The Greeting Machine: An Abstract Robotic Object for Opening Encounters

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***Abstract*— Opening encounters are an integral element of everyday social interaction, and are essential for forming and maintaining social relationships between people. We present an abstract non-humanoid robotic object called the Greeting Machine, designed to communicate positive and negative social cues in the context of opening encounters. The design includes a small ball rolling on a larger dome, with a custom gear and lever mechanism that supports a variety of subtle movements. Gestures were designed with movement experts, and were evaluated using a physical first-person qualitative study. Our findings reveal that an abstract robot designed with no specific metaphor can effectively take part in opening encounters. Furthermore, a minimal brief movement, designed as an Approach or Avoid gesture, may be enough to evoke positive and negative experiences. The ability to create opening encounters with low Degree of Freedom abstract robots is promising, both due to the low complexity, low cost, and design flexibility of such devices, and due to the possible generalization of the Approach and Avoid gestures for a variety of morphologies.**

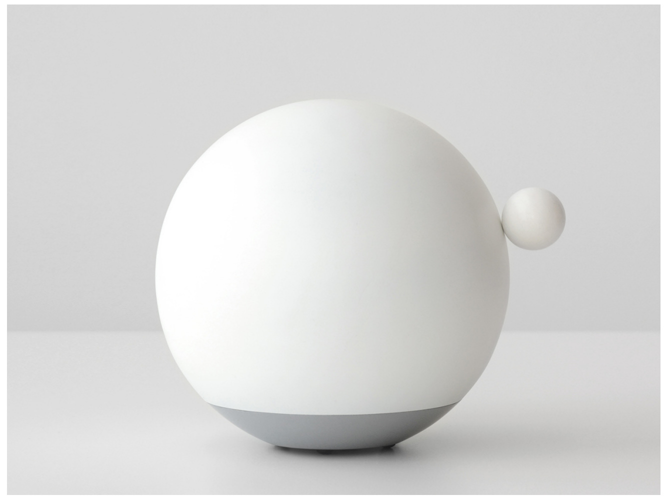

Fig. 1. The Greeting Machine, a low-DoF robotic object designed for opening encounters, in the form of an abstract ball rolling on a dome.

I. INTRODUCTION

Imagine the first few seconds of a social encounter when entering a space. During these initial seconds, you constantly receive and evaluate non-verbal cues coming from the other person [1], forming an immediate impression of their willingness for social interaction. The impression formed in such *opening encounters* will often influence both the course of the interaction and attitude in the interaction [2]. Research in human social interaction shows that opening encounters are a universal act [2], [3], which involves a rapid exchange of non-verbal cues indicating if one is welcoming or avoiding the other person [4], [5]. As such, opening encounters can be either positive or negative [1]. This ”non-verbal signaling” has been found to affect the following social interaction for example, a positive encounter can lead to prolonged social interaction, while a negative one can lead to avoidance of interaction [2], [4].

Opening encounters were also shown to influence psychological aspects beyond the interaction. Improvements in mood, motivation, and general wellbeing have been found following a positive opening encounter [2], [6], [7]. The importance of opening encounters is also evident in industry, where employees are assigned to provide positive opening encounters to customers [8]. In sum, opening encounters are an integral element of social interaction, essential for forming and maintaining social relationships [4], [5].

In this paper we present the design and evaluation of the “Greeting Machine”, a non-humanoid robot intended to take part in opening encounters.

Recently, robots have started to take a role of greeting or welcoming in a variety of service industries including retail, hotels, public transport and more [9], [10]. Robots performing this role are used to promote services, attract new customers, and create a pleasant atmosphere [11]. These robots are commonly designed with humanoid appearance and communicate opening-encounter cues by mimicking human behavior. Most of them also include verbal greetings [10]–[12]. Human Robot Interaction (HRI) researchers studied a variety of opening encounters with humanoid robots. Behaviors were usually human-like and included communication cues such as facial expressions, nodding, hand-waving, and eye gaze [13]–[15]. These human-like nonverbal behaviors were shown to be successfully interpreted as social cues [13], [16]. A few studies tested social interactions including opening encounters with non-humanoid robots designed as everyday devices, such as an ottoman, a car seat, and automatic doors [17]–[19]. The non verbal cues expressed by these non-humanoid robots were successfully interpreted as a social interaction related to greeting.

