designing and controlling the arm's movements. In contrast, group improvisation (3–1) involved more
⁶⁰⁷ complex dynamics. Dancers needed to navigate their interactions with both the robotic arm and their human partners.
⁶⁰⁸ This setting required a balance between leading and following, as dancers adjusted to the inputs from multiple sources.
⁶⁰⁹ P2 explained, "I have more attention on the humans...P1 gives us hints." The robotic arm's presence became less central,
⁶¹⁰ and dancers often found themselves following the cues and movements of their human partners rather than leading the
⁶¹¹ robotic arm.
⁶¹²

⁶¹³ The individual improvisational sessions with the robotic arm were characterized by continuous and fluid movements
⁶¹⁴ (Fig.7). Dancers focus solely on the robotic arm. The continuous engagement allowed dancers to delve deeper into the
⁶¹⁵ improvisation, fostering a strong connection with the robotic arm. P5 noted the coherent connection of the session:
⁶¹⁶

⁶¹⁷ Manuscript submitted to ACM
⁶¹⁸



Fig. 7. Examples of dancers' solo improvisational dance. a. P3, b. P5, c. P7 conducted continuous and intimate individual improvisational dance with the robotic arm.

"When I did 1-1, I had to do a lot of intimacy and stay with the robot." While in group improvisation, the dynamic shifted to more discontinuous movements, as shown in Fig.8. P5 stated, "3-1 is interacting with space and each other, but 1-1 somehow, I want to try to strip out, but I still need to draw back to the robot because it just fits into space in the centre. But with the human, I was able to step out to look at these two ladies dancing, then I joined, and then I took out and walked around." The necessity to interact with multiple dancers introduced interruptions and variations in the flow. P5 highlighted this by saying, "With more people in the space, I do that option around. I stop and restart." "When I feel something happening, probably, I see more people behind me and then they're moving forward, I stop, and then I leave the space." This discontinuity reflected the need to constantly adapt to the changing inputs and actions of the group, contrasting the more predictable and steady interaction with the robotic arm in individual sessions.

Human-robot connection emerged as a significant theme in the dancers' interactions with the robotic arm and human partners. In the individual improvisation, dancers reported a higher level of connection with the robotic arm. P5 described the one-on-one sessions as "more intimate," where the focus was on a direct and personal connection with the robot by noting, "When I did 1-1, our attention is directly on the robot. The robot's movements are designed by us, so we clearly know the structure, the timing, and the movements, so we are very intimate, and the relationship is more intimate." The dancers' constant and exclusive interaction with the robotic arm made it easier for them to develop a deeper connection with it. However, in group improvisation, the sense of intimate connection was diluted. The presence of multiple human partners shifted the focus away from the robotic arm, reducing the direct and personal connection. P5 observed, "3-1 is more variation and the level thing. When I did 1-1, I had to do a lot of intimacy stay with the robot." The group's dynamics introduced a broader range of interactions, making the relationship with the robotic arm with fewer connections.

This finding highlights the distinct experiences in individual versus group improvisational settings. In individual sessions, dancers led the robotic arm, engaging in continuous movements and intimate connections, viewing it as a manipulable object for precise control. In group sessions, the dynamics shifted to following both the robotic arm and human partners, resulting in discontinuous movements and a less intimate connection with the robotic arm. The



Fig. 8. Discontinuous and non-intimacy in group improvisational dance. P5 is doing "In and Out" when doing group improvisational dance with the robotic arm and human dancers.

varying dynamics of leading, following, continuity and human-robot connection between varied settings offer valuable insights into human-robot collaboration.

4.1.2 Transition From Constructed Design Responses to Improvisational Movements. In Workshop 1, dancers were asked to do the movement design for the robotic arm, and then improvise with it. Dancers reflected on their transition from responding to designed movement sequences initially to improvisational expressions later on.

Participants generally did not perceive their interaction with the robotic arm as traditional communication, primarily because they were responsible for designing the robot's movements. This established a predictable structure that differed from human partnerships' dynamics and communication. P1 illustrated this by saying, "I reacted to it by moving my own body to it... I was just moving my positions in the whole area like on the dance floor to interact with it." This quote highlights how the improvisation was about spatial positioning rather than an ongoing dialogue, illustrating communication is design-based, not interactive. Transitioning from this initial design-based approach, the robotic arm's predictable movements provided a framework that allowed for both structured and much more spontaneous interactions. P5 noted, "So, every time you repeat it, it's going to be the same. So, it gives me a very solid structure and then after that, I can have more freedom to dance." This structured framework offered dancers a foundation on which to base their improvisational movements, creating a balance between predictability and creativity.

A key theme was the shift from structured responses to improvisational movements. Initially, dancers engaged with the robotic arm's pre-designed motions, using them as a foundation for creativity. P4 noted, "When I dance with the robotic arms, the intention will be how I respond to my previous choreographed design. So, it is not purely improvisation." This reflects the premeditated nature of early interactions. However, as the process unfolded, dancers increasingly embraced improvisation. P1 described this progression: "At first, I wasn't improvising much because the movements were my design. But as it progressed, I did more improvisational things." The robotic arm's predictable movements provided a structured framework that supported spontaneous exploration. Participants adapted to the arm's cues, integrating spatial awareness and dynamic positioning into their responses. P1 highlighted this integration: "I considered vertical and horizontal positions, repositioning myself to interact with the space dynamically." This interplay between control, reaction, and creativity enriched the dance experience, fostering a balance between structure and expression.

4.1.3 Freedom of Movements in Individual Improvisation vs. Spatial Constraints in Group Improvisation. Workshop 1 and Workshop 2 revealed notable differences between individual and group improvisational dance, especially in spatial dynamics and the contrasting predictability of robotic movements versus the adaptability of human dancers.

