Dancing Droids:
An Expressive Layer for Mobile Robots Developed Within Choreographic Practice

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Abstract. In viewing and interacting with robots in social settings, users attribute character traits to the system. This attribution often occurs by coincidence as a result of past experiences, and not by intentional design. This paper presents a flexible, expressive prototype that augments an existing mobile robot platform in order to create intentional attribution through a previously developed design methodology, resulting in an altered perception of the non-anthropomorphic robotic system. The prototype allows customization through five modalities: customizable eyes, a simulated breath motion, movement, color, and form. Initial results with human subject audience members show that, while participants found the robot likable, they did not consider it anthropomorphic. Moreover, individual viewers saw shifts in perception according to performer interactions. Future work will leverage this prototype to modulate the reactions viewers might have to a mobile robot in a variety of environments.

Keywords: Human Robot Interaction · Robot Characters · Household Robots · Robot Performance

1 Introduction

As robotic systems are becoming increasingly present in human-facing, social scenarios, they hold the potential to help in assistive tasks in the household. Particularly inside the growing market of older adults, robotic systems can be useful in both functional and affective tasks [4], [5]. In a 2017 report [16] on automation, employment and productivity, social acceptance is described as one of the five key factors in the adoption of automated technologies. This acceptance is owed to multiple factors such as utility, ease of interaction, and hedonic value [27]. Another key factor comes from the concept of psychological attribution, whereby a user's opinion on technology is altered by their perception of a piece of technology, that is influenced by both the physical design characteristics as well as the story around the technology.

Further work suggests that there is a strong link between a user's perception of a robot's characteristics and subsequent user behavior [13], [28]. For instance, work in [24] outlines people's tendencies to interpret human behavior in terms of intentional causal mental states, such as beliefs, desires and intentions, suggesting that this interpretation is an automatic and immediate process that is hardwired into the brain's function. In [25], the authors find that the observation of intentional harm committed to an inanimate entity such as a robotic arm prompts an attribution of mind to the entity. [10] claims that the grouping of a robot in social organization based on gender, age or ethnic identity leads to increased anthropomorphic attribution of the robot, thereby leading to an increased sense of intentionality in its actions.

Users tend to create narratives that explain the animations of robotic devices. For example, consider the plethora of videos on the internet of cats on top of Roombas, and other attributions that range from hilarity to sadness, for this functional, relatively blank, yet prevalent, robotic device [19, 3]. In [12] we see instances where people name their Roomba robot, giving it a social identity. The achievement of social assimilation prompts the user to associate decisions made by the robot to its personality traits, as opposed to the functional algorithm that determines its movements. Prior work [13, 28, 2, 14] tell us that it is natural for humans to try and extract information from robotic actions, subsequently attributing intentionality to robot movement characteristics . In [12], for instance, user study participants describe the movements of a robot vacuum cleaning system, the Roomba as "cute" or "pathetic", even though such a correlation may not have been intentional aspects of the design.

Priming is a tool that can be used to tap into perception through an intentionally designed rhetoric that can be attached to different forms of technology. In [8], Darling et al. explore the relationship between emphatic concern and the effect of priming through stories on human-robot interaction. Results of the study show that people are less likely to strike the insects with a backstory and a name. Along with other prior work [9], [20], [23], this makes a case for the exploration of building characters around household robotic systems that can provide the user with a set of beliefs along with an associated predictability of behavior based on assumptions made from character traits of the system.

Inherently, performance art is an area that aims to suspend an audience's perception of reality through storytelling [11], [21], [26]. Thus, performance serves as a suitable medium to build characters around robots that prime the audience to induce a greater sense of attribution in subsequent interactions with the system. However, flexible platforms on which to build characters that can exhibit distinct character traits in a performance setting are needed in this setting. It is crucial that such a platform have distinguishable, customizable features that allow for the resolution of multiple, separable modes. To this effect, this paper uses the design methodology outlined in [18] and in-studio work with a dance choreographer to produce a customizable prototype suitable for theatrical settings and feasible for near term in-home integration.

The rest of this paper discusses this prototype, its development, and an initial characterization with human viewers. In Section 2, we review a previous design methodology employed here, along with an artistic exploration with an artist-in-residence. In Section 3, we discuss how this prototype was developed through artistic exploration with an artist-in-residence in a robotics lab, and the resulting design of our so-called Dancing Droid (DD). Section 4 outlines a user study and discusses its results. Concluding remarks are made in Section 5.