Non-humanoid robots have several advantages that make

*This work was not supported by any organization

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them leading candidates for social interaction in daily contexts [20]. From a design perspective, taking away the constraint of a human-like figure allows flexibility and freedom for the designer [21]. Moreover, non-humanoid robots are mechanically simpler, have fewer Degrees of Freedom (DoF), are more reliable and therefore are easier to control and cheaper to manufacture. Finally, in the context of social interaction, non-humanoid designs reduce unrealistic expectations, a known phenomenon with humanoid robots. These expectations include a desire for human-like behavior, that may result in frustration [20], [22]. From a broader perspective, animation studies on the relationship between appearance and acceptance indicate that abstract characters tend to be accepted more easily [23].

At the same time, non-humanoid robots also present challenges. Their limited movement capabilities restrict communication modalities, and most communication is typically done through physical gestures [24]–[29]. Therefore, the interpretation people assign to physical movements of non-humanoid robots is a key question. Specifically in the context of social interaction, it is critical to better understand if there is consistency between specific movements and their social interpretation.

A relevant indication was offered by the seminal study of Heider and Simmel who showed that people interpret even geometrical shapes as presenting social cues based on their movement alone [30]. From an HRI perspective, this suggests that movement of non-humanoid robots may also be interpreted as social cues [31] even if the robot's design is abstract and does not resemble or serve as a known device, such as furniture or a door.

Designing and studying non-humanoid robots that are extremely abstract has several advantages. First, it can lead to simple mechanisms providing high reliability, for use in user studies. Second, they can be studied independently of people's preconceptions about the object's abilities and purpose. But perhaps most importantly, abstract designs can help distill the fundamental characteristic of movement, which then can be mapped to a variety of morphologies.

Building on this motivation, we present the design of an abstract non-humanoid robotic object called the Greeting Machine (Fig. 1). We present the design, implementation, and evaluation of its ability to communicate positive and negative opening encounter cues. The robot is designed as a small ball rolling on a larger dome, with a mechanical design that supports a variety of subtle movements. Gestures were designed with movement experts, generated using a custom-written robot control framework [32], and evaluated in the context of an opening encounter. We found that people experience the robot's behavior as an opening encounter, and attribute a wide variety of relevant social expressions to the robot's gestures.

II. RELATED WORK

Relevant previous studies on non-humanoid robots can be classified according to the following domains: robots designed as everyday devices in the context of opening encounters; abstract robots in the context of emotional perception; and the relation between minimal movement and the perception of social cues.

A. Opening Encounters with Everyday-device-like Robots

Opening encounters have been studied with non-humanoid robots designed as everyday devices, such as an Ottoman, a car-seat, and a door. Tennet et al. (2017) designed and evaluated the expressiveness of car seat motion (2 DoF) [18]. Using the Laban effort features the researchers assigned different vectors for each expressive movement (time, space, weight, and flow). When the car seat movement pattern involved specific forward and backward movements of the backrest, participants perceived the seat as greeting them.

Another positive opening encounter experience was presented by Ju and Takayama (2009), who showed that extreme minimal movement (1 DoF) of an automatic door was perceived as a social cue. Door trajectory and speed influenced people's interpretation of the door's intentions. Specifically when the door opened (with or without a pause) in response to participants' proximity, participants perceived it as welcoming and inviting [19].

A further aspect of positive opening encounters was shown by Sirkin et al. (2015). They studied reactions to approach movements of a 'Mechanical Ottoman' and showed that participants viewed the ottoman's movements as "indicators of intention to interact". Specifically, a quick (but not too quick) movement towards the participant was interpreted as an offer to engage in interaction. The author's suggested path trajectory (indirect, curved) and a pause (at a meter distance from the participant) as additional factors to consider in movement design for social interaction [17]. These studies indicate that it is possible to communicate positive opening encounters with non-humanoid robots designed as everyday devices. Gestures and social cues conveyed by these robots are coupled with the robot's everyday function [33]. Our work extends this prior work by studying opening encounters with a robot designed as an abstract, unfamiliar object that does not have an everyday function.

