Playing with Robots: Performing Arts Techniques for Designing and Understanding Robot Group Movement

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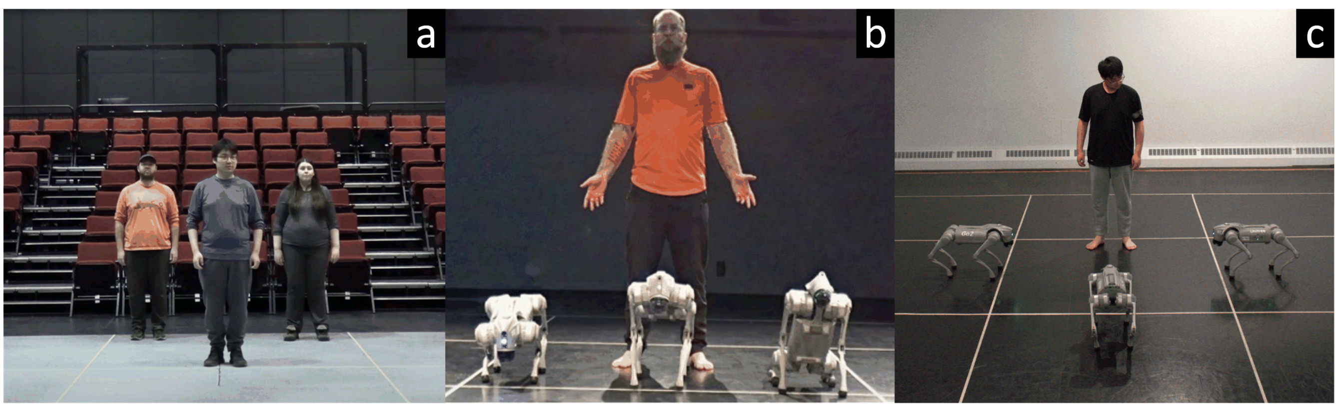

Figure 1: We propose using performing art techniques for designing and understanding robot group movement (a) In the first experiment we understand how humans move in groups through the lens of performing arts (b) We then designed a set of movement patterns that were implemented on a set of zoomorphic robots (c) In our final experiment, we evaluated the emotional response of participants when they were introduced to these group movements.

Abstract

In this work, we introduce a formal design approach derived from the performing arts to design robot group behaviour. In our first experiment, we worked with professional actors, directors, and non-specialists using a participatory design approach to identify common group behaviour patterns. In a follow-up studio work, we identified twelve common group movement patterns, transposed them into a performance script, built a scale model to support the performance process, and evaluated the patterns with a senior actor under studio conditions. We evaluated our refined models with 20 volunteers in a user study in the third experiment. Results from our affective circumplex modelling suggest that the patterns elicit

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positive emotional responses from the users. Also, participants performed better than chance in identifying the motion patterns without prior training. Based on our results, we propose design guidelines for social robots' behaviour and movement design to improve their overall comprehensibility in interaction.

CCS Concepts

• **Human-centered computing** → **Human computer interaction (HCI)**; **User studies**; **HCI theory, concepts and models**; **Empirical studies in HCI**; *Interaction techniques*; *Interaction design*; Interaction design theory, concepts and paradigms.

Keywords

Humanities, Art, Robots, Method

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1 INTRODUCTION

Robots have achieved advanced locomotion capabilities, both commercially and in research. As consumer zoomorphic quadrupedal robots (commonly referred to as robot dogs) become more prevalent, human interactions with groups of such robots will likely increase. This shift necessitates a deeper understanding of involved social dynamics, particularly how humans perceive group movements of quadrupeds. Designing and studying robot movements is a well-researched area of in human-robot interaction (HRI) and social robotics [28, 45, 102], yet much of the existing literature focuses on specific subsets of robots or contexts. For example, St-Onge et al. and Santos et al. explored swarm robot interactions [90, 91], Dietz et al. [87], and Fraune et al. [37] investigated dynamics and interaction effects with swarm robots, while more recent work has explored social facilitation effects of multiple non-anthropomorphic robots [70]. However, limitations persist with most studies focusing on swarm or miniature robots [29, 58, 70] and do not generalize to larger quadrupedal platforms with advanced locomotion [6, 43, 96]. Furthermore, when sophisticated robots are used, the emphasis is often on anthropomorphism rather than their movement patterns [60, 80, 89], static postures or heterogeneous systems with limited motion capabilities [93, 97], highlighting a gap in understanding how the movements of larger, zoomorphic robots impact human perceptions and emotions in social contexts.

Designing movement for quadrupedal robot groups requires systematic study to address whether a human feels safe being led by a group of robots and by extension if the movement evokes feelings of trust or threat. Current movement designs are often based on roboticist intuition, which may diverge from perceptions in the wild. Given the rich locomotion capabilities of modern quadrupeds, there is a pressing need to develop fundamental theories and empirical insights to inform movement design. Drama and performing arts, with their expertise in portraying emotion and motivation through movement and body language [61], offer a promising solution. Previous HRI research has leveraged these insights for robotic motion design [35, 38, 73, 79], focusing on areas such as methodology [7, 52, 53], theatre performance [17], and gestural interaction [61, 62]. However, no foundational work has systematically applied theories from the performing arts to the design of movement patterns for groups of quadrupedal robots.

This paper addresses the following primary research questions:

- How can theories from performing arts and drama inform the design of robot movements that emphasize spatial relationships and social responsiveness? (RQ1)
- How can these dynamic movements be adapted to generate coordinated motion patterns for groups of quadrupedal zoomorphic robots? (RQ2)
- How do these patterns affect bystanders' emotional responses, and what design insights can be drawn from their feedback? (RQ3)

To answer our research questions we conducted three studies. First, a participatory co-design workshop session to explore human group movement, focusing on spatial relationships and dynamics. Using a stage grid and foundational drama techniques such as "blocking", "neutral bodies", and "soft-focus" exercises [8], participants engaged in tasks simulating group movement in dynamic settings. Our second study focused on translating human dynamics to quadruped robots. We used insights from Experiment 1 to prototype movement patterns through stop-motion techniques, adapting the findings to a narrative-driven design. A professional actor and director collaborated in refinement, resulting in 12 unique movement patterns we implemented on a quadrupedal robot platform. Our final study explored user perception and emotional response to a quadruped robot group movement patterns. Using the circumplex model of affect [86], thematic analysis, and sentiment analysis, we assessed participants' perceptions, identifying five key themes: Trust, Social Relationships, Zoomorphism, Movement Dynamics, and Sensory Perception. Results showed an 85% positive-neutral response rate, with movements eliciting predominantly positive valence and arousal.

This work makes several key contributions to the field of human-robot interaction. First, it introduces the application of Drama and performing arts methodologies to inform the design of group movement patterns for quadrupedal robots, bridging artistic and technical approaches. Second, it presents the empirical design and validation of 12 movement patterns developed through participatory co-design and performance techniques, providing a structured design framework. Third, critical factors influencing trust, safety, and emotional engagement with group robot behaviours were identified, employing the circumplex model of affect [86] to analyze human emotional responses. Finally, it offers practical design recommendations for creating socially acceptable quadrupedal group movements, highlighting trade-offs between motion design, user experience, and emotional responses to enhance the efficacy of robot interactions. Developing empirically grounded design guidelines created in collaboration with performing arts advances the understanding of how motion patterns impact human perception, paving the way for socially engaging quadrupedal robots.

2 RELATED WORK

Our work investigates the intersection of social human-robotic interaction, theatre and the performing arts, and understanding robotic movement patterns.

2.1 Performing Arts and HCI

Leveraging an actor's physical knowledge provides insight into how body language and physical movements could inform non-verbal communication in robots [53]. Systematic approaches to incorporating human performance techniques into robot interactions have been proposed [7, 79], and explored with actors [35] and dancers [39, 63, 73] to see how to best utilize techniques and embodied knowledge. With movement expertise provided by performers, we can shape robotic movements to make them more socially acceptable and recognizable to onlookers [17, 46].

There has been extensive research in the HRI community linking humanoid robots and performing arts including acting [32], dance [41, 64], magic [51], and puppetry [52]. Prior research has studied the integration of performance techniques for interaction with mechanomorphic robots [13, 44, 57, 94] such as drones [26, 72], robotic limbs [77], and self-operating instruments [47]. Researchers leveraged the skills and embodied knowledge of movement by actors and dancers to direct the movement of robots conveying certain behaviours [38, 53, 63]. Cappo et al. contributed a real-time GUI for controlling multiple robots for theatrical performance [17]. Knight et al. introduced an acting methodology for social robots to leverage full-body affect expressions with a Nao robot [62]. Dynamics of human-robot groups in performance has also been studied [12, 32, 75]. When investigating humans and robots working together on stage, we may observe that humans view the robot as another actor [68], as a prop, or both depending on the context of the scene [26, 33]. In a study conducted with two human actors by Hoffman et al. the actors noted that subtle movements (i.e. gaze following) created expressions that made the robot feel like another "real actor" despite its appearance of a desk lamp [46]. Echoing Fallatah et al's findings, practice and rehearsal allow better preparation and anticipation for failures in movements and patterns [33]. Actors' techniques, when integrated into robot research and performance, can increase robots' anthropomorphic qualities and clarify the communicative intent of their movements.

The work discussed above primarily focuses on how actors interact with humanoid and mechanomorphic robots, missing how these collaborations could benefit the witnessed interaction of humans with zoomorphic robots. By embracing approaches used previously in enriching HCI through collaboration with performing arts, we can enhance the behaviour of zoomorphic robots to allow their intentions to be better comprehended by human bystanders, thus promoting social acceptance.

2.2 Reception of Robotic Behaviours by an Audience

The more robots become part of our lives and homes, the more essential it is to address how comfortable people feel with their movements. Valentina et al. note when a robot moves towards a human quickly and without notice, the human's mental stress increases [95], demonstrating a lack of trust and acceptance towards the moving robot. A lack of trust makes a human more likely to intervene in a robot's task before completion [42] resulting in decreased task efficiency, potential disruption of the robot's performance, and possible harm to the intervener. By utilizing movement patterns humans are familiar with and able to recognize the motive behind, we may increase social acceptance and decrease perceived threat of robots. The performing arts grant us the opportunity to better navigate this, as trained actors have intricate knowledge of "explicit methodologies for exploring the space of motion-based expression" [35] and have the same goal as a robot; that is, to convince an audience of an intention, motive, and/or behaviour [69]. Previous work showed that a robot with social cues could make a human more comfortable and open to collaboration [95].