During individual improvisation, dancers found the robotic arm's predictable movements provided a stable framework for creative exploration. P5 remarked, "Every time you repeat, it's going to be the same... It gives me a solid foundation and

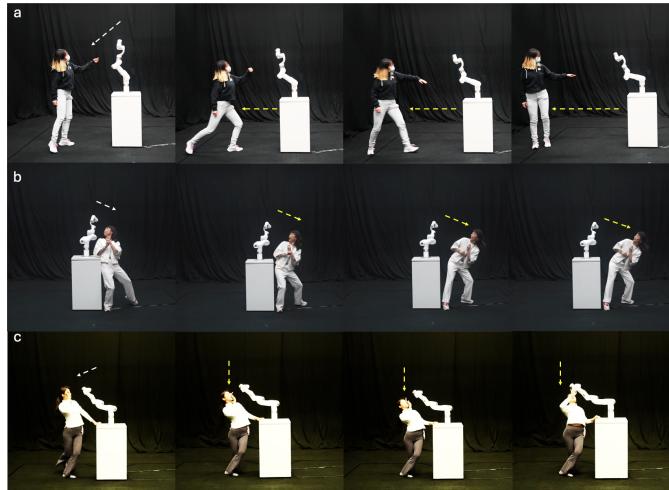


Fig. 9. Different dance movement strategies for navigating potential hazards introduced by the robot arm. (a) P3 gets away from the robotic arm to avoid collisions. (b) P4 moves her upper body to avoid being hit when the robotic arm gets lower. (c) P9 lowers her body to avoid hazards in the robotic arm.

freedom to improvise." This predictability enabled dancers to experiment with spatial configurations and choreographic possibilities without unexpected disruptions.

In group improvisation (3-1), the presence of human partners introduced spatial constraints and the need for heightened awareness of others' movements. P4 noted, "For humans, even if choreographed, reactions will vary because precision is less computationally determined." The unpredictability of human dancers required spontaneous adaptation, making interactions more dynamic yet challenging. P4 further observed, "In 3-1, we explore more. The robot is restricted, but humans can go up, down, and stretch the space."

Communication also differed significantly. Interactions with the robot were pre-set and design-driven, as P3 explained: "It's not communication. It's just we told it what to do." Conversely, human partners necessitated verbal and non-verbal coordination, offering greater spontaneity and creative dialogue. While some participants (P2, P3 and P4) appreciated the freedom and control of solo dances, others preferred group settings for their richness in expression and interaction. These differences underscore the distinct opportunities and challenges of human-robot collaboration in individual and group improvisation.

4.1.4 Spatial Awareness and Navigation Behavior Around Hazards Involving Robot. Integrating robotic arms into dance required participants to balance creative expression with safety considerations. In the 1-1 setup, dancers demonstrated heightened spatial awareness of the robotic arm's limitations and risks. P6 noted, "The robot doesn't move in two directions... I have to create something that considers that because the robot can hit me; it will not stop."

In the 3-1 configuration, this awareness expanded to include both the robotic arm and fellow dancers. P1 explained, "I was aware the robot wasn't hitting me and where my other partners were." This awareness influenced choreographic choices, ensuring safe and fluid interactions (Fig.9).

Overall, the workshops underscored the need for spatial cognition to navigate hazards and maintain a balance between artistic exploration and safety.

⁷⁸¹ *4.1.5 Perspective Taking in Performing for the Stage.* In the exploration of integrating robotic arms into dance performances, participants' insights shed light on the dynamics of visual balance and stage utilization across workshops. Their reflections provide an understanding of the interplay between choreographic aesthetics, audience perception, and the incorporation of robotic technology within dance performance.

⁷⁸⁶ In the 3-1 workshop, participants emphasized visual balance and stage utilization, considering audience perspectives ⁷⁸⁷ and camera angles to optimize the performance's impact. P1 explained, "I considered how the performance looks to the ⁷⁸⁸ audience, especially in group dances where the entire stage and camera angles are important." Participants also explored ⁷⁸⁹ the robotic arm's aesthetic qualities, such as fluidity and precision, integrating these elements into their choreographic ⁷⁹⁰ decisions and artistic vision.

⁷⁹³ **4.2 Perception and Presence of the Robotic Arm**



⁸¹¹ Fig. 10. Screenshots of a. P4, P5 and P6 individual dance with the robotic arm. b. When doing group improvisational dance with the ⁸¹² robotic arm, dancers put the robotic arm as the background and mostly interacted with the human dancers.

⁸¹⁹ ⁸²⁰ *4.2.1 Perceiving Robot as the Background Element in Group Dance.* The integration of a robotic arm in group dance ⁸²¹ settings significantly influenced dancers' perceptions and interactions. In 3-1 configurations, the robot often shifted to ⁸²² a background element, allowing dancers to focus on human partners. P4 noted, "In 3-1, I completely ignore the robot, ⁸²³ just interact with humans, and then the robot becomes my background." This marked a shift from the robot's central ⁸²⁴ role in 1-1 dances to a peripheral presence in group settings (Fig. 10).

⁸²⁵ Despite this, dancers sought to reintegrate the robotic arm into the performance, ensuring it remained part of the ⁸²⁶ choreography. As P4 explained, "When the interactions of humans came to an end, we tried to come back to the robot, ⁸²⁷ try to respond, not left it behind." This dynamic highlights the evolving interplay between human and machine, blending ⁸²⁸ innovation with artistic expression.

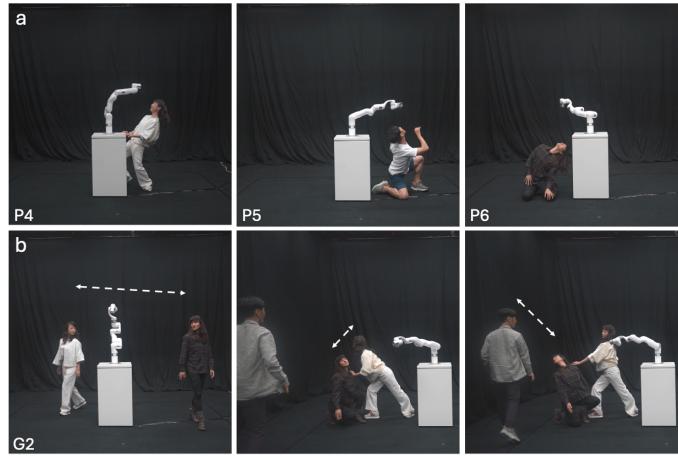


Fig. 11. Screenshots showing attention allocation in individual vs. group improvisational dance. a. Dancers put their attention on the robotic arm mostly when individual dance. Figure a shows the examples from dancers P4, P5 and P6. In group improvisational dance, dancers put more attention on the human dancers than the robotic arm.