B. Emotion Perception with Abstract Robots

Another class of studies evaluated people's emotion perception when interacting with abstract non-humanoid robots. For example, minimal movement of a robot designed as a stick [34] was consistently interpreted as representing the robot's inner state. A more recent study with a robotic speaker found similar results [35]. In some studies participants associated specific gestures with specific emotions (e.g. happiness, sadness, fear) [34], [35]. These studies imply that movement of an abstract robot has the potential to be interpreted as a positive or negative social cue. Our work extends this prior work by studying an abstract robot in the context of opening encounters (not emotion perception).

C. Minimal Movement and Social Cues

Based on indications from human-human interaction that people are able to perceive social cues from minimal human

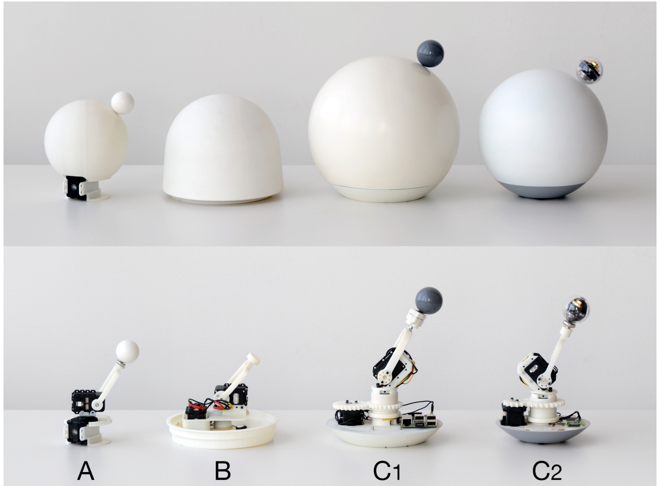

Fig. 2. The Greeting Machine iterative prototypes.

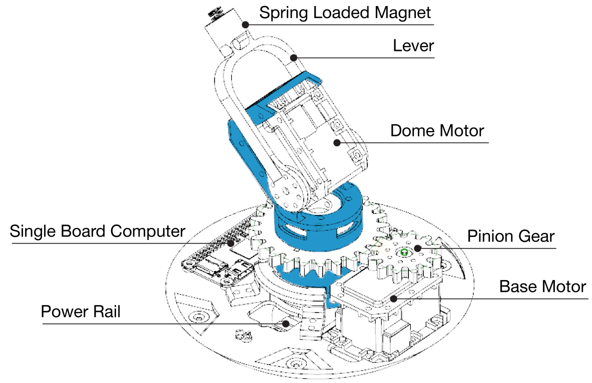

Fig. 3. The mechanism of the robot includes a base rotation linked to a tilting lever. The lever holds a magnet actuating the ball outside the shell.

movements [36], HRI researchers tested if minimal gestures of non-humanoid robots can be perceived as social cues. For example, minimal posture changes of abstract robotic objects were perceived as an indication for the robot's engagement in a task, when synchronized with a human performing a task [25], [37]. Our work extends this prior work by studying minimal movement in the context of opening encounters.

III. DESIGN PROCESS & IMPLEMENTATION

The design process of the Greeting Machine, a non-humanoid abstract robot was initially inspired by the Gestalt theory study of basic geometric shapes [38], [39]. We also drew inspiration from the studies by Heider & Simmel [30] and character animation, specifically the practice of reducing emotional expression to simple animated geometric shapes [40]. From the variety of geometric shapes, we focused on a design language of spheres and curvilinear movement, informed by the studies of Arnoff *et al.*, who found that curvilinear forms are associated with emotions of pleasantness, happiness, and warmth [41], [42]. A series of initial sketches and low-fidelity prototypes converged to a two-part design: a larger static sphere (dome), and a smaller moving sphere that rolls around the larger sphere surface as a gesture mechanism (ball). The relation between the two spheres was intentionally designed to not resemble a human face feature such as a pupil or nose. One metaphor the design team was inspired by is an abstract spherical "creature" (the ball) navigating a spherical "planet" (the dome).