Other works analyzing the perception of robots in theatrical contexts have shown that viewers assign human characteristics to robots. D'Andrea et al. described how crew members and viewers of their performance would give robots names, personalities, and other human characteristics [26]. This can also be observed in Hirata's "I, Worker" where the interactions of the two robots on stage conveyed such visceral emotion to the audience that viewers were crying during the final scene [68]. These examples of how performance can increase social acceptance of robots by viewers demonstrate how theatre can be an invaluable resource for studying the human part of HRI. Performing arts can also provide knowledge about how to adjust a robot's candour to suit audience expectations; achieving both comfort and believability in viewing, just as how we gauge the animacy of an agent may affect how we judge its movements [27]. Through analyzing previous explorations into robot theatre, Knight et al. showed that how a robot moves and engages with its environment impacts how an onlooker views its intention. However, they do not observe this in practice with real robots and human viewers [61].

Research on audience reactions to robotic performers primarily examines the robot's capacity to improvise and modify its performance in response to audience feedback [13]. Jeong et al.'s adjustable personality vectors allowed users to change a robot magician's levels of humour, aggression, and politicalness resulting in portrayals and exclamations of embarrassment at failings to elicit audience sympathy during the magic routine [51]. Rodriguez et al. created a robot system that adjusts its improvised poetry performance based on applause [85]. Hoffman et al. employed an anticipatory action framework to enable a robot to play improvised jazz music on the marimba alongside humans and found that adding an expressive head (even a non-humanoid one) assisted with musical-social cues such as head bobbing and eye contact that aid in keeping a beat and facilitating turn-taking [47]. Little has been done to analyze how a viewer perceives movement patterns by non-humanoid robots, especially in groups. Analysis of how an audience perceives a robot in a performance context tends to rely on how emotion is conveyed, relying heavily on the words and facial expressions conveyed by the robot while performing.

Using performers' knowledge of movement has been successfully tested in simulation [7]. Meng et al. had performers refine movements made by a simulated robot dog until they appeared to demonstrate the target dance form, however never tested the response to these refined movements on physical robots in real space and only analyzed a single robot in a simulated environment [73]. The expansion of this to robots in physical space interacting with humans is a natural progression. There is a significant lack of study on the perception of robots in a group interacting with each other [37]. Group movement dynamics also lack investigation, with behaviours of individuals not directly translating to the behaviours of groups [1]. Additionally, much of the work done surrounding groups in HRI revolves around a singular robot trying to ingrain itself in a group of humans, rather than a human interacting with a group of robots [1]. Much like an ensemble cast in performance, the coordinated actions of agents working toward a common goal can convey diverse meanings to an audience. By studying how human movements in robotic forms elicit reactions, we can explore their impact on group robot interactions and assess whether human-inspired movements in non-humanoid robots affect human responses positively or negatively.

2.3 Movement Mapping

Creating socially acceptable and recognizable movements in robots greatly benefits from the expertise of professional performers. Performance-based approaches include motion capture techniques [69], movement exploration workshops [39, 53], and the optimization of machine learning models [63]. Humans find it easier to relate to faceless robots when their movements are fluid and animalistic [32]. By using patterns that originate in the human form, we can expect humans to accurately recognize these movements even with limited context [23]. Translating recognizable human movements to non-anthropomorphic robots may assist in accurate human perception of movement.

Much of the work involving the mapping of human movements onto robots, unfortunately, doesn't leave a conceptual [69] or simulatory [38, 73] stage. As noted by Jochum et al., using choreography can help us address user acceptance, social acceptance and safety concerns in HRI, but this choreography must be imposed onto physical robots in real space to fully make use of the advantages collaborating with performing arts in HRI can provide [53]. Cuan et al.'s exploration in physical space did not have defined movements that users were supposed to recognize, focusing on the evocation of meaning in an abstract sense [23]. This abstraction of movement tends to be a trend when assessing the recognition of movement of robots by humans, especially with non-anthropomorphic robots [12, 57]. In these cases, the robots' movements are open to interpretation, with no incorrect interpretation by an onlooker, as they are supposed to make a viewer feel something, regardless of how that viewer defines that feeling.

There appeared to be a maximum of eleven defined states among recent investigations into recognition of behaviour and emotion, but many define significantly fewer [40, 51, 63, 85]. The definition of behaviours portrayed through movement is even more limited, with only two defined states [63]. Additionally, investigations into what a robot conveys to an audience typically focus on emotional states (happy, sad, etc.) or what a robot conveys while stationary or in breaks of movement. Movement and movement patterns can enrich performance and what an onlooker can gather about the meaning of an interaction [61].

3 DESIGN RATIONALE

This section discusses the rationale behind our design choices for experimental facilitation.

3.1 Why Performing Arts?

The effective use of space (and spatial relationships) to convey meaning, known as "blocking," [15] is a key expertise of drama and performance professionals like actors and directors. Additionally, the dramatic arts have a multi-millennia history [2] of theory and practice convincing an onlooker of emotion or intent not genuinely felt by the performer, a goal shared by HRI researchers [69]. Social HRI is closely related to drama and performance [61]. As Mullis suggests, robots' poorly designed dynamic behaviours result in their "poorness-in-the-world" [77]. We believe that applying performing arts theories can elevate robot movements.

3.2 Why Quadruped Robots?

We used quadruped robots for the following reasons:

- **High-Fidelity Movements:** In comparison to the swarm robots whose movements have been extensively studied in literature [29, 90], quadruped robots offer higher fidelity and broader range of movements.
- **Utilizing Zoomorphism**: Quadruped robots exhibit zoomorphic behaviour. Human familiarity with quadrupedal pets may increase success in eliciting emotional responses.
- **Widely Accessible and Scalable to Form A Group:** While full-sized humanoid robots exist, their cost restricts their access. More accessible humanoid robots (e.g. Nao from Aldebaran) lack high-fidelity and natural movements. Recent developments in capabilities of quadruped robots support impressive locomotion. They are actively used in the HCI community in applications such as accessibility [14, 20, 49, 100], wayfinding [59] and social comparison [101].

4 EXPERIMENT 1: UNDERSTANDING HUMAN MOVEMENTS IN A THEATRICAL GRID

Designing effective robotic group movements in social settings requires understanding human group dynamics. Drama provides valuable tools, particularly "blocking" [15], which emphasizes every body's position in space's contribution to action, tension, and narrative [54]. There are no "neutral bodies" on stage; spatial relationships inherently convey meaning. To explore how performing arts principles inform robotic movement, we addressed the question: *How can theories from performing arts and drama inform the design of robot movements that emphasize spatial relationships and social responsiveness?* Using Bogart and Landau's Viewpoints system [8], we conducted explorations of human group dynamics. Participants engaged in movement exercises to analyze how proximity, alignment, and orientation influenced interactions. These findings provide a framework for translating human group behaviours into robotic movement patterns aligning with human social expectations, ensuring natural and intuitive interactions.

Once group patterns are formed, the focal point is also established, which means power can pass through the group. Power, or

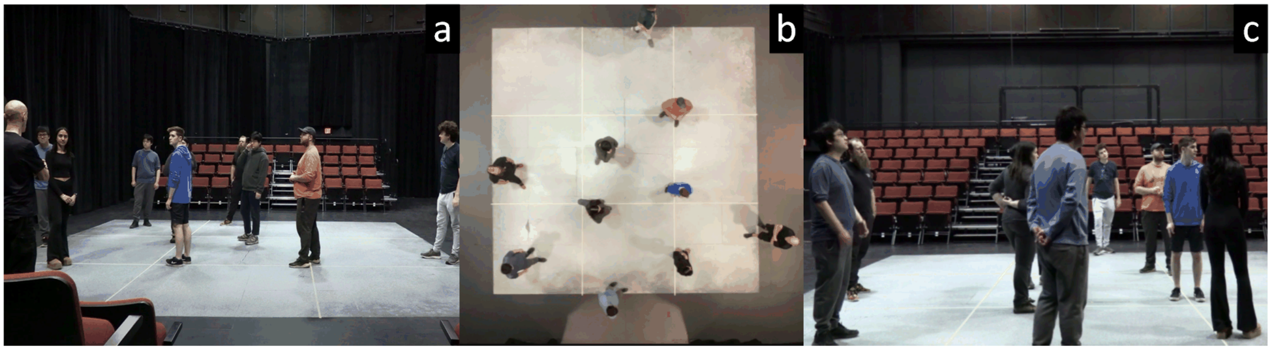

Figure 2: A group of actors on a grid being instructed by a director from three different angles: (a) downstage angle (b) overhead camera at the center (c) stage left.

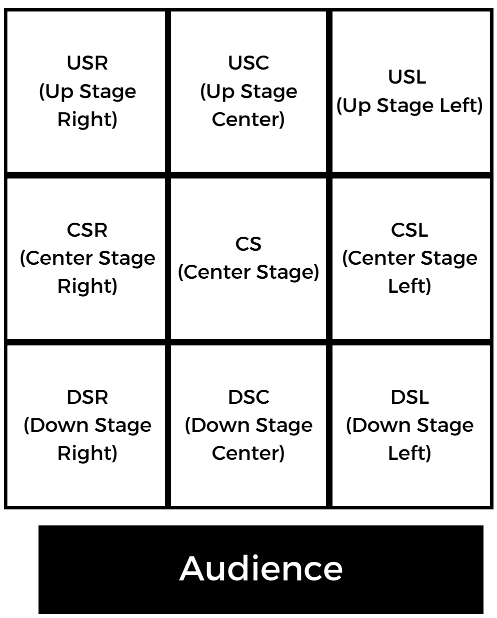

Figure 3: Stage positioning breakdown displaying the designation of each position on the nine-square theatrical grid.