4.2.2 Attention Allocation in Individual vs. Group Improvisation: More Elements to Divide Dancer Attention. Moving from the individual (1-1) to group (3-1) improvisational sessions with the robotic arm shifts distinctly in where dancers direct their attention, alongside perceptions of the robotic arm and creativity. During individual sessions, dancers engage in a singular interaction with the robotic arm, regarding it as a central element in their performances.

When transitioning to group improvisational sessions (3-1), dancers encounter heightened complexity in distributing their attention, with various elements for cognition. P6's reflection on the dynamics of attention during group improvisation, states, "More elements to divide the attention. We can have an influence on others and at the same time influenced by others. The robot has a fixed choreography, but human movements are not fixed, the way we looked each other, and we touch, we can influence and be influenced. The element of not knowing but also being able to shift the way of awareness and energy. The way the Energy is projected towards others can have influence, but project to the robot nothing will change." This dispersion of attention is exemplified by P5's reflection, emphasizing the need to allocate energy and relational dynamics between human partners and the robotic arm.

Additionally, dancers draw creative inspiration from the gestural vocabulary of the robotic arm, incorporating its articulations and postures into their choreographic dance. This artistic process is informed by their cognitive interpretation of the robotic arm's architecture and operation, with the trunk area serving as a hub of kinetic innovation and choreographic materials(P4, P6). This view finds resonance in their focused attention on the trunk or core area of the robotic arm, seen as a hub of kinetic vitality and choreographic integration. P4 elaborates on this idea, detailing their attentive focus on the middle and lower segments of the robotic arm, symbolizing their perception of it as an anchor for movement generation. Similarly, P6 metaphorically draws parallels between the robotic arm and her head, highlighting its "eye" as the source of motion. Despite technical constraints and safety considerations, dancers adeptly utilize the expressive potential of the robotic arm's gestures, using them as cues for choreographic innovation (P6). During group setting, the perceptual significance of the robotic arm's trunk or core area persists as a main point for movement inspiration.

Comparing individual (1-1) and group (3-1) improvisational contexts, dancers navigate an interplay of attention dynamics and creative ingenuity. While individual sessions allow for undivided focus on the robotic arm and its gestures, group sessions introduce additional elements that claim a reallocation of cognition. Nonetheless, the perceptual centrality of the robotic arm's trunk or core area persists as a cornerstone of dancers' interaction and artistic expression across both contexts, revealing its pivotal role in choreographic exploration and improvisational interaction. This dynamic illustrates how improvisation in group contexts facilitates a balance between individual expression and collective collaboration. Participants emphasized that while solo interactions with the robot deepened their personal connection and self-expression, group settings prompted shared creative decisions and a heightened sense of group identity through collaborative choreography.

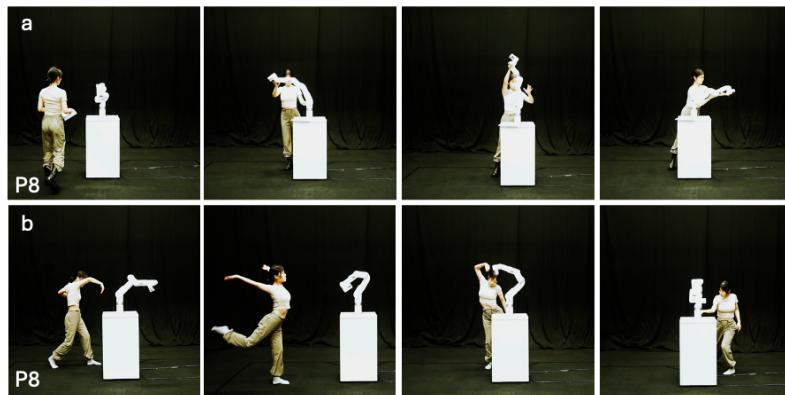


Fig. 12. Relationship between dancer and the robotic arm changed from movement design to improvisational dance. Dancers perceived the robotic arm as a tool when doing movement design, while perceived the robotic arm as a partner when doing improvisational dancing. a. P8 did movement design for the robotic arm by manually moving the joints of the robotic arm and perceived it as a tool. b. P8 did individual improvisational dance with the robotic arm and saw it as a dance partner.

4.2.3 Context-specific Perception of Robot as Tool vs. Partner. The dynamic role of the robotic arm in the dancers' perception evolved significantly across different contexts of interaction. Initially regarded as a tool during the choreographic design phase, the robotic arm transformed into a perceived dance partner during the improvisational dance session. Additionally, comparing human and robotic partners reveals distinct differences in adaptability, predictability, and creative interaction. In Workshop 1, during the movement design, the robotic arm was predominantly perceived as a tool by the dancers. P4 stated, "Not much feeling. Because the robotic arm is manipulated by me. So, it's still an object in a way." The robotic arm was largely viewed as an extension of the dancers' creative intent, manipulated to explore choreographic possibilities. Dancers projected contextual roles onto the robotic arm, as noted by P4, "Even though I tried to put in a character so if I want to be playful, then I become playful. If I want to be sad or emotional, then I become emotional. So that's how humans put in the emotional context on the robotic arm." Despite being perceived as a tool, the robotic arm became a medium for expression. For example, P6 perceived it as her finance, and P5 perceived the robotic arm as his student.

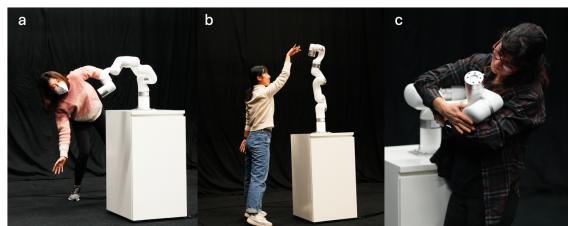
During improvisational dance sessions, the robotic arm was perceived more as a dance partner. P2 described, "When I danced with it, at some point I felt it was like a real dancer, but the robot should not be so sudden, unlike a human." This indicates a shift in perception, with the robotic arm being seen as capable of mimicking a dance partner's presence.