A few prototypes were explored to strike the right balance between the mechanical requirement of movement range and the overall aesthetics (Fig. 2). These prototypes included a small two-ball design (A), with actuation underneath the robot; a dome-shaped ground body (B), and two versions of a spherical shape with cut-off bottom - (C1) and (C2). The latter approach was eventually chosen for its clean appearance and expressive movement range.

A. Technical Implementation

From a mechanical design perspective, the Greeting Machine consists of a 2-DoF polar coordinate mechanism mapped to the sphere's surface by actuating a base rotation of a tilt lever (Fig. 3).

A rare-earth neodymium magnet is mounted at the end of the lever. The ball is placed on top of the dome's surface, and through magnetic force the ball moves in a rolling motion across the outer surface of the base sphere.

The design of the ball's internal mechanism required special attention, with two goals in mind: (1) The ball should roll and not drag across the shell surface, and (2) when the ball rapidly changes direction, a secondary motion should be clearly noticeable indicating the inertia of its movement in a cartoon-like fashion. Fig. 4 shows a variety of ball designs we tested. The relevant factors were the material of the outer shell and the internal mechanism. Material exploration included 3D printed plastics (PLA / ABS), injection molded plastic, steel, and rubber. Internal mechanism explorations included 1 and 2 DoF motion constraints, as well as shape, quantity, and size of the ferromagnetic material. For example, 20mm round neodymium magnet, 15mm round ceramic magnet, 12.7mm steel bearing ball, and multiple 5mm steel balls. The final design included a non-magnetic 12.7mm steel bearing sphere inside an injection-molded exterior, with no internal motion constraints.

Fig. 4. Various rolling balls designed and tested with the Greeting Machine, spanning a variety of external materials, internal rolling constraints, and ferromagnetic components.

Fig. 5. A choreographer and character animator discuss gesture design using a puppet version of the Greeting Machine.

B. Electronics and Software Control

The hardware includes a Raspberry Pi model 3 control board and two Dynamixel MX-12w motors. The software is based on a custom-written robot control framework running on the Raspberry Pi and written in both Java and Python. The software framework enables translation of gestures designed in 3D animation tools (we used Blender) to motor commands, supporting complex gesture design by non-programmers [32].

C. Gesture Design

Designing gestures for an opening encounter using an abstract non-humanoid robot is uncharted territory, as there is no direct mapping of human gestures to abstract non-humanoid robots. Prior work in the field focused on humanoid robots that mimic human greeting gestures [43], [44], and on non-humanoid robots designed as everyday devices that can leverage the device's metaphor and function to communicate an opening encounter [18], [19].

We used guided improvisation in collaboration with movement experts [45], [46]. Since the robot is an abstract non-humanoid object, the experts could not use their body to demonstrate the gestures. To that end, we built a 1:1 low-fidelity prototype of the Greeting Machine as a passive puppet, on which the movement experts demonstrated the gestures they envisioned as most appropriate for opening encounters. The experts were four movement specialists: an animator, a puppeteer, a choreographer, and a comic artist. The low fidelity prototype included a probe, a small ball connected to the end of a stick, enabling demonstration of gesture trajectories on the dome (Fig. 5). We invited all movement experts to a four-hour joint brainstorm session. We explained the related theory on opening encounters and the challenge of mapping humanoid gestures to an abstract non-humanoid object. The experts used the probe intensively, asked us to walk into the room and towards the Greeting Machine from various angles and in various behaviors, including changes in pace, body orientation, and pauses. They demonstrated various gestures using the probe, engaged in active discussion about various artistic inspirations such as object theater, character animation, and puppetry, discussed possible personalities for the Greeting Machine, and debated specific movement characteristics such as start position, pace, style of movement, end position, vertical vs. horizontal movement, straight vs. curved trajectories, and more.