2 Implementing Desired Attribution Through Choreographic Practice

In prior work we developed a robot design methodology to project character archetypes onto robotic systems of different form factors [18]. This work uses the Kansei Engineering iterative design approach [17], in conjunction with the Product Channel Consumer paradigm [6] and Laban Movement Analysis [22]. This methodology focuses on the information transfer between the robotic system and user [15]. The methodology is outlined in [18], where we used it to abstract known, archetypal characters onto virtual robots. In that work, we learned that in developing backstories based on well-known fictional cartoons, user interactions with these robots come with a lifetime of biases as a result of repeated exposure and memories of the character traits. Thus, in this work, we wanted to explore more subtle, customizable characters with less exaggerated personality types, with the goal of increasing the predictability and familiarity of the hardware without inciting a lifetime of bias. Thus, an artist-in-residence was recruited to work in tandem with a hardware platform development [7].

Inside this residency, we have learned what kinds of features this artist would want in an on stage agent. Moreover, we have an opportunity in which to test perceptions of the robot in a highly flexible contextual embedding (live performance in a theater). Thus, the two efforts have become synergistic and create a unique opportunity to develop a prototype that will helps us learn how to create intentional priming experiences for users of future robot designs. In this collaboration, it became evident that a customizable, cheap robotic layer was needed to augment existing robotic platforms in order to fulfill the expectations of the artist. Through this artistic collaboration, we collaboratively accrued observations that informed our design goals. These observations are:

- The motion of the hardware is limiting; particularly sharp changes in velocity, which characterize a *flick* or *punch* require large force/torque profiles that real hardware struggles to create.
- The hard, plastic moldings of many robots restrict much of the texture of the onstage system. Moreover, several designs, such as on the Aldebaran NAO, tend to imply masculine gender through defined bicep muscles, broad shoulders, and fixed, industrial colorways.
- Many systems incite science fiction comparisons *immediately*, which can be hard to battle. This is especially true of humanoid systems.
- Touching, say a cheek, to these platforms does not create the kind of relationship that even, say, touching a peach to a cheek.
- Having the same robot portray different characters is challenging, specifically in non-humanoid form factors.

– Choreographing movement is an arduous process that involves a lengthy compile time and necessitates the presence of a programmer.

3 Hardware Development

As a result of the findings in the prior section, prototype features should include:

– Customizability in modalities such as color, shape, and texture.
– Expressivity through dynamically unconstrained degrees of freedom like lights.
– Bilateral symmetry established through eyes and movement orientation.
– Accessibility through the use of cheap and readily available parts.

The design in Figure 1 was used to develop a prototype through the implementation choices described here. We use the iRobot Create 2.0 mobile platform as the form factor for the Dancing Droid (DD) prototype. This unit is cost effective, easy to work with, and shares the base design as one of the most popular and prevalent in-home robots, the iRobot Roomba. The DD is comprised of four modular components, easing the process of assembly. These four components, the shell, the core, the eyes, and the expressive lights, are delineated below with explanations of the fabrication and assembly process.

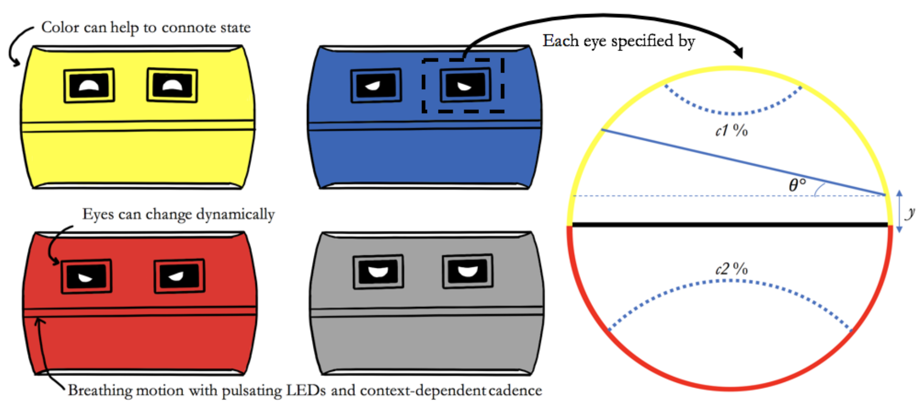

Fig. 1: Left: Different characters layered on the same base platform. Here, we see different versions of dynamically expressive eyes, different colors that can help to connote character traits. The center line represents an LED strip that pulsates to mimic breathing motion. Right: Expressive eye model