937 However, the perception varied among dancers. P4 mentioned, "When I am dancing, I do perceive it as a partner.
 938 Otherwise, I perceived it as a prop." The transition from tool to partner depended on the interaction context. P5's
 939 reflections highlighted this shifting role: "When I designed the movements, I used it as a prop, as a toy. But when
 940 dancing, it felt more like a partner...."
 941

942 In Workshop 2, the robotic arm was predominantly perceived as a tool, especially in a group setting. P4 stated, "More
 943 humans to care about. It suddenly changed the relationships with the robot... 3-1, I completely ignore the robot just
 944 interact with humans and then the robot becomes my background." The social dynamics of the group altered the robotic
 945 arm's role, making it part of the stage setup. P5 also noted, "It is more like a set. As a prop to us. And we need to be part
 946 of it." Here, the robotic arm was perceived more as part of the stage than an active partner.
 947

948 The perception of human dance partners contrasted with that of the robotic arm. Human partners were seen as
 949 more responsive and adaptable. P1 stated, "Dancing with a human dancer, you will learn the movement from him/her. I
 950 did not have to tell what movement of him/her, just dance." This spontaneity and mutual learning were not present
 951 with the robotic arm, which was more predictable and controlled. In addition, P2 found dancing with robots more
 952 stimulating due to the heightened alertness required: "I think compared to dancing with humans, dancing with the
 953 robot is more exciting, because it's a kind of except for, they may hurt you. So this kind of makes your nerves try to
 954 keep an alarm. So I can feel even like after 20 seconds, my heartbeat is still faster." And P4 mentioned, "The difference
 955 will be because this robotic arm movement is designed by me. I know exactly how I design it. So, when I dance with the
 956 robotic arms, I am responding to my previous designs. Now, if I danced with a live person, sometimes very subtly, hit
 957 the movement change. I will react in a slightly different way so it's less predictable. So the robotic arm is much more
 958 predictable because they're completely designed by me so I know exactly when the movement will be." Moreover, P6
 959 added, "Well, if I'm dancing with a person that is a professional dancer or something I will know this person is trained
 960 to be more aware of another person and not to injure. Because we're not fighting, we are dancing or something. But it
 961 depends, if I'm dancing with a child or with a person has a different notion of space and time or ability. So, this person
 962 also I need to also have a different awareness myself. So, the robot I mean, initially, it is it is something that will make
 963 me aware that it will not be aware of me, and it will not do anything to not hurt me. But if I stayed long enough, and I
 964 knew exactly what it was going to do, I could then play with that."
 965

966 The perception of the robotic arm evolved throughout the workshops, from being viewed as a tool during movement
 967 design to being seen as a dance partner during improvisational sessions, and back to a tool in group settings. This
 968 evolution reflects the dynamic nature of collaboration dance with robot, highlighting both the potential and limitations
 969 of robotic arm in performance practices.
 970



971 Fig. 13. Examples of that dancers desire for more human-like interaction with the robotic arm. a. P1: Eye contact. b. P2: Touch. c. P6:
 972 Hug.
 973

989 4.2.4 *Dancer Desire for More Human-like Interactions with The Robotic Arm.* Several participants expressed a desire for
 990 human-like qualities in the robotic arm, such as greater responsiveness and adaptability, to better mirror the dynamics
 991 of human-human collaboration. Dancers consistently expressed a desire for more human-like interactions with the
 992 robotic arm, envisioning it as a versatile, anthropomorphic partner. P1 remarked, "I was expecting the robot to be more
 993 interactive...not stationary, but with four limbs, a body, and a head." Similarly, P3 anticipated movements that mimicked
 994 human behavior: "I expected [it to] behave like the arm of a human." This preference reflects dancers' familiarity
 995 with partnering and improvisation in traditional performance contexts and suggests a potential design direction for
 996 enhancing engagement and co-creation in human-robot collaboration. These expectations highlight dancers' longing
 997 for greater mobility, tactile interaction, and a humanoid form. (Fig.13)

1000 Despite engaging with the robotic arm through movement design and improvisation, the desire for human-like
 1001 qualities persisted. P2 compared the robot to a "perfect student," appreciating its precision but noting its limitations
 1002 compared to human partners: "When I dance with a human, there's connection...the robot does not have that." Dancers
 1003 also observed the robot's lack of fluidity and responsiveness. P3 noted its "sense of pause," and P5 described its limited
 1004 range of movement: "With humans, I can do many more possibilities...this one is with limitations."

1005 Participants often personified the robot as a snake, child, or dancer, reflecting their tendency to attribute human
 1006 characteristics to it. This personification influenced their creative processes, allowing them to build compelling narratives
 1007 and thematic depth in their performances.

1008 Overall, dancers' feedback underscores the importance of designing robotic arms that better simulate human
 1009 interaction, enhancing both functionality and creative engagement.

1010 4.2.5 *Absence of Human-like Features and Physical Connection: Limitations in Feedback.* Dancers highlighted the lack
 1011 of human-like features and physical connection in the robotic arm, which hindered their ability to form inspiration or
 1012 collaboration. P1 noted, "Cannot inspire each other to do the movements like a human dancer," while P2 described it as
 1013 a dancer that "can follow the rhythm...but [is] sudden, unlike a human." Without mutual inspiration or adaptability,
 1014 dancers felt they were directing rather than collaborating with the robot. P1 added, "I'm deciding what the (robot)
 1015 partner is going to move," underscoring the absence of dynamic interaction.

1016 The robotic arm's limited physical capabilities further constrained dancers. Unlike human partners who can twist,
 1017 fold, and move fluidly through space, the robot's motions were static and restricted. P5 observed, "With humans, I can
 1018 do much more...this one (the robot) is with limitations," while P6 emphasized the lack of resilience, noting, "Robot won't
 1019 stop or fall, unlike human dancers."

1020 Additionally, the robot's lack of real-time feedback posed challenges. P3 remarked, "The flexibility and speed of the
 1021 robot are limited," and the need for programming contrasted sharply with the natural, adaptive responses of human
 1022 partners.

1023 Despite these limitations, some participants appreciated the exploratory nature of interacting with the robot. P4
 1024 stated, "We're trying to understand each other, trying to explore the possibilities." While the absence of human-like
 1025 features and feedback posed challenges, the process still fostered creative exploration, hinting at potential for future
 1026 improvements.

1027 4.3 Exploring Choreographer-Robotic Arm Collaboration

1028 4.3.1 *The Robotic Arm as a Connection Point Between Two Dancers.* Robotic arms serve as central elements that
 1029 connect dancers in group choreography, providing focal points for interaction and coordination, which enhances spatial
 1030 Manuscript submitted to ACM



Fig. 14. Examples of the robotic arm as a connection point between two dancers when choreography. In group 2 two dancers were choreographed to use the robotic arm as the medium for dancing.

arrangement and visual balance on stage. One choreographer noted, "The value of the robotic arm lies in giving the two dancers something in common" (G3).