Toward the end of the session they reached a consensus, recommending to focus on the start position and the ball's direction of movement. Specifically, movement should start from a position that is hidden from the approaching person, so the ball gradually reveals itself to the person. They called this movement an ”Approach” gesture. In addition, they suggested a reversed movement, with a start position in front of the approaching person, and gradual movement away from the person until the ball is hidden. They called this movement an ”Avoid” gesture. They also recommended that in both Approach and Avoid gestures, the movement should not be designed as a direct point-to-point movement, but rather as a winding and animated movement, with curves and turns along the way.

Based on the movement experts' recommendations, we defined two main gestures: Approach (back-to-front) and Avoid (front-to-back). We also defined two styles of movement: Straight (direct point-to-point) vs. Animated (indirect, with curves and turns). In addition, we defined two types of ball visibility: Always Visible (the ball is always present in participants' field of view) vs. Partly Visible (the ball is hidden from participants' field of view, either at the start or end of the movement). Gestures were implemented by an animator. The result was a set of four Approach and four Avoid gestures (Fig. 6).

IV. EVALUATION STUDY

We conducted a physical first-person qualitative study with the Greeting Machine in the context of an opening encounter to evaluate how participants perceive the minimal gestures of the abstract robotic object.

A. Method

1) Participants: 26 participants (undergraduate students, ages 19-24 (88%) and 25-34 (12%); 19 females, 7 males) were recruited and received course credit for participation. All participants signed a consent form and filled a demographic questionnaire. The experiment was carried out in English.

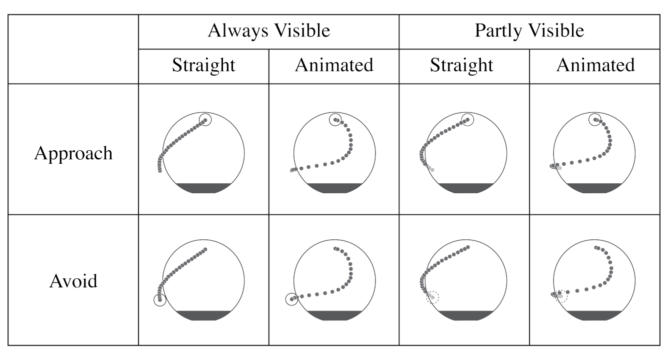

Fig. 6. The eight gestures used in the study, designed according to the movement experts' recommendations. The ball represents the end position.

2) Procedure: The experiment was conducted in a research lab to evaluate participants' experience with no association to a specific environmental context (i.e. home or work). The robotic object was presented in a vacant carpeted room with a large partition initially blocking participants' view (Fig. 7). To create an opening encounter experience, participants were instructed to walk alongside the partition, stop at a specific position (marked by X on the floor) and then turn and face the center of the room, where the Greeting Machine was visible. When participants turned to face the Greeting Machine, a gesture was triggered. No other instructions or descriptions of the robotic object were given. The Greeting Machine was placed on a small desk (75cm high) at a distance of 1.5m in-front of the X mark. By using a fixed distance for all interactions we verified there are no proxemic influences. The researchers viewed the experience from a control room through a camera, and used a Wizard of Oz (WoZ) [47] mobile application to trigger a desired gesture. When the gesture ended, a short sound was played indicating the interaction was over and that the participant should leave the room. After a short break outside the room, the participant re-entered the room and experienced another opening encounter with a different gesture. Each participant experienced 8 gestures, which were counterbalanced across participants. Upon completing eight interactions (one with each gesture) participants were asked to re-enter the room for a 10 minute semi-structured interview. The interview included questions concerning participants' overall experience, their thoughts about the design of the robotic object, and their suggestions for real-life applications of the Greeting Machine (i.e. 'what did you think the robotic object was doing when you entered the room?'; 'what was your general impression of the robotic object?'.) During the interview the Greeting Machine did not perform any gestures. The experiment lasted approximately fifteen minutes and was documented by audio and video.

B. Qualitative Analysis Process

Interviews were transcribed and read several times to develop a general understanding of the data before the coding process began. We followed the Thematic Analysis approach [48] including three stages. First, the primary rater reviewed all transcripts and identified initial emerging themes. The initial themes were presented to a second researcher and discussed in depth, inconsistencies were discussed until resolved and a list of mutually-agreed themes was defined. Second, the primary rater and an additional rater analyzed a selection of the data independently, inter-rater reliability was tested and found to be high (Kappa = 84%). Third, following inter-rater reliability validation, the two raters analyzed the rest of the data.