Shell The shell encloses the electronic components and gives the DD its intended shape. In order to keep the mass as low as possible, the shell is created by stacking sheets of Expanded PolyStyrene Foam (EPS). The EPS foam is obtained in sheets 1” thick and cut to size in order for it to fit in a laser cutter. The laser cutter is configured with the appropriate settings and the shapes to be cut are input as files generated by the Creo Parametric software package. Once cut, these pieces of EPS foam are glued together to form the base of the DD. The hemispherical top is made of EPS, and is obtained off the shelf. In order to have customizable color, both base and top are covered in colored lycra material.

Internal Control Architecture This core is the center of computing and power distribution of the DD, as shown in Figure 4a. The components are housed in a custom-designed and 3D printed shell that efficiently packs all the electronic components into a compact area, enabling it to fit inside of the shell described in 3. The components housed in the core are a Raspberry Pi 3 with Raspberry Pi Hat, an Arduino Uno with power distribution circuit, a 20100 mAh battery pack and a 3xAA (4.5V) battery pack.

Dynamically Unconstrained Degrees of Freedom Two 1.4" TFT LCD screens are positioned between the dome and the base to create expressive "eyes". As mentioned previously, these screens establish bilateral symmetry and provide an element that can change without less significant velocity constraints than the motion of the vehicle (the dynamic constraints of the LED screens are below the resolution of human perception). They are controlled the Raspberry Pi 3 by means of an Adafruit Snake Eyes Bonnet, an accessory for the Raspberry Pi that was designed explicitly to drive two miniature displays from the same source. The eyes displayed are designed based on an "expressive eye model", as shown in Figure 1. In this model, we start with a base circle that for the eye that divided into the upper and lower halves. We provide specifications for the left eye, with the right eye taking a mirror image of the shape described. We change the following variables to create different eye shapes:

- Chord with clockwise degree and y-axis distance
- Concave circle with percent size *c1* (upper half) and *c2* (lower half).

Additional lights comprised of an individually addressable RGD LED strip that surrounds the base of the Styrofoam shell create the desired "breathing motion" from our design. This strip is programmable and can thus be used to exhibit a different cadence and intensity (brightness) of simulated breathing. Initially, we designed a smooth pulsating simulation of breathing, but this element can be modulated to show changing internal state to a human viewer in an intuitive manner – parallel to other tasks the robot may be fulfilling.

Assembly This construction resulted in an expressive shell that is layered on top of a iRobot Create 2. By changing the programming logic in the Raspberry Pi 3 and the Arduino Uno, we can specify custom expressive eyes, breathing cadence and movement profiles. The finished product is shown in Figure 5. This was used in a user study as is described in the following section.

4 Initial Characterization

The DD prototype was characterized in an showing of an artistic performance piece, entitled *Time to Compile*, at Brown University as part of a residency through the Conference on Research on Choreographic Interfaces (CRCI). The performance was attended by 40-50 individuals. Audience members, from a pool of 36 formal RSVPs, were optionally invited to participate in our user study.

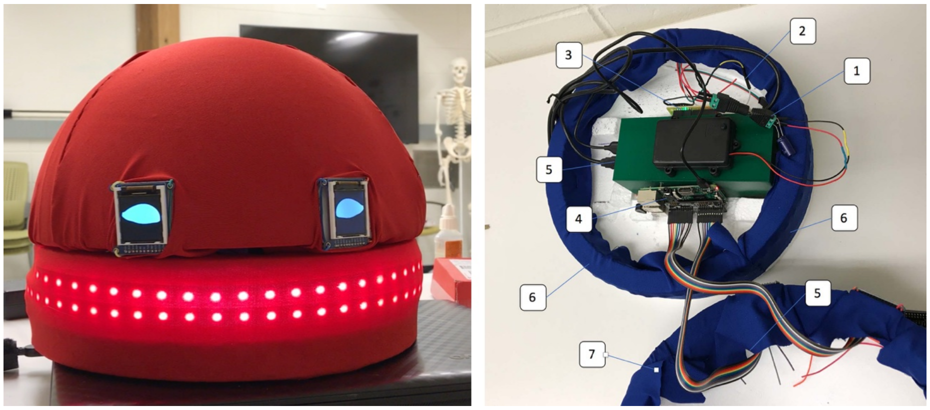

Fig. 2: The finished prototype is shown in the figure on the left, and the internal wiring is shown in the figure on the right. The numbered components are: 1) Power connection between expressive lights and three-cell battery. 2) Data connection between Arduino and expressive lights. 3) Arduino Uno with custom hat. 4) Raspberry Pi with Snake Eyes hat. 5) Ribbon Cables connected to TFT screens. 6) Bottom Shell. 7) Top Shell.