In addition, choreographers perceive connections and interactions between dancers and robotic arms as shown in Fig 14, regardless of whether the performance involves one or multiple dancers. As one choreographer expressed, "So yeah, so either one or two people come in, there are a lot of connections, interactions and relationships there" (G2). This common understanding of robotic arm choreography reflects choreographers leveraging technology to facilitate interplay between artistic expression and technological mediation within dance practices (Fig.14).

The robotic arm unified dancers, enhancing spatial and visual coherence in choreography. Its integration balanced attention between human and technological elements, vital for artistic expression. Choreographers skillfully leveraged the arm to foster connections and maximize its potential in solo and dual-dancer scenarios.

4.3.2 Choreographing for Human vs Robot Dancers. Choreographers noted key differences in working with human dancers versus the robotic arm. Human choreography focuses on themes and relationships, while robotic choreography prioritizes form and imitation. This distinction is crucial for integrating technology into dance. One participant stated, "The difference is that I feel that in the past, choreography for people always had a theme and a fixed form" (G3). Choreographers act as mediators between human dancers and technological elements, balancing artistic vision with technical functionality, and navigating a shift towards a technologically mediated choreographic aesthetic.

The theme setting creates a narrative or emotional context, guiding expressive exploration. Conversely, form setting emphasizes technical and spatial organization. As noted, "In the previous workshop 2, it was theme setting, but now we are setting the form" (G3). This shift determines the creative direction, focusing either on narrative depth or technical precision.

Choreographers face challenges in communicating with robotic arms, requiring physical force for manipulation. One choreographer explained, "When communicating with the robot, [you] need some force to achieve the movements" (G2). This claims to recalibrate traditional choreographic communication.

The transition from theme to form setting marked a significant shift. "In Workshop 2, it was theme setting. Now we are setting the form" (G3). This impacted movement space and scheduling, making Workshop 3 more limiting. "The details are set, and it's more limiting" (G3). This highlights how choreographic approaches influence spatial dynamics and creative freedom.

Some choreographers used similar techniques for robotic arms as for human dancers. "I used similar choreography techniques for the robotic arm as I did for human dancers, emphasizing motif inspiration" (G1). This adaptability emphasizes the challenges and possibilities of integrating robotic arms into dance. In summary, Workshop 3 illuminated the distinct and evolving considerations in choreographing for robotic arms versus human dancers. The transition from thematic to formal choreography marked a significant shift in creative approach and relational dynamics.

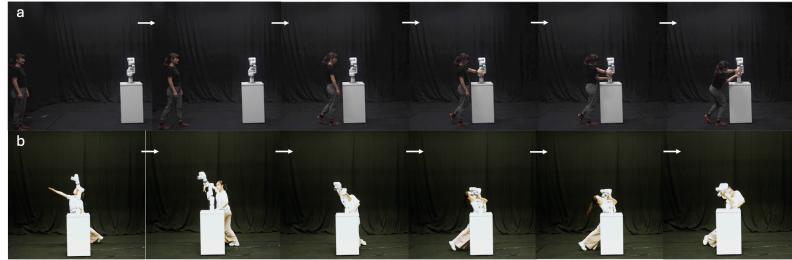


Fig. 15. Different levels of emotion-based engagement during performance as directed by the choreographer. a. P6 was asked by the choreographer to approach the robotic arm slowly, and then touch it gently as her fiance. b. P7 was choreographed to hug the robotic arm as her dancer partner.

4.3.3 Emotional Engagement and Spatial Arrangement Compared to Improvisation. In Workshop 3, choreographed dances fostered greater emotional engagement than the improvisational dances of Workshops 1 and 2. The structured choreography enabled dancers to fully express emotions, as one participant noted, "Choreography is more involved in emotion, and this action can better reflect the emotion" (G3). Additionally, choreographed movement patterns and spatial arrangements significantly shaped interactions between dancers and the robotic arm, enhancing the flow and coherence of the performance. A participant remarked, "The influence is our movement space and scheduling space designed by the director" (G3).

Choreographers emphasized spatial arrangement and visual balance when integrating robotic arms, creating compelling compositions. Compared to improvisation, choreographing demanded more attention to spatial balance. One choreographer stated, "I will try to balance it as much as possible, according to the visual effect of balancing" (G3). This careful positioning enhanced aesthetic coherence and emotional impact. Another participant added, "Consider a transformation of its position to increase the overall performance effect, balance, and aesthetics" (G3).

Workshop 3 underscored the critical role of emotional expression and spatial arrangement in choreographed dances with robotic arms. The structured choreography allowed for deeper emotional immersion, while thoughtful design of movement and space ensured a harmonious and impactful performance. This highlights the importance of choreographic strategy in maximizing the potential of robotic arms in dance.

5 DISCUSSION

5.1 Integrating Robotic Arm into Embodied Practice and Somatic Awareness

Integrating robotic arms into dance practice fosters a unique interplay between technology and embodied performance, offering new avenues for choreographic exploration and somatic awareness. Introducing robotic arms into dance challenges the traditional boundaries between humans and machines, creating a hybrid form that necessitates new choreographic approaches. This integration is not merely about adding a technological component but involves rethinking the principles of dance itself. Previous work highlights the importance of designing interactive systems that are sensitive to the nuances of human movement, fostering a seamless blend between human dancers and robotic elements[48][49][47]. Similarly, the study by Carlson et al.[15] stresses the significance of embodied interaction in developing intuitive interfaces that enhance the performer's experience. Our findings resonate with these perspectives, demonstrating that effective integration requires choreographers to engage deeply with both the technological capabilities and the somatic experiences of dancers. In contrast to Riviere et al.[48][49], which focus on movement