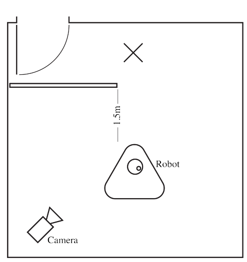

Fig. 7. Evaluation study setting: Participants walked along the partition, stopped and turned to watch the Greeting Machine's gestures.

V. FINDINGS

750 quotes were analyzed, leading to the following three themes: *Opening encounters statements*; *Context of Use*; and *Design Aspects*.

A. Opening encounters statements

Most participants perceived the interaction with the Greeting Machine as an opening encounter, reporting on a social and emotional experience. They perceived the minimal gestures of the abstract non-humanoid robot as social cues. Participants described the Approach and Avoid gestures as indication for the Greeting Machine's willingness or unwillingness for social interaction: *"When it was turning and facing me then I thought it was really welcoming [...] when it was facing the other side I had the feeling that he doesn't want to see me, that I should leave him alone, that I should leave the room."* (P6).

Participants often perceived the Greeting Machine's intent as loaded with judgment *about them*. When an Approach gesture was triggered, most participants perceived it as signaling that they were acceptable for social interaction (i.e. a positive opening encounter cue): *"when he moves he was like 'I just want to interact with you'."* (P20). Participants described varying levels of acceptance from the opening encounter: *"[...] he would be like 'oh I'm super excited,' or he would be like 'I just need to know who she is'[...] when he was moving a little bit more maybe he was excited to see me."* (P20). One participant diverged from this trend and perceived the Approach gesture as an aggressive cue signaling that he was not acceptable for social interaction: *"I felt it was just looking at me, staring at me, the same way you pass by the street and there is an aggressive dog at the gate and it looks at you in an unpleasant way."* (P8).

When an Avoid gesture was triggered, most participants perceived it as signaling that they are not acceptable for social interaction (i.e. a negative opening encounter cue): *"I had the feeling he, it, is avoiding me, like it feels uncomfortable. That's why it wants to turn away."* (P6). They described the Greeting Machine as intentionally ignoring them: *"When it was turning away, it was trying to shut me down and pretend that I'm not here."* (P17). One participant felt that the Greeting Machine was judging her: *"It was pretty judgmental, it looks at you, it detects that you're here, and then decides whether it wants to face you or doesn't want to face you."* (P10). Others mentioned that the Greeting Machine does not want to interact with them because of the robot's internal state, not because of them. They attributed emotions to the Greeting Machine that would explain the avoid gesture such as "shy" or "scared": *"I felt it was actually hiding [...] like he was scared. I thought maybe* *he doesn't know me but if I start being nice to him, he will turn and look at me."* (P1); *"When he looked away he was shy, maybe he doesn't know who I am, maybe I'm a new owner who hasn't used him before."* (P16). One participant hypothesized that the Greeting Machine's internal state was a result of his own behavior *"Maybe he was scared of me, because he sensed that I was angry at him."* (P14).

Most participants mentioned the ball's visibility in their statements regarding the opening encounter. The Partly Visible gestures (ball not always present in participants' field of view) were associated with stronger emotional expressions than Always Visible gestures. This was especially evident in Avoid gestures: *"When it went all the way back I was expecting something else to happen, hmm.. I just felt like...I think I felt a little rejected.* (P3). The Straight vs. Animated style of movement was not mentioned as a factor influencing the opening encounter experience.