These audience members filled out a presurvey before the performance, a post-performance survey, and a post-interactive installation survey. The responses for the DD specific questions are gathered here. Complications with event logistics and audience appetite for participation results in a limited set of user responses. Audience members were asked to fill out multiple surveys on their phones over the course of the night, which was, in the end, not a convenient method for data collection. Future performance-as-research explorations will improve how the surveys are incorporated in a more controlled way into the actions requested of the audience.

There were 7 participants who filled out the DD specific questionnaire. Of these, 3 were male, 3 were female, and 1 did not identify gender. The age range was 28 - 62 years old. During the performance, these participants were divided into two groups. Both groups saw the robot inside the larger context of *Time to Compile* which takes place in the setting of an abstract robotics lab and uses four total performers to represent the process of programming on a team.

Group 1 participants saw the interaction with the DD during the second half of the performance, witnessing a positive relationship between human performer and robot (left of Figure 3). The performer stood, redirected the DDs movement by tapping it with a foot or kicking it playfully, and smiled, demonstrating that it was a fun and positive interaction. If the DD went out of the boundaries of the performance space, the performer treated this momentary escape as a little joke, before containing the robot by redirecting its movement once more. The performer used calm, deliberate movements, displaying a positive relationship with the DD.

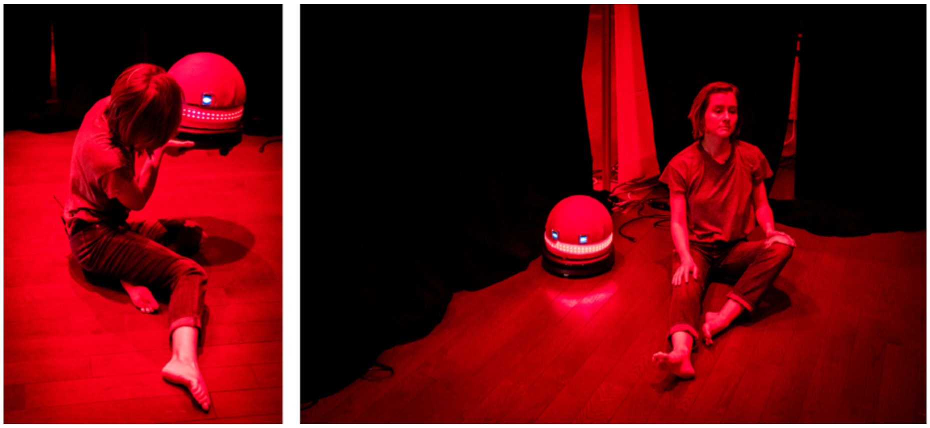

Fig. 3: Left: positive relationship (high valence, high power) during performance; right: negative relationship (low valence, low power) during performance.

Group 2 participants saw the performers interaction with the DD during the first half of the performance, witnessing a negative relationship between human performer and robot (right of Figure 3). The performer struggled with the robot while on the ground, redirected the DDs movement by anxiously hitting it with a hand or foot, and appeared stressed and upset by the robot. If the DD went out of the boundaries of the performance space, the performer would realize it was far away then frantically try to catch it, back away or recoil if it was coming closer or made contact unexpectedly, displaying a negative relationship with the DD. Each of these vignettes were created by variable movement profiles of a human performer.

4.1 Results and Analysis

We aim to explore perceptions of the DD after viewing a positive or negative human interaction relationship as well as gain a baseline characterization of the robot through an established query method. We use an adaptation of the Godspeed questionnaire, a measurement tool often used in human robot interaction research, to evaluate the participants attitude towards robots using semantic differential scales [1]. These questions condense to the three qualities of Anthropomorphism, Animacy, and Likeability. Additional questions also measure the participants attitude about the robots intelligence, outlook, and movement profile, leading a fourth combined quality of Engagement.