1145 decomposition and interactive tools such as Knotation, our study distinctly investigates how non-humanoid robotic
1146 arms influence dancers' navigation of their somatic awareness. Unlike their emphasis on analyzing human movements
1147 for creative collaboration, we examine the adaptation process necessitated by the robot's mechanical and non-humanoid
1148 movements, which transform spatial and somatic practices. Furthermore, our findings show how workflows with
1149 non-humanoid robotic arms can inform creative tool design across domains. The iterative programming and physical
1150 manipulation motivate users to collaborate with interactive systems rather than just operate them [21]. Workshops'
1151 structured interaction between human dancers and robotic arms shows how such workflows can promote collaborative
1152 problem-solving and embodied learning in education, therapy, and other creative fields. Iterative design processes in
1153 choreography could be used to teach spatial reasoning or teamwork in team-based training. The findings suggest that
1154 robotic arms can spark new ways of working and innovation across diverse professional practices by emphasizing
1155 adaptive co-creation. Additionally, the spatial exploration and adaptability strategies identified in solo versus group
1156 settings could inform animation workflows in game design[60][4], where teams collaboratively iterate on character
1157 movements in virtual environments. Similarly, iterative programming through demonstration, as employed in our
1158 movement design phases, could be adapted to collaborative prototyping in product design, enabling end-user creativity
1159 to shape technological behaviors. These insights demonstrate the potential for robotic systems to support not only
1160 artistic endeavors but also interdisciplinary applications that benefit from dynamic human-technology collaboration.
1161

1162 While earlier research has emphasized the role of inanimate objects as material extensions in dance[5], our study
1163 extends this discourse to non-humanoid robotic arms as dynamic collaborators. Unlike static objects, robotic arms
1164 bring mechanical precision and programmable adaptability to the performance space, creating new possibilities for
1165 choreographic interaction. This highlights the unique somatic and cognitive adjustments required when dancers engage
1166 with programmable, inanimate partners

1167 The shift from human-centric to robotic choreography brings a focus on form and precision, diverging from the
1168 thematic and relational nature of traditional dance. Our workshops revealed that choreographers had to navigate these
1169 formal constraints, adapting their methods to accommodate the robotic arm's limitations. These findings emphasize
1170 that solo improvisation with the robotic arm fosters deep personal engagement and self-expression, as dancers explore
1171 their own creative boundaries in response to the robot's movements. In contrast, group interactions balance individual
1172 contributions with collective expression, highlighting how group choreography enables dancers to co-create a shared
1173 narrative while maintaining their personal artistic identity. This contrasts with previous emphasis on flexibility and
1174 negotiation in technology design for dance, highlighting the need for adaptable choreographic strategies that can fluidly
1175 integrate technological elements without compromising artistic intent[58]. Carlson et al. also emphasize the iterative
1176 design process in creating interactive systems that support the dancer's creative expression[15]. These approaches
1177 show the necessity for choreographers to develop hybrid methodologies that balance the technical demands of robotic
1178 choreography with the expressive richness of human dance. Furthermore, our research underscores the variation
1179 in dancers' somatic awareness as they transition between improvisational and choreographed environments while
1180 engaging with non-humanoid robots. This complements Mackay et al.[47], which emphasizes the utilization of tools
1181 such as Knotation for depicting choreographic structures, by demonstrating the evolution of somatic awareness during
1182 real-time, embodied interactions with robotic arms.

1183 In addition, familiarity with robotic movements emerged as a key factor in enhancing dancers' somatic awareness
1184 and interaction quality. In our study, dancers who were more familiar with the robotic arm's sequences could focus
1185 on personal expression and interaction, reducing cognitive load and facilitating a more intuitive performance. This
1186 aligns with Alaoui's findings that decomposing movement sequences into smaller, manageable parts can help dancers
1187

¹¹⁹⁷ internalize complex phrases, thereby enhancing somatic engagement[48][49]. Carlson et al.'s work further supports this,
¹¹⁹⁸ suggesting that embodied interaction with technology can deepen the dancer's kinesthetic awareness, leading to more
¹¹⁹⁹ fluid and responsive performances. These insights highlight the importance of incorporating pedagogical strategies
¹²⁰⁰ that emphasize familiarity and repetition in robotic choreography.
¹²⁰¹

¹²⁰² Our study suggests that choreographed dances with robotic arms can elicit significant emotional involvement from
¹²⁰³ dancers, provided the choreography balances structure and expressive freedom. Prior research demonstrates that
¹²⁰⁴ structured choreography can serve as a stable foundation for emotional exploration, as seen in her studies on movement
¹²⁰⁵ decomposition and its impact on learning and performance quality[49][47]. Another work also notes that narrative
¹²⁰⁶ and emotional depth in interactive performances are enhanced when the technology supports rather than dictates the
¹²⁰⁷ artistic vision[19]. By designing robotic choreography that allows for both precision and emotional expressiveness,
¹²⁰⁸ choreographers can create compelling narratives that resonate deeply with both performers and audiences.
¹²⁰⁹

¹²¹⁰ Effective integration of robotic arms into dance requires attention to spatial arrangement and visual balance. Our
¹²¹¹ workshops highlighted the importance of strategic positioning to create visually compelling compositions. Alaoui's
¹²¹² research on technology design in dance emphasizes the necessity of considering spatial dynamics to enhance the overall
¹²¹³ aesthetic and narrative coherence of performance and emphasize the role of spatial awareness in interactive systems,
¹²¹⁴ advocating for designs that facilitate a harmonious blend of human and robotic elements [58]. Similarly, This involves a
¹²¹⁵ delicate interplay between dancers and robotic components, ensuring that the technological presence enhances rather
¹²¹⁶ than detracts from the performance's visual impact.
¹²¹⁷

¹²¹⁸ **5.2 Rethinking the Relationship and Perception between Dancer and Robotic Arm**

¹²¹⁹ **5.2.1 Comparison: Human and Robotic Arm Dancers.** The robotic arm presents unique challenges and opportunities
¹²²⁰ compared to human dance partners. Participants noted the absence of verbal communication and the need for alternative
¹²²¹ feedback forms, such as visual and haptic cues. It has been emphasised that the importance of non-verbal communication
¹²²² in choreographic movement[55]. The robotic arm's precision and consistency were valued, yet its inability to improvise
¹²²³ and respond organically was a limitation. Future research should focus on enhancing the robot's real-time responsiveness
¹²²⁴ to mimic the adaptability of human partners. Compared to Alaoui et al.[2], which examines creativity facilitated by
¹²²⁵ digital tools, our findings concentrate on real-time, embodied interactions with non-humanoid robots. While their
¹²²⁶ research focuses on visual representation, ours examines physical and somatic adaptations to the robot's mechanical
¹²²⁷ limitations, enhancing understanding of co-creative processes in performance.
¹²²⁸