Participants also described their own response to the Greeting Machine's willingness or unwillingness for social interaction. When they felt that the Greeting Machine found them acceptable for interaction, responses were positive: *"When it stared at me, I was happier than when it wasn't. When it turned to me, it made me smile a little."* (P15); *"When it looked straight at you then you knew the situation was fine, because it was greeting you and everything was okay."* (P26). When they felt that the Greeting Machine found them unacceptable for interaction, they felt rejected *"I was a little annoyed: Why is he not looking at me again?"* (P1). Some of them even became angry: *"when he was facing the wall, it was really not nice. I was standing right there looking at him. I was thinking: Why are you doing that? It's not nice, not polite."* (P6). Participants were also intrigued by the fact that this abstract object could make them feel emotional: *"When I would walk in and it would face away from me, it was like "I don't want to talk to you". It's weird, because it's an object and it shouldn't make me feel anything, but it did. It's the same as if a person wouldn't want to talk to you."* (P10).

B. Context of Use

Participants envisioned themselves using the Greeting Machine in a variety of use cases, almost all in context of opening encounters. Most participants described it in a home setting: *"I would put it in my house by the entrance, so when I walk in this robot is greeting me. It's similar to when you come home and a person greets you. It may be a robot but it feels similar to a person greeting you."* (P10). Others described it as a greeting robot for guests: *"Maybe I could use it as a device to greet house guests when they come by the door. It could make them feel more at home."* (P21). Few participants explained why a workplace setting is more appropriate: *"It would make more sense in my office, because at home most of the time I have people who are welcoming me, and in the office I work late nights, so it would be nice [...] giving me a feeling that I am not alone. Clearly I realize that I am alone, but it's still something that is there [...] I don't know how to explain it."* (P13). Other participants associated it with dispelling loneliness or a bad mood: *"It would be really cool if you're living alone or you're far away from everyone you love, you come in and it's excited to see you"* (P20); *"When someone is having a bad day and comes back home, and suddenly they turn around and: Hello!"* (P14).

C. Design Aspects

Participants described the Greeting Machine in abstract terms with no association to a specific function. They mentioned form, color, visual aesthetics, and movement. Participants did not have a consistent metaphor for the Greeting Machine: *"It was different.. it's just a thing."* (P10), *"It looks futuristic, like nothing from this real world or from this decade, like something from the distant future"* P(17). Some participants related directly to the spherical aesthetic language: *"Its spherical form makes it kind of calm."* (P3), *"very clean, white, and circle, and a little ball"* (P19). Several participants thought the design was too limited. Some of them stated a robot should resemble humans: *"The interface is so extremely simple, that you don't feel like it's an actual robot [...] If it's about interaction with other people it should look more human."* (P23).

Interestingly, participants' desire to have more human features did not prevent them from perceiving the gestures as opening encounters. For example, P5 criticized the design and suggested it should resemble humans: *"It's very simple. It looks more like an object and less like a person [...] just like a thing that's there, and doesn't make it look friendly or welcoming or warm."*. However the same participant described the interaction as: *"It turned to me and turned away and then turned to me again. It set off this whole scenario in my head, when I come back from work. I felt it's similar to someone waiting for me at home, a person I live with, who can be mad at me or happy to see me."*.

VI. DISCUSSION

In this work we presented an abstract non-humanoid robot designed for opening encounters, with no specific metaphor related to an everyday device. A set of gestures were designed in collaboration with movement experts, and were evaluated in terms of the reactions from people experiencing them. Using a qualitative within-subject study, we demonstrated that even minimal Approach and Avoid gestures of an abstract robotic object can be perceived by people as both positive and negative opening encounters. Specifically, participants perceived the interaction with the Greeting Machine as an emotional and social experience. Participants' rich statements validate that an extremely abstract non-humanoid robot, performing minimal Approach and Avoid gestures, can signal to participants whether they are suitable for social interaction.

The difference between Approach and Avoid gestures greatly influenced participants' perception of opening encounters. In most cases, the different gestures led to opposite emotions. Approach gestures were associated with a range of positive emotions perceived as willingness for social interaction, including *acknowledging, welcoming, happy to see me, wanting to interact with me, excited to see me, etc*. Avoid gestures were associated with a range of negative emotions, perceived as unwillingness for social interaction, including *being shy, ignoring, avoiding, wanting me to leave the room, wanting me to leave him alone, rejecting me, etc*. In addition to the difference between Approach and Avoid, the ball's visibility was also mentioned by participants as a factor influencing their experience. Participants' statements had higher intensity when the ball was not Always Visible. The difference between Straight and Animated movement was not mentioned by participants as a factor influencing their experience.