"status" in performance practice [81], is usually reflected in positioning, with proximity emphasizing social hierarchy. In group formations, those further back can claim power by isolating themselves from the cluster. This status dynamic also applies to triangular shapes, with the central figure possessing more power. Furthermore, if the person with the focal point suddenly directs attention elsewhere, power and focus will also shift to that position. The concept of balance and movement further illustrates how status is fluid, changing with body position and group.

4.1 Method

The Viewpoints system is a framework exploring six elements of group dynamics—space, shape, time, emotion, movement, and story [8]. Viewpoints provide a shared vocabulary for analyzing embodied behaviours and fostering spontaneous ensemble interactions [9]. This approach was adapted to examine physical and social dynamics in non-theatrical contexts, focusing on how movement patterns translate into HRI scenarios. We conducted two three-hour participatory co-design sessions [84] in a university theatre using the Viewpoints system, each with 18 participants (n=36) aged between 18 and 37 with diverse gender expressions. The floor was marked with a nine-square grid (Figure 3), a standard theatrical tool for spatial organization and movement tracking. Participants were introduced to basic stage terms (e.g. Up Stage Center = USC) to navigate the space and engage in structured prompts simulating "in the wild" social interactions. A professionally trained director facilitated these exercises (Figure 2).

All interactions were video and audio-recorded from multiple perspectives, ensuring comprehensive coverage of spatial and social behaviours. Data was analyzed using physical, thematic analysis [11] and interaction analysis [56] to identify patterns in group dynamics and engagement. This drama-informed methodology offers valuable insights for HRI by emphasizing spatial awareness, non-verbal communication, and intuitive group interaction. These findings provided a foundation for subsequent research into designing movement patterns that promote positive social human-robot interactions.

4.1.1 Soft Focus Exercises. Soft focus exercises [8] are a key component of drama and performance training, designed to cultivate relaxed, peripheral awareness. They emphasize expanding awareness beyond habitual patterns of perception and behaviour. Techniques such as mirroring, group movement, and energy flow exercises develop physical awareness, trust, and ensemble cohesion. These methods support actors in staying grounded, present, and responsive.

The participants engaged their peripheral vision to navigate the space without colliding with each other. This exercise acclimatized players to the idea of fluid movement while also serving to introduce the edges of the play space. These exercises included simple prompts, like "without directly looking at them and without them knowing, find someone in the crowd to follow", "pick someone out of the group and stay as far away from them as possible", and "copy

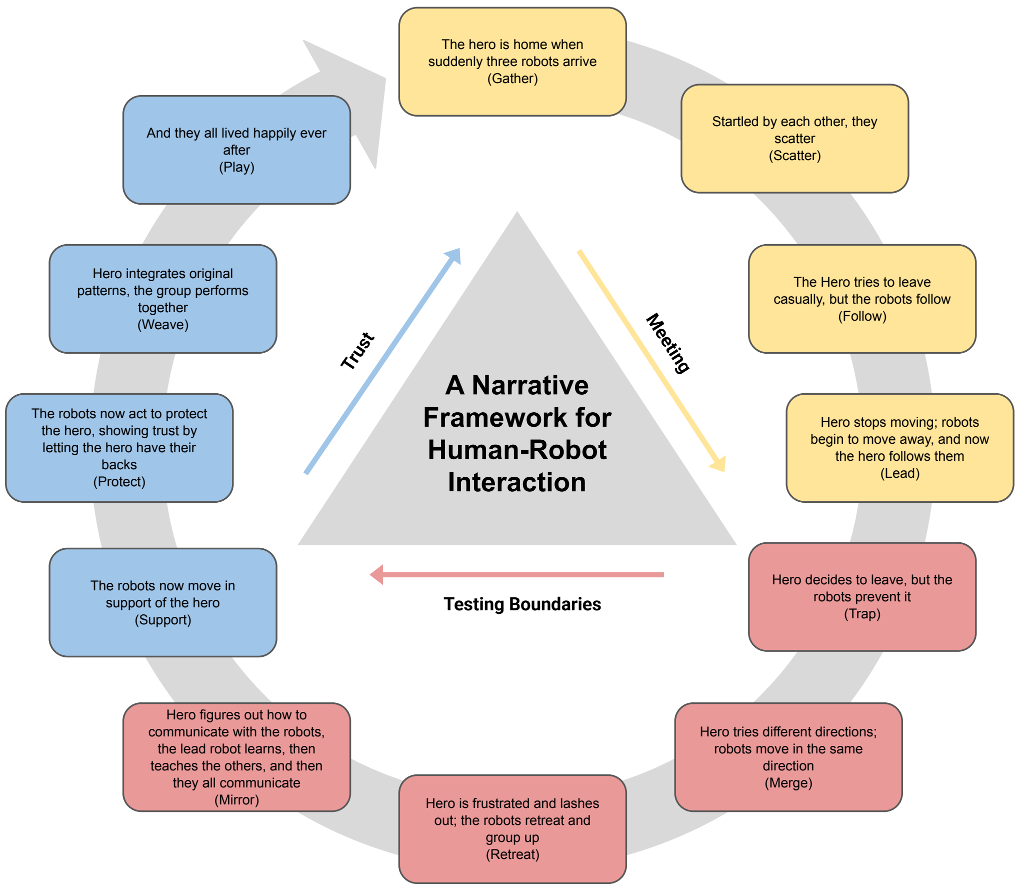

Figure 4: A narrative framework where each step of the Hero's Journey story cycle has been translated into 12 short scenes with interactive keywords.

the movements of someone in the group". The players were asked to "drop" what they were doing between each prompt and return to a "neutral walk". Exercises like this promote spatial awareness and synergy between a group of actors, a process commonly referred to as "ensemble building" [9].

4.1.2 Larger Social Interactions. Having established smaller three-person ensembles, player groups were combined to explore larger social interactions. In these scenarios, players were given different starting and ending positions and varying objectives. For example, players received prompts such as "A and B want to meet, the rest of you are trying to prevent it", "A, B, and C are on a leisurely walk while D, E, and F have somewhere important to be". These scenarios allowed for investigating how similar and opposing goals can impact physicality and group dynamics, especially between "estranged" groups or when groups must interact while attempting to complete an objective.

Crucially, robots were not introduced in these early sessions to allow observation of natural human movement dynamics and human-human interaction in large semi-social settings [88]. This experiment served three purposes: (1) to observe people's physical behaviours and dynamics in given social contexts, (2) to test the applicability of drama techniques for social exploration with laypersons for use in subsequent studies, (3) to establish group movement scenarios in controlled social settings. These formed the foundation for our subsequent studies, in which blocking and body positioning of the participants was translated into our final robot movement patterns. Recordings of responses to prompts and social scenarios provided a lexicon of postures and movement language that helped inform decisions for robot interaction in our second workshop and subsequent user study.

4.2 Results

To synthesize the results, we transcribed sessional video and audio recordings and reviewed them through an ethnographic performance lens [30, 83]. Our research team familiarized themselves with the recordings, cut and labelled them based on the exercise, and generated themes based on movement patterns that emerged across the two three-hour workshop sessions. Audio capture, including post-exercise discussions between participants, was transcribed and

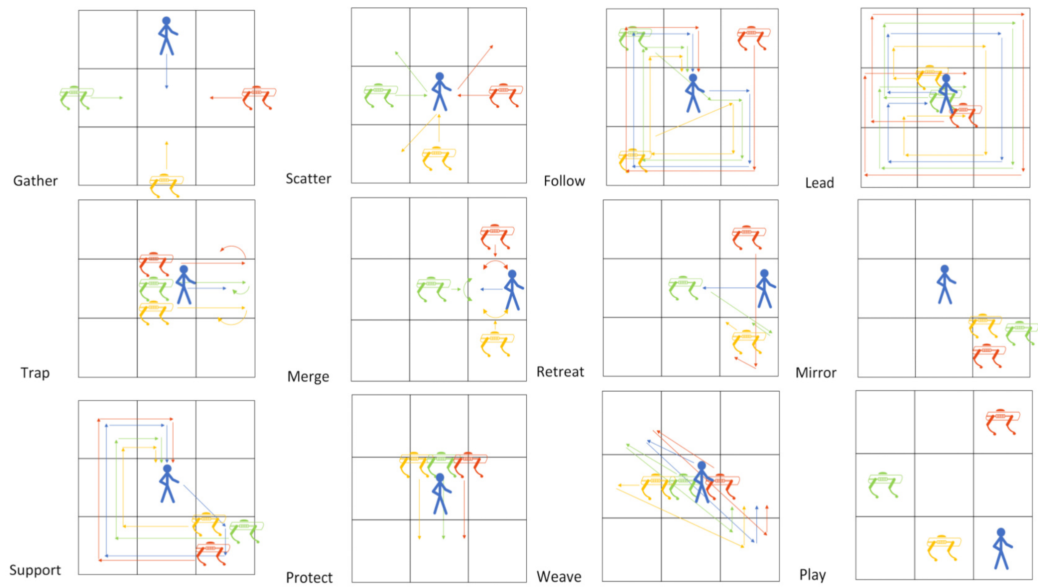

Figure 5: A lo-fidelity prototype of 12 patterns with path that illustrates the movement of the quadruped robots and the performer in Experiment 2.

analyzed using NVivo[1]. The data and themes were then reviewed by the professionally trained performers, directors, and our research team for domain-specific themes or insights that might have been missed in initial viewings, such as the formation of certain shapes, or participant hierarchies. Viewpoints has been used in various theatrical productions, particularly in group or ensemble-based work, where physicality is central to storytelling [8]. Using Viewpoints we were able to identify and categorize what would otherwise look like spontaneous movements into two primary categories, *(1) spatial*, that is, space and physical relationship, and *(2) time*, or temporal aspects of performance. Using these two categories, the research team manually reviewed the collected videos looking for spatial aspects of participant group movement: shape, gesture, architecture, size, weight, movement, tempo, and topography to understand shapes and the change of social dynamics including hierarchies and how they changed throughout the workshop. Once the physical characteristics of the ensemble were identified we examined the temporal tendencies that emerged from each prompt including: tempo, duration, kinesthetic response, and repetition. Through Viewpoints and embodied interaction analysis [31, 92], we can understand how bodies express meaning through movement, gesture, and space. Below, we highlight key themes that our analysis revealed.