¹²²⁹ **5.2.2 Emotional Communication in Robotic Arms.** The robotic arm's limited emotional expression capacity is a critical
¹²³⁰ improvement area. Participants found the robot's movements mechanical and lacking the subtlety of human emotion.
¹²³¹ The importance of emotional design in creating meaningful interactions with technology has been highlighted[42].
¹²³² Enhancing the robot's ability to convey a broader range of emotions through sophisticated movement algorithms would
¹²³³ improve its role in dance, allowing it to participate more fully in the performance's emotional and narrative aspects.
¹²³⁴ Riviere et al.[49] emphasize the narrative capabilities of digital tools in the creation of dance. Our research expands
¹²³⁵ upon this by examining how the absence of emotional feedback from non-humanoid robots alters choreographers'
¹²³⁶ creative narratives, compelling them to emphasize structure and deliberate designs rather than spontaneous emotional
¹²³⁷ connections.
¹²³⁸

¹²³⁹ **5.2.3 Robotic Arm: Partner or Tool? Lead or Follow? Exploring its Role in Dance Performance.** The dual role of the robotic
¹²⁴⁰ arm as both a partner and a tool was a recurring theme. Some dancers viewed the robot as an extension of their body,
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¹²⁴²
¹²⁴³
¹²⁴⁴

1249 while others saw it as a separate entity. It has been discussed that duality, where technology can function as both an
1250 instrument and a collaborator[57]. This dual perception influences how dancers interact with the robotic arm and
1251 integrate it into their performances. Prior study focused on the exploration of motion and object interaction[54], argue
1252 that inanimate elements in performance serve as either extensions of the body or as external stimuli for creative action.
1253 Similarly, our findings reveal that the robotic arm functions as both a creative partner and a functional tool. Unlike
1254 static objects, its programmable movements provide dancers with a dynamic framework, bridging the gap between
1255 interactive materiality and performative agency. Our findings highlight how dancers adapt to the robotic arm as a dual
1256 agent compared with prior work[47]. This involves not only its tool-like predictability but also its integration as a
1257 co-performer with its own mechanical idiosyncrasies.
1258

1259 The dynamic of leading and following in dance with a robotic partner presents unique challenges. Participants
1260 desired more fluid and responsive interactions where the robot could adapt to their movements in real-time. Virtual
1261 reality applications that adapt seamlessly to user inputs could inform the development of more responsive robotic
1262 dance systems[29]. Developing a robotic arm that can respond dynamically and adapt to the dancer's movements could
1263 enhance the collaborative aspect of the dance, allowing for more spontaneous and organic performances.
1264

1265 The integration of robotic arms into dance opens new avenues for narrative and storytelling. Participants highlighted
1266 the potential for robots to embody characters or abstract concepts, adding complexity to the performance. The potential
1267 of integrating virtual elements into physical performances has been stressed to enhance storytelling[8]. Incorporating
1268 robots into dance allows artists to explore new narrative structures and create performances that blend human and
1269 robotic elements innovatively.
1270

1271 **5.3 Dancer Must Adapt Their Movements to The Robotic Arm**

1272 The integration of robotic arms into dance practices requires dancers to adapt to movements that significantly differ
1273 from theirs. This adaptation is a complex process that involves both cognitive and physical adjustments, as well as a
1274 deep engagement with the technological elements. Our findings provide a detailed account of this adaptation process.
1275 One critical aspect of adapting to robotic movements is the necessity for dancers to reinterpret and recontextualize their
1276 understanding of movement. Previous work on capturing movement decomposition supports this idea by emphasizing
1277 the importance of breaking down complex movements into manageable components for teaching and learning in
1278 contemporary dance[48]. This process is equally applicable when dancers interact with robotic arms, as it enables them
1279 to understand and internalize the mechanical and pre-programmed nature of robotic movements. Our findings align
1280 with the emphasis on decomposition[48], as choreographers in our workshops highlighted the need to dissect robotic
1281 movements to better integrate them into human choreography.
1282

1283 Moreover, the study on the role of artifacts in collective dance sheds light on how external elements, such as robotic
1284 arms, can influence dance practices[49]. Carlson et al. argue that artifacts serve as crucial points of reference and
1285 interaction, shaping the spatial and temporal dynamics of performance. This perspective is particularly relevant to
1286 our findings, where robotic arms acted as both partners and props, necessitating that dancers continually adapt their
1287 movements to the robotic elements. The dynamic interplay between human and machine in our workshops echoes
1288 Carlson et al.'s findings, highlighting the importance of artifacts in contemporary dance.
1289

1290 Furthermore, how dancers learn to dance has been explored to emphasize kinaesthetic learning and the importance of
1291 iterative practice[47]. Our workshops revealed that dancers adapted to robotic movements through repeated interaction
1292 and feedback, echoing Rivière et al.'s emphasis on the iterative nature of learning and adaptation in dance.
1293

1301 In summary, adapting to movements that differ from a dancer's own involves incorporating traditional choreographic
1302 principles with innovative strategies tailored to robotic elements. Insights from previous works show the importance
1303 of movement decomposition[48], kinaesthetic learning[47], and the role of artifacts[49] in facilitating collaboration
1304 performance with technology. These concepts are crucial for choreographers and dancers to navigate the challenges of
1305 integrating robotic arms into dance, enriching the creative potential and performative experience of dance.
1306
1307

1308 5.4 Limitations

1309 Integrating robotic arms into dance practice presented several challenges and limitations. The spatial constraints
1310 imposed by the robotic arm's setup significantly influenced the dancers' movements. The fixed position and limited
1311 range of motion of the robotic arm forced dancers to adapt their improvisations to a confined space, which restricted
1312 their ability to perform more dynamic and expansive movements. This limitation required dancers to rethink their
1313 designs and adapt to the robotic arm's mechanical constraints, often leading to simplified and less fluid performances.
1314
1315

1316 The small sample size of nine participants limits the generalizability of this study's findings to the broader dance
1317 community. While our participants were professional dancers, they did not fully represent the diversity of dance forms,
1318 such as cultural dances (e.g., Flamenco or Bharatanatyam) or acrobatic aerial styles (e.g., pole dancing or aerial silks). A
1319 larger and more diverse sample could reveal how different movement vocabularies and traditions affect interactions with
1320 robotic systems. For instance, cultural dancers might adapt uniquely due to their storytelling or prop-based practices,
1321 while ballet dancers' structured techniques could influence their ability to work with non-humanoid designs. Expanding
1322 the participant pool in future research would provide deeper insights into how robotic systems foster creativity and
1323 collaboration across varied artistic and cultural contexts.
1324
1325