Compared with the Approach gestures, participants reactions to the Avoid gestures involved more descriptive, complex reactions, with increased intensity and more causal attributions. For example, a typical description of Approach gestures was: *"It was really welcoming, like 'look at me', very friendly"*, while a typical description of an Avoid gesture was: *"It doesn't want to see me, like, it wants me to leave him alone"*. This imbalance corresponds with the common human tendency to perceive negative stimuli in a richer way than positive ones, even when their informational value is equivalent. It was previously shown that negative experiences are considered for longer periods and elicit more extreme attributions. When evaluating objects, negative aspects are typically weighted more heavily than positive ones. Specifically, people consider negative feedback and rejection as extreme negative events [49]. These may explain the intensity of the reactions to the Avoid gestures. An alternative explanation for this imbalance may be the unexpected nature of negative events [49]. When humans interact with robotic devices in social contexts, they commonly expect the robot to comply with social norms, and in this case - be positive or neutral. Challenging these expectations leads to perceiving the robot as rude and condescending [18]. Hence, participants' unmatched expectations in the Avoid gestures condition may have led to the heightened effect.

Participants' suggested use cases were very relevant for opening encounters, including welcoming themselves, or guests, at the entrance of a house. Some mentioned the experience could be a positive greeting when entering their home when there's no one there. One participant even associated the robotic object experience to a mother welcoming children when they come back from school (P23). Such use cases imply that despite its abstract design and minimal movement, participants were able to envision the Greeting Machine as an appropriate entity for an opening encounter.

The variety of associations participants mentioned when discussing the Greeting Machine's appearance indicated that the design was not associated with a consistent metaphor, (neither human nor an everyday-device), thus supporting the claim of an "abstract design" for the Greeting Machine. This inconsistency did not interfere with participants' ability to perceive the gestures in an opening encounter context, as suggested by the participants' interpretation of the experience (welcoming, ignoring, etc.) and the metaphors they used to describe its movements (looking, hiding, etc.). A possible explanation for this finding is that the movement parameters themselves contributed to peoples sense of being invited or declined for social interaction. This is in line with indications that people tend to attribute social interpretations to moving abstract objects [30].

When specifically asked about the Greeting Machine's design, some participants appreciated the abstract design while others thought that a robot *should* resemble humans, and that the abstract design is too simple. However, the same participants that stated they prefer a more humanoid design had no reservation when envisioning the Greeting Machine as a meaningful entity in an opening encounter. This finding points to an interesting duality. On the one hand, participants expected robots to have human-like features. On the other hand, the same participants perceived the abstract Greeting Machine as a relevant entity for social interaction.

We conclude that interaction with an abstract non-humanoid robot can be experienced as a positive or negative opening encounter. Furthermore, minimal movement, designed as Approach and Avoid gestures, is enough to generate these positive and negative emotions. The potential in creating opening encounters with low DoF non-humanoid abstract robots is promising for two reasons. First, the low complexity, low cost, and design flexibility of such devices can increase their use in research and their market adoption. Second, and most important, the findings from this work inform that abstract designs can help distill the fundamental characteristic of movement, which then can be mapped to a variety of morphologies. As opening encounters are a crucial component of social interaction, our findings may contribute to gesture design of social robots that has additional functions beyond greeting.

Limitations

The present study has several limitations. First, there was a larger representation of females in our sample. We acknowledge this limitation, however our findings demonstrate that both male and female participants used a variety of emotional expressions for the interaction. Future work should explore gender effects in this context. An additional limitation is a possible novelty effect due to the unfamiliarity of the robotic object. While this effect may account for positive responses, our findings show a wide range of both positive and negative responses. Lastly, as our findings are based on University students, their generalizability to different age groups and cultures should be further studied.

ACKNOWLEDGEMENT

We would like to thank Shlomi Azoulai for his early design contribution, Daniel Kuvent for his technical contribution and Nano Magnetics Ltd. for providing magnets that aided in the prototyping process.

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