4.2.1 Emergence of Shapes. The exploration of these prompts revealed commonalities across players, including gaze, focus, and pacing. Notable was the emergence of triangular shapes, emphasizing status in verb-based interactions [50, 76], resulting in one leader and two followers, or vice versa, regardless of prompt. In scenarios where status was to be presumed equal, two followers and a single leader almost always resulted during movement. Even in instances where the groups moved through the space in relative uniformity or a line beside each other, when not assigned status, status fell to the person in the middle. We were unsurprised to find this default pattern emerge. Our director collaborator noted, when staging a play, triangular blocking patterns are among the most common, powerful choices. They allow instant communication of status and can serve as an arrow to guide the audience to a specific point.

4.2.2 Gaze Patterns. Our observations led us to consider how players identified and directed attention toward the focal point. Methods of achieving focus varied. Some utilized "focus-looking" with a direct, intentional gaze aimed at the point of interest, clearly signalling where attention should be directed. Others employed "soft-looking" a more peripheral, relaxed gaze that subtly suggested a new focus point. The choice between the two added nuance to interactions, as focus-looking often communicated hierarchy or urgency while soft-looking conveyed more fluidity and openness. The movement patterns were similar in both small and large group scenarios, with players using their bodies and gaze to denote focus and importance, however, context changed the intention and intensity of interactions.

5 EXPERIMENT 2: EXPLORING THE INTERACTION BETWEEN AN ARTIST AND GROUP OF ROBOTS

In Experiment 1, we focused on understanding human movement patterns. We designed this drama-based studio workshop experiment to address our second research question: *How can these dynamic movements be adapted to generate coordinated motion patterns for groups of quadrupedal zoomorphic robots?* Here, we translate our

[1] https://lumivero.com/products/nvivo/

previous findings into a series of movement patterns for a group of three robots. In their research, Abrams and Rosenthal-von der Pütten found large groups can experience difficulties with cohesion and that pairs are not viable for the study of groups [1]. By modeling the movement patterns of a three-robot group on observed participant behaviours, we hypothesize that these patterns will produce more natural and socially familiar dynamics.

5.1 Designing Movement Patterns

Based on the movement lexicon from Experiment 1, we derived a coherent set of movement patterns for a group of robots. We then applied a loose narrative structure and labels to the patterns based on the classical "Hero's Journey" [16, 78]. An experienced performing artist/director used this to create a drama piece that involved robots and a human actor. For each scene, the director made a detailed script involving aspects such as the physical movements of both the actor and robots. We direct the reader to our supplementary material, which provides this study's detailed script and direction.

5.1.1 Story. The overall script for the movement design follows twelve scenes describing a movement pattern for the robots and actor (Figure 4). The scenes were modelled after the Hero's Journey, a narrative framework describing a protagonist's transformative adventure and is found across myths and stories worldwide [16]. The structure is typically divided into three acts: (1) Departure (which we call **Meeting**): The hero begins in the ordinary world, receives a call to adventure, hesitates, meets a mentor, and crosses into the unknown. (2) Initiation (**Testing Boundaries**): Facing trials, allies, and enemies, the hero confronts their greatest ordeal, undergoes transformation, and gains a reward. (3) Return (**Trust**): The hero journeys back, overcomes a final challenge, and returns to the ordinary world with newfound wisdom or power to benefit their community. The Hero's Journey offers a useful framework for our purposes by making the user (actor) into the "hero", navigating stages of curiosity, hesitation, trust-building, and mastery while the robot acts as a mentor, guide, or collaborator. This approach emphasizes the development of trust and comprehension between agents. By leveraging the Hero's Journey, we can frame interactions as transformative experiences, fostering deeper emotional connections, enhancing usability, and promoting trust and acceptance of robotic systems.

5.1.2 Prototyping Movement Patterns. The terminology for the movement patterns was derived through brainstorming with two theatre specialists and our research team. We had two main criteria for choosing these names: (1) They should be easily comprehensible, and (2) the tense of the words should be consistent. Once names were finalized, the movements were designed (Figure 5). Before scaling up the movements to studio level, stop motion was employed for prototyping the movements at a smaller scale.

Stop Motion. Stop motion is an animated filmmaking technique in which objects are physically manipulated in small increments between individually photographed frames to appear to move independently or change when the series of frames is played back [82]. This enabled testing and iteration of our movement patterns without programming robots. We used 3D-printed models of the robots

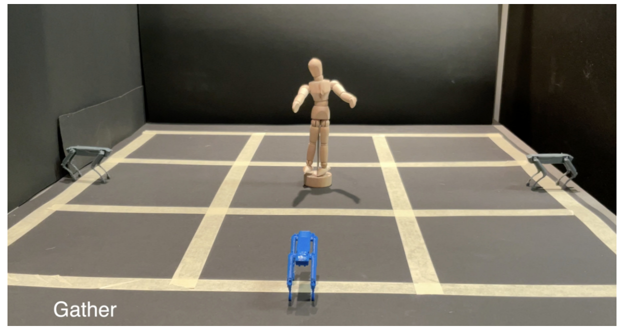

Figure 6: Frame taken from our stop-motion animation. Stop-motion animations were created on a smaller scale to accommodate iterations in the movement design.

and a wooden human figure to create stop-motion animations (Figure 6). These were iterated with the performing arts specialists to match the story and the scenes.

5.2 Implementation

After finalizing movement patterns through stop-motion, robots were programmed to execute those movement patterns. Commercially available quadruped robots are becoming increasingly economically viable [2](starting from <~$3,000 USD). This is a crucial criterion for this project since we intend to study group performance and require multiple robots. Movement patterns were implemented using the Unitree Go2 platform as it is increasingly used in the HCI community [14, 48] and has superior locomotion capabilities. The robot is equipped with a super-wide-angle 4D LIDAR, 12-set aluminum knee joint motors (allowing speeds of ~3.7m/s), and ultrasonic sensors, which can be used to perceive the surrounding environments.

We used UniTree's app to create coding instructions for each robot (Figure 7). Each robot was assigned a script and corresponding starting position on our 3x3 grid to ensure that the overall movement pattern was executed. Movements were planned in sequence to ensure smooth transitions from one action to the next. All the robots were synchronized to ensure more cohesive interactions. We used three separate smartphones each linked to a specific quadruped with the correlated instruction scripts. Since a central device does not control the quadrupeds, collisions are inevitable if they are not adequately coordinated. To synchronize motions, we ensured the following:

- When possible, each robot traverses a path that does not overlap with other agents. This is not always feasible due to the nature of the action series (i.e. sometimes agents must cross paths).
- When path crossing occurs, the quadrupeds run on timers to wait for the path to be clear before proceeding.

Locations were determined on a 3x3 studio grid (used in subsequent studies) to ensure that each robot's movement instructions were fine-tuned for our experimental studio setup.

[2] https://shop.unitree.com/products/unitree-go2

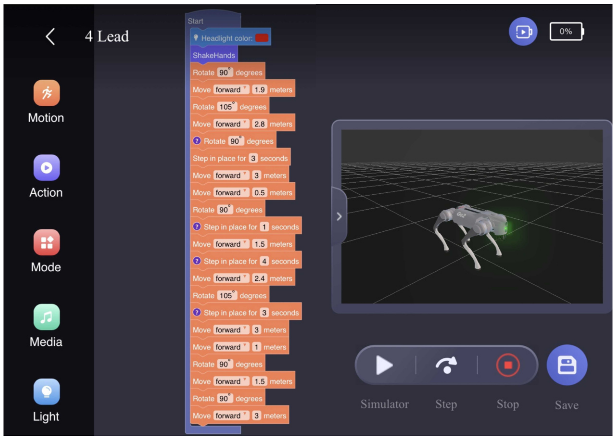

Figure 7: Implementing the movement patterns with a UniTree EDU robot using scratch-style coding instructions.

5.3 Study: Performance Workshop as an Embodied Research Methodology

Our second study utilized the narrative framework from our stop-motion storyboards and was designed to test our movement patterns in controlled human-robot social interactions. We created twelve movement scenarios designed for three quadrupedal robots and one human. A professional director provided context and motivation for each scenario based on the movement findings from Experiment 1 [88]. A professionally trained actor served as our human agent. Both the actor and director had previous experience working in HCI contexts.

We held our workshop in a smaller rehearsal venue at our university, providing a more intimate space to focus on the response and interactions from our human participant. Switching to a smaller space allowed us to control the lighting, focusing the performer's attention on the grid. We again utilized a nine-square grid (from the prior experiment and our stop motion scenarios) for topographical reference for both the participant and the robots. Each cell in the grid had a measurement of 1.97x1.97m resulting in a total of 35m^2. The grid size remained consistent through subsequent work.

This workshop provided a curated space for exploring human-robot interactions without the pressure of performing for an audience. Combining elements of design thinking with concurrent exploration and iteration, the session began with a visualization exercise [18, 19] to immerse the performer in the experience. Over two hours, twelve scenarios were enacted, separated by short breaks to reset the robots, which were programmed independently and controlled off-camera. The workshop was recorded for further analysis, with the performer engaging in active reflection through dialogue throughout, serving as a real-time "performance journal" [22, 71]. This iterative process fostered an embodied practice [25, 84], blending structured exploration with improvisational freedom [54]. The session concluded with an unstructured interview, offering additional insights into the performer's experience. This methodology highlights the value of performance workshops in generating embodied, iterative insights into HRI [10].