1326 Although participants self-reported no prior experience with the robotic arm, some participants may have had
1327 experience dancing with other inanimate objects (e.g., chairs, umbrellas). While these experiences were not explicitly
1328 addressed in the interviews, such prior interactions with non-living objects could have influenced their approach and
1329 perceptions of the robotic arm. This limitation should be considered when interpreting the results, as prior experience
1330 with inanimate objects may have shaped their responses and interactions in ways not fully captured by the study.
1331
1332

1333 Mechanical limitations such as joint resistance and movement speed posed additional challenges. Dancers found it
1334 difficult to synchronize their movements with the music, as the robotic arm could not keep pace with faster tempos or
1335 execute more complex movements smoothly. These mechanical constraints necessitated a careful balance between
1336 the robot's capabilities and the choreographic intentions, often requiring significant adjustments to the original dance
1337 routines.
1338

1339 The static nature of the robotic arm also posed a significant constraint. Unlike human dancers who can move fluidly
1340 across the stage, the robotic arm's fixed position limited the spatial dynamics of the performance. Dancers had to
1341 navigate around the stationary robot, which influenced their movement patterns and limited their ability to engage in
1342 more spontaneous and interactive choreographic elements.
1343

1344 Technological challenges further compounded these issues. The pre-programmed nature of the robotic arm restricted
1345 the dancers' ability to make spontaneous adjustments during the performance, limiting the improvisational aspect of
1346 the dance. Safety concerns were also prevalent, as dancers had to remain cautious to avoid collisions with the robot,
1347 which could not stop quickly if it moved unexpectedly. This preventive approach sometimes hindered the natural flow
1348 of the performance.
1349

1350 Additionally, the absence of human-like features and the lack of physical feedback from the robotic arm impacted
1351 the dancers' ability to form a meaningful connection with their mechanical partners. Unlike human dancers who can
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1353 provide real-time feedback and adapt dynamically, the robotic arm's pre-set movements lacked responsiveness, which
1354 limited the depth of the interaction. This absence of mutual inspiration led to a more directive approach, where dancers
1355 felt they were instructing the robot rather than collaborating with it.

1356 Despite these constraints, some dancers recognized the unique capabilities of the robotic arm, such as its precise
1357 rotational movements, which offered new possibilities for choreography. However, the overall experience highlighted
1358 the need for further advancements in robotic technology to enhance the fluidity, responsiveness, and interactive
1359 potential of robotic arms in dance performances. Future research should focus on addressing these limitations to
1360 facilitate a more seamless and integrated collaboration dance with non-humanoid robot.
1361

1362 5.5 Exploring Applications in Kinaesthetic Development and Dance Education: Interdisciplinary 1363 Collaboration and Knowledge Transfer

1364 The integration of robotic arms into dance reveals new opportunities for kinaesthetic learning and collaborative move-
1365 ment design, advancing interdisciplinary collaboration between robotics, dance, and technology. Our study highlights
1366 how non-humanoid robotic arms encourage dancers to adapt to mechanical constraints, fostering innovative approaches
1367 to movement creation. This supports kinaesthetic education by enhancing dancers' ability to refine techniques and
1368 balance artistic intent with technical limitations.

1369 **Adapting Movements to Robotic Constraints** Dancers iteratively adjusted their movements to align with the
1370 robotic arm's capabilities, such as 360-degree rotation and static positioning. This process created a dynamic learning
1371 environment, enabling the exploration of expressiveness within defined mechanical boundaries. These adaptations
1372 illustrate how robotic tools can encourage both novice and expert dancers to engage in creative problem-solving.

1373 **Enhancing Performance and Audience Engagement** The robotic arm introduced unique opportunities for
1374 performance, offering consistent and precise movements that enhanced choreography's aesthetic and emotional impact.
1375 Performances emphasized audience engagement, evoking active participation and emotional connection through
1376 innovative interaction with the robotic arm.
1377

1378 **Future Directions and Collaboration** The study underscores the potential for further development in robotic
1379 flexibility, emotional responsiveness, and expanded movement capabilities. These advancements could deepen the role
1380 of robotics in dance, enriching creative expression and collaborative practices. Moreover, interdisciplinary collabora-
1381 tion—uniting robotics, computer science, and performing arts—fosters innovation and knowledge transfer, enabling
1382 broader applications beyond dance.
1383

1384 6 CONCLUSION

1385 This study explored the integration of the non-humanoid robotic arm in dance, focusing on creative movement,
1386 collaborative choreography, and narrative expression. Through three workshops, dancers interacted with a robotic arm
1387 in individual and group settings, revealing how these dynamics shape human-robot collaboration. In one-to-one settings,
1388 dancers demonstrated more fluid movements and a stronger connection with the robot, suggesting that the robotic
1389 arm's mechanical precision stimulated creative improvisation. However, in group settings, the robot often became
1390 a background element, causing divided attention and more segmented movements among dancers. This indicates
1391 that choreographers must carefully integrate robotic elements into group performances to maintain coherence and
1392 engagement, balancing the robot's mechanical constraints with the dancers' creative freedom. This work highlights
1393 how non-humanoid robotic systems can inspire new approaches to movement design and expand the possibilities of
1394 artistic collaboration.
1395

Our findings show the need for dancers and choreographers to adapt traditional methods to incorporate robotic arms effectively, blending dance techniques with new strategies tailored to the robot's capabilities and limitations. Familiarity with the robotic sequences enhanced dancers' somatic awareness and interaction quality, suggesting the importance of iterative practice and deep engagement with technological elements. This study highlights the necessity for future research to focus on enhancing the robot's real-time responsiveness, emotional expressiveness, and adaptive capabilities to better support artistic expression. This study highlights how robotic arms enhance creative workflows in dance and offers a framework for integrating interactive systems into domains like education and collaborative design, where users co-create with technology. These insights demonstrate how technology can drive innovation in dance, emphasizing the potential for interdisciplinary collaboration to augment human creativity in novel and transformative ways.

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