5.4 Findings

As the workshop progressed the performer became more comfortable in the environment and playing with the robots but felt restricted by the rigid scenario descriptions. For example, in the early scenarios, the performer was reluctant to turn their back on the robots. When asked about this, they replied that the nature of the robots and their relationship was both zoomorphic and alien, stating, "The scenario dictated that I encountered them in the wild... the first thing that came to mind was, 'How would I respond to dogs in the wild?' I would be cautious because I don't know their intention, especially when in a pack". The performer's early interactions were complicated by the foreign or "alien tech" appearance of the robots saying that, "dogs have physical cues that were absent in the robots, no tails, no facial features. So, it was hard to discern what they wanted". They also cited exposure to media as influencing their initial response to the robots, "they felt very 'Terminator 2' initially. My impulse was both defensive and combative". This feeling of unease was exacerbated when resetting the robots. As they were picked up to be repositioned the internal gyroscope perceived the movement as falling over and the robot began kicking its legs in an attempt to stabilize. This startled the performer, who audibly exclaimed their displeasure, the kicking motion resembling a "baby deer" trying to find its legs and questioning the autonomy of the robots.

Given the negative first impressions the performer had with the robots, the most surprising finding from our workshop was that the trajectory of the performer mirrored the trajectory of the scenario narratives. The performer started "tentative and cautious" around the robots, citing the "inorganic and mechanical nature of their uniform movement" coupled with the "thumping sound accompanying their marching" as unnatural and off-putting. Additionally, the performer felt "outnumbered" by the robots especially when surrounded. However, they found that "teaching behaviours" to the robots facilitated a sense of play. Furthermore, the robots' response to the performer's movements and gestures "shifted the status in the room". This shift resulted in the performer feeling in a position of power or control over the robots, freeing the performer to play with the robots even mimicking their jumping action in the final scenario, a surprise "impulsive" action to both the research team and the performer.

Following this, the 12 movements were divided into 3 categories, mimicking a 3-act structure. Each category consisted of 4 movements, with the first, **Meeting**, consisting of Gather, Scatter, Follow, and Lead, the second, **Testing Boundaries**, consisting of Trap, Merge, Retreat, and Mirror and the final category, **Trust**, consisting of Support, Protect, Weave, and Play (Figure 8).

6 EXPERIMENT 3: UNDERSTANDING USER PERCEPTION ABOUT GROUP ROBOT MOVEMENT

In our first study, we used drama techniques to understand the importance of movement, spatial relationships, and real-time responsiveness in dynamic group social settings (RQ1). Our second study translated human physical social dynamics to robots and

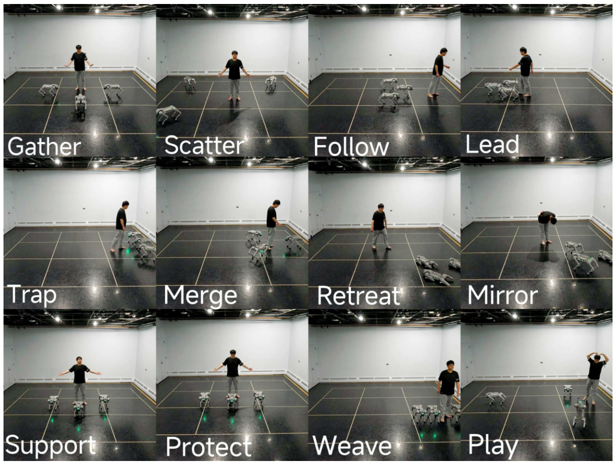

Figure 8: Movement patterns derived from our experiments which were used in Experiment 3.

explored implementing a narrative structure to these social movements, where understanding physicality, spatial relationships, and responsive movement is key to creating intuitive and effective interactions (RQ2). In our final study, we investigate how these patterns influence human emotional responses to find what design recommendations can be derived from their feedback (RQ3). We selected the Circumplex Model of Affect to assess the emotions elicited by participants for three key reasons: (1) it is the most widely used model for understanding motion perception [21, 66], (2) it has been effectively applied in prior studies on swarm robot movement perception [87], and (3) it facilitates direct comparison of our findings with existing research.

We hypothesize two significant challenges in this experiment: (1) since artists created the movements, the associated terminology may have comprehension issues among laypersons, and (2) the movements have been derived from drama and performance arts, typically performed by humans. The degrees of freedom for human movement are higher and smoother than current state-of-the-art robots. Thus, it is essential to understand how well these movements transfer to robots.

6.1 Procedure

We recruited 20 voluntary participants (mean age: 25.5, sd: 3.96, 14 male, 6 female) for the user study. One of our research questions is to explore how performance theory is applied and affects the process of HRI. Thus, our first two experiments were conducted using the theoretical framework and stage setup of drama and performance. We conducted this experiment inside a studio, divided into a 3x3 grid, according to the traditional 9-square performance grid. This grid was identical to Experiment 2. This arrangement not only aligned with our research framework but also offers the following advantages: (1) standardized venues provide consistency. Since the performance grids are always identical, and the quadrupeds' behaviour and movement patterns are fixed, we do not need to reprogram the quadrupeds. This also ensures that the designed behaviours are consistent between the participants during experiment 3 and between experiments 2 and 3; (2) we want participants to be part of our story and interact with the robots and thus treated them as performers. Following the stage arrangement of the previous two studies can make the setting more logical while creating a performance environment; (3) setting boundaries to narrow the scope and make the study more controllable. One of our research questions explores how performance theories can enhance HRI connections through spatial dynamics. Since "space" is an abstract concept, we narrow its focus by defining physical boundaries. This approach helps participants concentrate on the designated area, encouraging them to disregard activities occurring outside the grid in contrast to an open-space setting. Before the start of the experiment, participants were asked to complete a pre-study questionnaire. We designed the questionnaire to assess self-reported measures (on a 5-point Likert Scale) of participants' familiarity with computers/technology and robots, and comfort levels with being (1) the owner of a robot and (2) being an onlooker of interactions with a robot in public. Participants were also asked about their familiarity with pets and their confidence level in identifying the intent of a robot. All 20 participants completed the study.

Following the pre-study questionnaire, participants engaged with the robots and movement patterns on the grid. After each trial, participants were asked to choose the movement pattern and category most closely aligned with the demonstration. Following this, participants were asked to mark their emotional response on the Circumplex Model of Affect, using the version presented by Cui et al. 2023[24] containing the words "Delighted", "Angry", "Bored", "Relaxed" and "Neutral". These selections were divided into High Valence High Arousal (HVHA), High Valence Low Arousal (HVLA), Low Valence High Arousal (LVHA) and Low Valence Low Arousal (LVLA) as presented in [3] with the addition of a Neutral state to accommodate selections not within a defined quadrant. We instructed the participants to follow the think-aloud protocol.

After the experiment, participants were asked to complete a questionnaire that asked for self-reported measures on feelings regarding the robots' movements (from threatening to welcoming), fluidity of movements, ease of recognizing movement patterns, and to reassess their comfort levels in interacting with a robot in public as a bystander/onlooker and as an owner. Participants were lastly asked to create a narrative describing all the movements in sequence. This was done to better understand participant perceptions of the underlying narrative. An example of one of these narratives from P9 is "I was going to test my three new robots today by going out with them in the middle of the night. They followed me through a park until they thought they saw something dangerous and protected me until we got home. I taught them how to bow and they started playing with each other until we all felt low on battery!"

Participants were free to terminate the experiment at any time. The entire session was audio and video recorded. Each participant took 45-60 minutes to complete the study, with approximately 35-45 minutes for the main task and 10-15 minutes for the questionnaires and pre- and post-interviews. The study was approved by our institution's research ethics board. All the participants received a $20 remuneration for participating in the study.

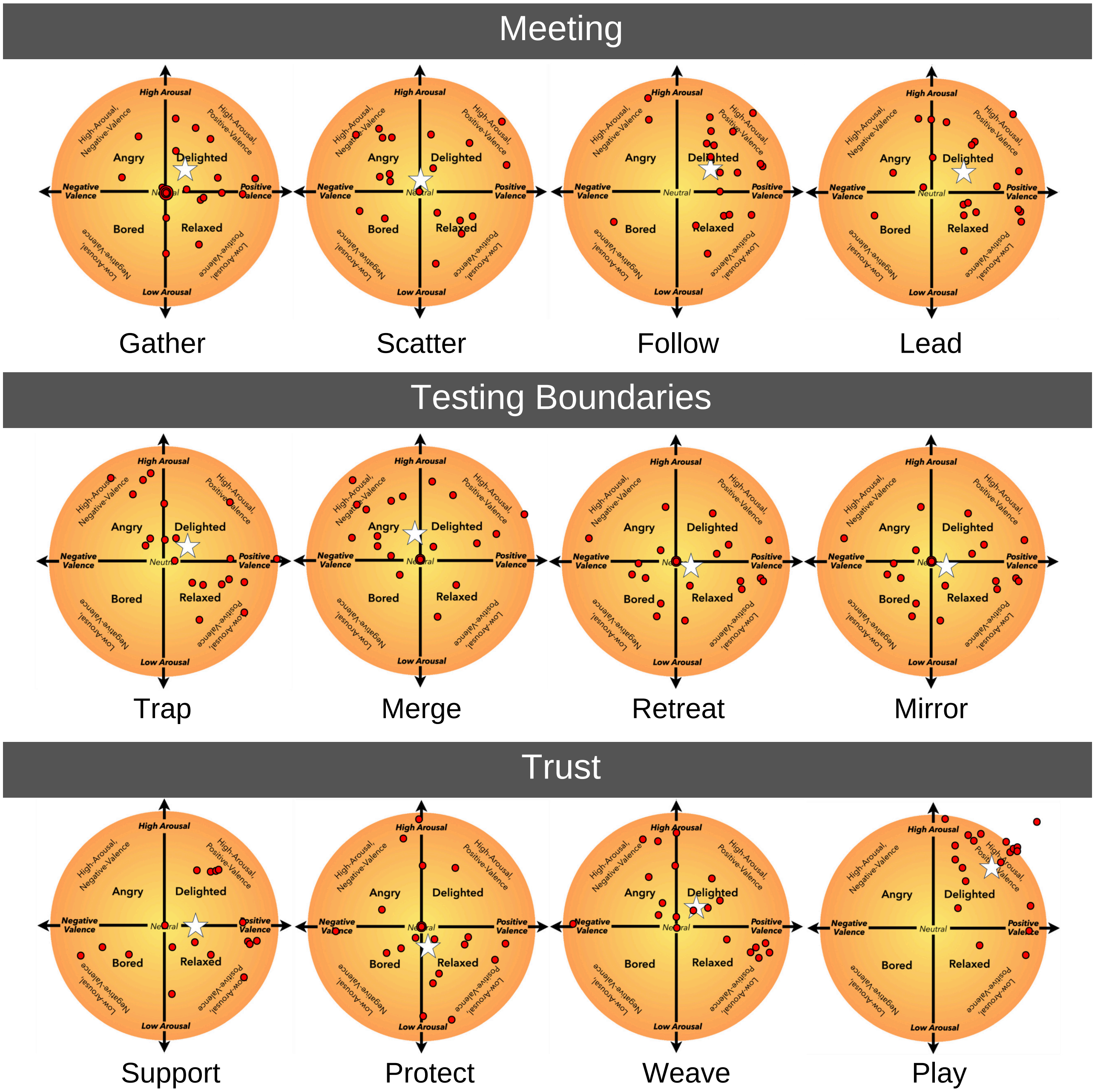

Figure 9: Results from Experiment 3. Emotional responses are derived from the circumplex model of affect for each of the movement patterns. Stars show averages.

6.2 Results

We used an interactive analysis approach to examine all videos in detail, focusing on both onstage performances and post-study interview responses. We identified and systematically coded key observations using NVivo, organizing them into distinct themes and deriving overarching guiding principles.

6.2.1 Circumplex Model of Affect. After each movement participants were asked to place the interaction on the Circumplex Model of Affect, which we used to assess the emotional response evoked by each pattern. Quantitatively, the valence and arousal scales were normalized to range [-1, 1], with 0 being neutral. 95% of movements had an average placement within the two high valence quadrants (HVLA and HVHA). This can be seen in Figure 9. Figure 10a shows the pair-wise Spearman correlation for the valence ratings. It is

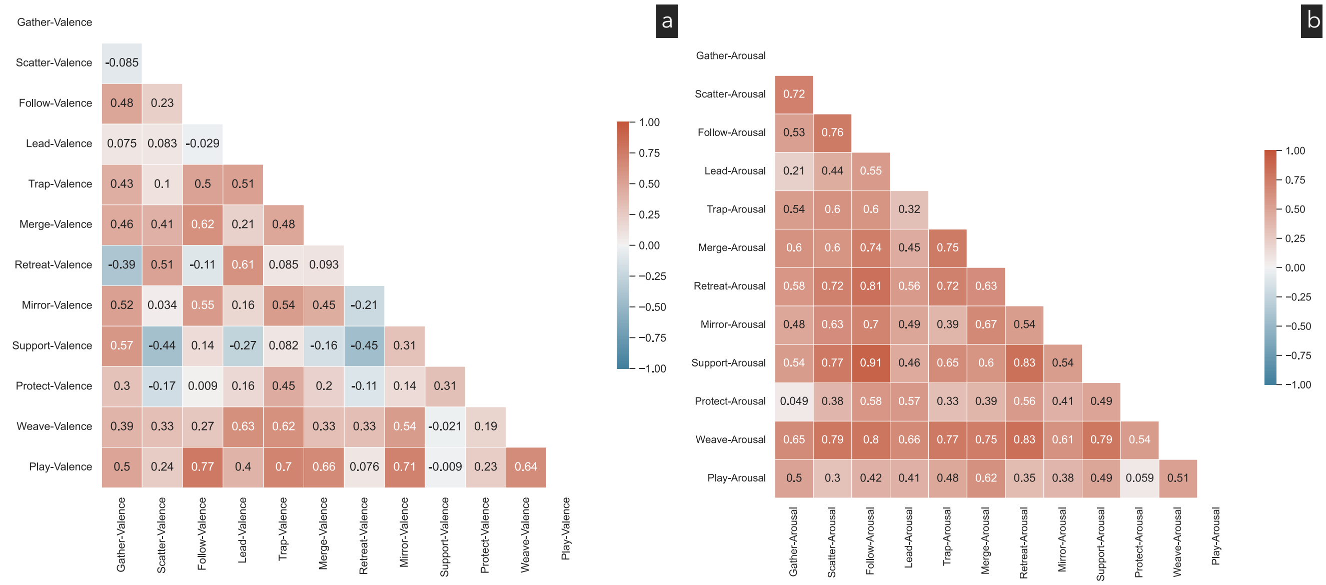

Figure 10: Correlation matrices for valence and arousal ratings for the movements.

interesting to note the negative correlation between opposite movement pairs. For instance, Retreat-Support demonstrate a negative correlation of -0.45 ($p<0.05$), Support-Scatter also have a similar correlation (-0.44, $p<0.05$). Similarly, Play-Follow, Play-Mirror pairs had high positive correlation of 0.77($p<0.0001$) and 0.71($p<0.01$). Figure 10b shows the pair-wise correlation between the arousal levels for all patterns. One finding of note is positively correlated arousal levels. The movement pair Follow-Support has the highest correlation with 0.91 ($p<0.00001$), closely followed by Retreat-Support and Retreat-Weave with 0.83($p<0.00001$). It appears movements involving robots moving away or distancing themselves from the actor (e.g. Retreat) had a negative correlation with patterns with increased proximity (e.g. Support).

6.2.2 Intended vs Perceived Movement. In follow-up analysis, we compared participants' reported perceptions of movement patterns with the intended patterns, as visualized in the correlation matrix shown in (Figure 11). Notably, 9 of the 12 movement patterns had overall accuracy exceeding 0.2, indicating participants could identify these at rates better than chance. This aligns with prior findings that correct movement pattern selections above 16% are statistically significant [90]. Compared to prior studies [29, 58, 90], which examined fewer patterns, our larger set provides more nuanced insights. For example, previous studies reported an accuracy rate of 22.16% for identifying emotions from six robot motions. In contrast, our findings reveal that all participants correctly identified the movement Play, while Gather and Mirror were recognized with high accuracy levels of 80%. These results underscore the robustness of participant perception in distinguishing complex movement patterns.

The movements Merge and Weave were more difficult to perceive, likely due to naming conventions. 30% of participants asked for clarification on the definition of the terms "merge" and/or "weave". This uncertainty likely is why they were selected the fewest times. Additionally, Trap, Lead, and Merge are patterns that participants misinterpreted the most. For example, Merge is misinterpreted as Trap 40% of the time, and Trap is misinterpreted as Lead 40% of the time. These misinterpretations can be attributed to several factors: (1) differences between how experienced performers perceive movement patterns compared to laypersons, (2) the movement patterns require more distinction, (3) our diverse participant pool (not all of whom are native English speakers), where their underlying cultural background could also influence their association of motion patterns to words.

6.2.3 Narratives from Participants. We tested the validity of our narrative framework from our second study here by following the same sequence of patterns with our lay participants in study three. Narratives were elicited from participants by asking them to connect all the movement patterns they had been exposed to. While it is unconventional to use sentiment analysis on such qualitative data, we have incorporated it into our analysis for the following reasons: (1) prior work proposed using sentiment analysis to explore a large corpus of textual data and reflections, (2) this allowed us to understand the overall sentiment of the narrative that participants attributed to the sequence of movements, (3) sentiment analysis has been previously used along with circumplex model to better understand user behaviour and emotional response [67]. We used the Python library Natural Language ToolKit (NLTK) [4] to conduct sentiment analysis on participant feedback to the narratives. 85% of narratives were neutral-positive, with the average positivity score being 3.92 times greater than the average negativity score. The impact of our narrative framework was echoed in our qualitative analysis as well; "I felt like a progression of knowing the behaviour of the robots. Initially, I felt a bit cautious and trying to gauge their behaviour. Later, it became quite natural to me on how they might behave" [P18].

		Perceived movement											
		Gather	Scatter	Follow	Lead	Trap	Merge	Retreat	Mirror	Support	Protect	Weave	Play
Intended movement	Gather	**0.8**	0	0.05	0	0.05	0	0	0	0	0.05	0	0.05
	Scatter	0	**0.6**	0.05	0	0	0	0.15	0	0	0.2	0	0
	Follow	0	0	**0.45**	0.05	0.05	0	0	0.1	0	0	0.2	0.15
	Lead	0	0	0.05	**0.4**	0.05	0	0	0	0.05	0.2	0.05	0.2
	Trap	0.05	0	0	0.4	**0.2**	0.05	0	0	0.1	0.2	0	0
	Merge	0.05	0	0	0	0.4	**0**	0	0	0	0.15	0.15	0.25
	Retreat	0.1	0	0	0.05	0.05	0	**0.45**	0	0.15	0	0	0.2
	Mirror	0.05	0	0.05	0	0	0	0	**0.8**	0	0	0	0.1
	Support	0	0	0.4	0.15	0	0.05	0.05	0	**0.1**	0.25	0	0
	Protect	0.2	0	0	0	0	0.15	0	0.05	0.1	**0.35**	0.1	0.05
	Weave	0	0	0.15	0.15	0.05	0.1	0	0.05	0.15	0.3	**0**	0.05
	Play	0	0	0	0	0	0	0	0	0	0	0	**1**

Figure 11: Correlation matrix showing the overall movement perception.

6.2.4 *Qualitative Thematic Analysis.* We performed a thematic analysis [99] of the surveys and feedback from our participants. Using NVivo we identified five primary themes based on participant observations. Our primary themes include, **Trust**, **Zoomorphism**, **Social, Sensory** and **Movement**. Within the main themes, thirteen corresponding focused sub-themes emerged (Figure 12). We expand on our findings below.

Alienation Effect. Participants often struggled to perceive themselves as part of the group of robots, instead identifying as external observers. This sense of detachment was reflected in instances such as P14 facing difficulty describing the Merge movement and, when prompted to include themselves in the thought process, shifted to the term Protect. Similarly, P15 interpreted the lead robot's behaviour at the beginning of the Lead pattern as "indicating it wants the others to follow", yet did not see themselves as part of the group, as they chose not to follow the identified robot leader; this participatory distance was echoed by P2, P9, P10 and P12. In drama, such distancing aligns with the Alienation Effect (or Distancing Effect), which aims to heighten awareness of the artificiality of a performance to reflect the "real" world. In the context of HRI, this alienation can be attributed to the absence of empathy or a social connection with the robots [5, 36]. Interestingly, participants reported a turning point in trust during or after the Mirror pattern, citing moments where they felt the robots were learning from and responding to their actions: "I would say the part where I started feeling protected or feeling like the aggression wasn't as much after the bows" [P9]. This shift highlights how perceived responsiveness can mitigate the othering effect and foster collaboration and trust with para-social robots, addressing a key challenge in designing effective group interactions.

Proxemics of Movement. Participants became unnerved when the robots were close, especially those who had seen the robots collide previously. For example, P5 noted, "It seems like when you see the dogs coming to you, you just wanna make some space for them to walk." This aligns with previous research on individual robots in which the possibility of collision with a robot most greatly affected the trust between the human and the robot they were interacting with [33, 42]. Movements 5-8 – which fell within the Testing Boundaries category – were designed to test both physical and metaphorical boundaries in interactions. Following this testing, participants cited increased comfort getting close to the robots in interactions than they were initially.

Mechanics of Movement. The synchronicity of movement displayed by the robots led multiple participants to make military comparisons. P15 described the robots as "a bit militaristic", while P18 noted, "They were working like soldiers." Similarly, P8 commented on synchronization, saying, "because they were in sync, so was all of them all the steps." Besides, some participants highlighted that the sound of the robots' synchronized stepping made it hard to discern which ones were moving when out of sight, further reinforcing the comparison to soldiers. Moreover, participants noted that more efficient and economical movements were perceived as more threatening and militaristic. P14 noted that economy of movement influenced placement on the arousal scale of the Circumplex Model of Affect. Additionally, movements that appeared to "waste energy" were ranked higher on the arousal scale compared to simpler movements. This contrast can be best illustrated through analysis of the final movement, Play, where the robots' actions were described as "doing stuff that doesn't really serve any purpose other than being fun" [P14]. This movement received the highest average arousal and valence scores. A key takeaway from these findings is that fast, overly synchronized movements can be perceived as intimidating.

Influence of Zoomorphism on Movement Perception. Quadrupeds can evoke emotional responses similar to those elicited by animals like dogs in comparison to mechanomorphic or anthropomorphic robots [34]. Movements that remind of pets can help in making movements more recognizable and emotionally engaging. When considering the movement of a group of robots, participants preferred natural movements. Excessive zoomorphism can trigger the uncanny valley effect, "one leg moving at a time seemed to ping some sort of uncanny valley thing in my brain because I know that that's not usually how animals walk... the very small steps...

Themes	Focused Themes	Theme Overviews	Participant Feedback
Trust	Play (Positive) (N = 17)	Understanding how the robots move allowed for enjoyment of the actions	P2: "At first, they were really funny. After the 2 or 3 steps (movements), I got their gist and how they work, so it was a lot easier interacting with them and even teaching them to bow and see them play"
	Trap (Negative) (N = 10)	Participants did not yet understand the robots; causing feelings of unease	P3: "From what I've seen it was like the robots were trying to see if they can trust me; they observed my behaviours and followed me around..."
Zoomorphism	Perception (N = 11)	Referal of the robots as "dogs" allowed the participants to relate to them more easily	P13: "I felt like at first the dogs came to me to be friends with me so that I would develop trust with them. And they did follow me to show their obedience. Also by trying to imitate me, I think they wanted to be friends with me."
	Expectation (N = 10)	Viewing robots as "dogs" created behavioural assumptions	P13: "I don't really think about them as robots. I feel like they're real dogs."
	Emotional Connection (N = 7)	Robots executing varying levels of animal-like movements affected participants perception	P12: "When it took the one extra step forword it felt threatening or it felt friendly or something but without a face or something that like, shows, a bit more clearly conveys these emotions like at least for me is this like bugging the thing?..."
Social	Introverted (N = 6)	Robots colliding with each other caused participants to feel uneasy	P5: "When you see two dogs somehow crush into each other… it seems like when you see the dogs is coming to you, you just wanna make some space for them to walk. This one is not really friendly."
	Extroverted (N = 7)	Robots do not have the ease of social navigations that humans do	P3: "Most of the time I was just confused what they're actually going to do. Because they don't have any face or something like that... maybe if there's no display to see"
	Alienation Effect (N = 6)	Participants felt separate from the robots, simply observing them rather than working with them	P8: "Sometimes it felt when they were including me more maybe that was moreful positive and then sometimes they were just doing their own thing among themselves which was more negative I guess."
Sensory	Environment (N = 5)	Isolated to the study parameters with limited outside influences	P15: "I would say gather again, they basically just got into a line... To second guess myself a bit, I suppose if I felt threatened by you guys, it could be protect, they sort of made like a little wall"
	Sound (N = 5)	Loud, repetitive and synchronized stomping of robots' feet was intimidating	P4: "The sound their walking is made, their steps and they're not much aware of the obstacles in front of them make participant feels negative."
Movement	Mechanics (N = 5)	Energy conserving movements are wary, whereas energy wasting movements are joyful	P14: "For last movement, I'd say the lack of economy of movement... they're not acting super deliberately and trying to conserve movement or anything; they're just doing stuff; their movements are bigger and more expressive than they have to be."
	Proxemics (N = 4)	Robots proximity to the participant can cause varied perception	P18: "I felt like maybe I'd have to be careful, maybe they would just jump on me or something… after three or two scenarios... we were keeping a safe distance—that's the point I felt, I can actually play with them; they're not going to jump on me"
	Anticipation (N = 4)	Knowledge of being in the study environment affected participants anticipation of movements	P19: "On the other hand, I know that they're robots and this is just an experiment, so I wasn't that much threatened by them right"

Figure 12: Themes that emerged from the participant study with descriptions and supporting feedback from participants.

made the sort of danger response go off" [P14]. Here, robots become unsettling as they approach but do not fully achieve naturalistic qualities, impacting bystander comfort [74].

Social and Emotional Interactions. Throughout the study, the robots were referred to as "dogs" both for form factor and behaviour. Participants found it more accessible to compare the robots to something they have at least a passing familiarity with. With this familiarity, they would hesitate less upon interaction. This did bring up a few instances of expectation among the participants. Multiple participants made comparisons to their pets when explaining why they selected a certain term or asked if they could pet the robots. One participant, who told us about their fear of dogs, was quite hesitant coming into the experiment, but by the end said they were more comfortable with the robots than with dogs as "the robots can't bite [and]...they didn't show any aggressive movements" [P18].

Situational Awareness of the Group. A key observation we made during our analysis of human movement in the first experiment is the inherent situational awareness between humans when moving as a group, as explored in our first study with Viewpoints [8]. This is a crucial design consideration that must be translated for robot group movement. Jones et al. [55] propose the idea of distributed situation awareness among swarms. The robots we used in our studies were equipped with high-resolution LiDARs and possessed the capability to understand their environment to take necessary actions (e.g. obstacle detection). For our work, obstacle detection was disabled to allow movement patterns to be conducted with minimal interference due to dirt/dust on the LiDAR. Future explorations will require the use of obstacle detection for the precise understanding of the spatio-temporal relationship that exists between the groups.

Environmental Settings. Some study participants noted how knowing they were in a controlled setting affected their choice of what was being demonstrated. For instance, P15 mistook the PROTECT as GATHER citing the researcher team's presence and experiment setting as the reason saying, "If I felt threatened by you guys, it could've been PROTECT, they made a little wall." Other environmental factors like sound played a role in participant response to the robots, "they were very rhythmic and louder than a normal dog. It felt like beating of drums... and also because they were in sync, so was all of them all the steps" [P8].

6.2.5 Analysing Self-Reported Measures. We also analyzed the self-reported measures, such as participants' preferences for interacting with robots as onlookers or owners and the influence of their computer proficiency in understanding movement patterns. We could not find any significant difference with these self-reported measures.

7 Discussion and Design Guidelines

Our goal was to understand how translating human movements to zoomorphic robot groups impacts human understanding and emotions in social contexts, a previously unexplored area. Using performance methodologies, we found consistent patterns in social human movement. We then extrapolated these patterns and applied them to a narrative framework to understand how the structure impacted robot-bystander relationships. Finally, we ran a large study asking participants to identify and reflect on robot group movement patterns. Here we discuss the findings of our three studies and offer guidelines based on our drama and performance informed explorations.

7.1 Applicability of Outcomes

When robots interact with bystanders the robot behaviour can impact perception and the bystander emotion [98]. Bystanders can infer the intentions of a group of quadruped robots based on their movements. We found no significant disparity in comfort level as the owner of a robot or onlooker/bystander of a human interacting with a robot in a public space from before participation in the study to after participation. Additionally, there was no significant correlation between a participant's familiarity with pets and their accuracy in assessing movement patterns (evidence of this can be found in the supplementary material). However, poor design may result in misinterpretation.

With thoughtful design, behaviours can be used to convey the robot's internal state, facilitate communication in specific conditions (such as environments where verbal interaction is impossible), or serve as an emotional companion robot, which can enhance user interaction and entertainment, delivering emotional value through non-verbal cues. Additionally, given specific zoomorphic design choices in quadrupedal robots conveying emotions and information through behaviour rather than words reflects social expectations. For instance, robotic dogs that speak may conflict with user expectations, potentially triggering the uncanny valley effect and reducing the robot's interactivity and user engagement [65].

7.1.1 Command and Language Interpretation of Movement. Language interpretation posed a significant challenge in our study, with 8 participants requesting clarification on terms used to describe the 12 movement patterns. Terms like "weave" and "merge" were particularly problematic, selected the least (4.2% and 2.9%, respectively) and showing 0% accuracy in interpretation. Participants also expressed confusion over terms like "follow" and "lead", with P3 explicitly questioning whether the terms referred to the robots or themselves.

Our findings highlight the need for more intuitive language when describing robotic movements. Incorporating user-centered approaches to language selection, such as participatory design sessions or iterative refinement of terms with non-expert users, could enhance clarity. Additionally, offering synonyms for each movement may better accommodate diverse linguistic and cognitive interpretations. Addressing this challenge is essential for ensuring movement commands in HRI are both accessible and unambiguous, fostering smoother and more effective collaboration.

7.1.2 Stop Motion as an Efficient Technique for Prototyping Group Movement. Stop motion, a well-established technique in filmmaking and performing arts is underutilized in HCI and HRI research. Our design process for group robot movements demonstrated its value as a prototyping tool, offering scalability and spatial awareness. By scaling down physical space, stop motion simplifies complex interactions, enabling the rapid creation of animations for iterative feedback. Additionally, it aids in visualizing spatial relationships and refining group dynamics, facilitating the design of movement patterns and situational awareness exercises. Similar to traditional HCI prototyping methods, stop motion allows for efficient testing and iteration before full-scale implementation. Its potential to enhance the design of coordinated robot behaviours makes it a valuable yet under explored tool in HCI and HRI, particularly for group interaction scenarios where precision and coordination are essential. This technique deserves further attention as a practical and cost-effective addition to the HCI/HRI design toolkit.

7.2 Performing Arts Techniques Based Design Guidelines

Based on the results, findings, and feedback from our three studies, we propose the following guidelines for designing and understanding robot group behaviours:

(1) **Establish Initial Trust Through Simple and Approachable Movements.** For first time interactions, use non-threatening, exploratory movements such as Gather, Scatter, Follow, and Lead for establishing a connection. These patterns initiate engagement, evoke curiosity, and avoid overwhelming participants. Additionally, they encourage users to transition from passive observers to active participants, fostering integration into the interactive environment.

(2) **Test Boundaries to Build Familiarity and Understanding.** Movements like Trap, Merge, Retreat, and Mirror help explore physical and social boundaries between robots and users. These actions build on prior behaviours, showcasing functionality and fostering familiarity. Boundaries can include both positive and negative elements, as long as they aid user adaptation. Gradually increasing proximity as trust develops encourages natural and comfortable engagement.
(3) **Incorporate Playful and Interactive Behaviours for Positive Emotional Responses.** Patterns like Mirror and Play, which emphasize fun and mimicry, elicit high levels of positive engagement. These playful and interoperable patterns can transform initial hesitancy into trust, enhancing the emotional bond between users and robots. Use such behaviours strategically to create moments of joy and interaction, deepening the connection between humans and robots.
(4) **Avoid Perfect Synchronization in Group Movements.** Overly synchronized group robot movements can appear militaristic and unsettling. Introducing variability in timing, proximity, and patterns makes group behaviours feel more natural and relatable, fostering positive user perceptions.
(5) **Leverage Zoomorphic Movement for Emotional Resonance.** When designing quadruped robots, draw inspiration from the movement patterns and behaviours of analogous animals, such as dogs, to evoke familiarity and positive emotional responses. However, balance this approach carefully to avoid excessive zoomorphism, which may lead to discomfort through the uncanny valley effect.

8 LIMITATIONS AND FUTURE WORK

8.1 Limitations

8.1.1 Central Server. To design the movement of the robots, we used a simple coordinated approach in which robots were independently controlled and their paths precisely programmed. The robots we used and the method with which they had to be programmed required this. In future work, a central server that handles and controls the movements can help in further automating the design process and avoiding human error in coordination.

8.1.2 Battery Life. The current version of our robots has a limited battery life of approximately 2 hours, which meant that any testing and iteration of movement patterns had to take this into account, with regular breaks for recharging. We anticipate that with recent developments in battery technology, this issue can be solved with robots with longer battery life.

8.1.3 Hardware Limitations. Another limitation of our hardware is that each of the robots had slight differences in their locomotion capabilities. This meant that despite using an identical script, there were slight variations in angle and distance during execution. During our prototyping phase, we took additional measures to account for these variations. Hardware limitations restricted complex movements in the patterns, as we did not have full access to the sensors in the robots.

8.1.4 Language Misinterpretations. As mentioned previously, there were many instances where the language used to describe movements was unclear to participants and likely affected their choices when selecting a movement description. This is because the terms were derived from performing artists who might have slightly different language usage than non-expert users. In the future, multiple synonyms of each term should be provided to provide more clarity to users from different backgrounds.

8.1.5 Studying Deeper Social Robot Interactions. In Experiment 3, while participants knew they were interacting with robots, many were unsure how to engage with them meaningfully, creating a gap between intention and interaction. This often resulted in users positioning themselves as observers rather than active participants in the performance, which hindered deeper interaction. Moreover, a majority of participants expressed a tendency to dominate the robots rather than treat them as equals in the study. As a result, the collaborative potential of interactions was underutilized, limiting the depth of engagement. Future studies should explore methods to encourage participants to see robots as equal partners to achieve more meaningful and balanced interactions.

8.1.6 Participant Demographics. Many of our participants were young people (mean age 25.5) with high self-rated technical ability (13/20 participants had a technical degree related to computers or programming and the average rating was 4.5/5). In continuation of this work, users with a wide variance in experience with technology should be involved, to see how movements are perceived by those with a possible distrust of technology.

8.1.7 Environmental Settings. Our experiment was conducted in an ideal environment, using a pre-planned 3x3 grid. During the experiment, only one participant and three robotic dogs were present in the space. However, real-world application environments may contain more distractions due to differences in space and surroundings. Therefore, further validation is needed to assess the feasibility of our experiment in practical settings.

8.2 Future Directions for Research in Robotic Movement Patterns

Building on the current study, several promising directions for future research could deepen our understanding of robotic movement patterns and their role in human-robot interaction. These directions focus on adaptive behaviours, human-robot collaboration, emotional expressiveness, long-term interaction, and the integration of advanced technologies, ensuring a more comprehensive approach to designing robotic behaviours.

8.2.1 Adaptive and Context-Aware Movement Design. Future research could explore how robotic group movement patterns adapt dynamically to their environment and social context. In dynamic environments, robots must respond effectively to unpredictable elements such as crowded spaces, moving obstacles, or bystander behaviour. Additionally, cultural factors influence the perception of movements, as norms for personal space, gestures, and non-verbal communication vary widely across cultures. Research could also design task-specific movement behaviours for scenarios such as caregiving, search-and-rescue, or entertainment, where the robots' physical and social responses must align with their operational context.

8.2.2 Enhancing Human-Robot Collaboration. A deeper focus on human-robot collaboration could investigate how robots and humans work together as equals. Robots could dynamically adjust their roles within a group, transitioning between leading, following, or supporting based on human behaviour and situational demands. Studies could also examine the social facilitation effects of robotic group behaviours, understanding how these behaviours positively influence human performance, motivation, and teamwork. Furthermore, designing movements that calibrate user trust over time would ensure reliability and reduce user anxiety, fostering more effective and harmonious collaboration.

8.2.3 Expanding Emotional and Narrative Design. Future research could further leverage principles from drama and performing arts to develop more expressive robotic movement libraries. These libraries would include movements designed to evoke specific emotions or convey complex narratives, enhancing the robots' social and communicative capabilities. Integrating movement with multi-modal communication, such as lights, sound, and haptics, could create richer interactions. Additionally, exploring the role of intentionally unsettling or "negative" behaviours could reveal new opportunities for robotic applications. For example, movements that evoke militaristic or tense imagery could be useful in security tasks or immersive entertainment scenarios, where such behaviours align with interaction goals.

8.2.4 Exploring Long-Term Human-Robot Relationships. While most current studies examine short-term interactions, future research could investigate the long-term effects of human-robot relationships. Sustained interaction studies would help understand how user perceptions and behaviours evolve over extended periods. Research could also explore how robots take on nuanced social roles in daily life, such as companions, co-workers, or assistants, and how these roles influence human well-being and productivity. Alongside these studies, addressing ethical considerations—such as dependency, privacy, and the psychological impact of prolonged interaction—would ensure the responsible development of social robots.

8.2.5 Generalizing Beyond Quadrupedal Robots. Expanding current findings to other robotic forms could provide universal insights into movement design. For example, studies could explore heterogeneous robot group interactions, such as drones and ground robots, with varying movement capabilities. Varying speed, gait, and acceleration could assess how they may affect emotional responses and perceptions of movement. Research might also investigate how abstract or industrial robots, which lack zoomorphic characteristics, can benefit from principles drawn from performance arts and narrative design. This expansion would create more versatile guidelines for designing socially engaging robotic systems across diverse platforms and applications.

By pursuing these research directions, future studies can push the boundaries of HRI, enabling robotic exhibition of adaptive, expressive, and context-sensitive behaviours. These advancements would enhance the utility of robotic systems, and also foster meaningful and emotionally resonant human-robot interactions. As robots become increasingly integrated into human environments, designing movement patterns that align with social, cultural, and emotional expectations will be crucial to ensuring their acceptance and effectiveness.

9 CONCLUSION

In this paper, we integrated principles and techniques from Drama and the performing arts into Human-Robot Interaction research to address the under-researched area of dynamic expressive movement for groups of quadruped robots. We developed a series of interaction patterns for a group of three quadrupedal robots that were both positively and accurately perceived by human users. Our research was conducted in three phases. First, a director collaborated with non-expert participants to explore trends in group movement using Viewpoint movement techniques. This process conceptualized of a foundational set of movement patterns. Next, our expert iteration performance workshop involved a director and an actor working directly with the robots. The actor's expertise in movement refined a set of twelve movement patterns, providing nuanced feedback to enhance the robots' expressive capabilities. Finally, in our user study and evaluation, 20 participants interacted with the finalized movement patterns. Participants provided emotional responses and selected descriptive terms from a predefined list for each movement. Their feedback was analyzed to identify elements contributing to positive or negative perceptions of the robots' movements. Our iterative studies demonstrate the value of performing arts methodologies in robot movement design, bridging the gap between technical and artistic disciplines while also outlining a framework for designing and refining robot movements through exploratory workshops and expert feedback. By systematically assessing user feedback, critical factors influencing the positive perception of group robotic movements were identified. Finally, we contribute a foundational set of principles and guidelines for designing group movements for quadrupedal robots. These guidelines aim to promote positive human perception and emotional engagement in scenarios involving robot ensembles.

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