In Figure 4, we see what each participant rated the DD on the four Godspeed scales of Anthropomorphism, Likeability, Animacy, and Engagement. The most negative scores were for Anthropomorphism, with an average score of 15.2. Even so, the most positive scores were for Likeability, with an average score of 57.8. Animacy and Engagement were similar, with an Animacy average score of 36.3 and an Engagement average score of 41.0. It is important to note that

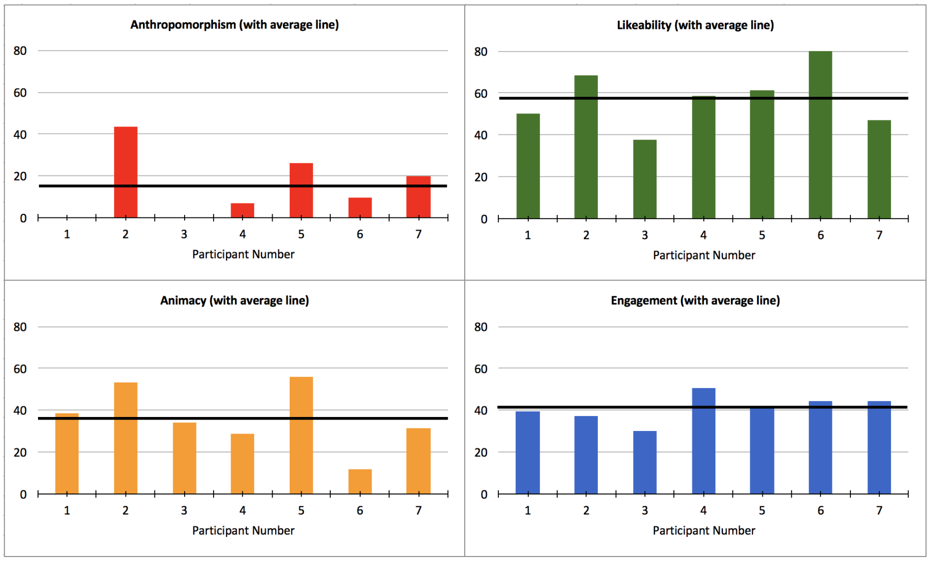

Fig. 4: Individual participants' ratings on the four Godspeed scales of Anthropomorphism, Likeability, Animacy, and Engagement. These results show that the lowest ratings were for Anthropomorphism (average of 15.2) and the highest were for Likeability (average of 57.8).

the Engagement scores may not be fully representative as the participants never interacted themselves with the DD, but only witnessed a human performer in different interaction modes. Future investigation of the perception of the DD could include a time for participant interaction with the robot, in order to examine how that personal engagement may alter their ratings of the robot.

For example, Participant 4 rated the DD very negatively, but also identified that past experience with robots included a lot of time with a different robot in the performance known as Baxter. This participant reported after the performance that the Baxter was desirable, while the DD was annoying and childish. It may be possible that this participants past experience with Baxter influenced their perception even of other robots. They may use Baxter as a baseline concept of what robots should be like, but the DD does not share many aspects of design or function with Baxter. Future research on the perception of the DD will more intentionally investigate peoples predisposed perception of the robot, as the bias participants have coming into the study is a strong factor to change in a short performance. Additionally, we hope to use more detailed user surveys to measure smaller changes in opinion.

5 Conclusions

In this paper, we presented a novel robot prototype design that was developed in order to be an expressive agent in a dance performance. This was done by applying a previously developed design methodology to project character traits onto a ground robotics platform. Initial validation with users was also presented. We worked with an artist to validate the results in a performance setting. Thus, this expressive platform, the DD, was developed based on specifications developed inside this collaboration. Results show that while participants gave high scores when considering the DD for Likeability, they also gave low scores for Anthropomorphism. The differences in Godspeed ratings between performance groups were not consistently strong enough to conclude that performance group defined the participants' perception of the DD.

In future work, we hope to conduct more user studies in theatrical settings and on more form factors. Theatrical settings, which are natively social environments as many people attend shows with friends and family, allow us to change individual knobs of our system such as priming and context elements on larger participant groups to get a clearer picture of the variety of impressions on human viewers that we can create using this platform.

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References

1. Bartneck, C., Kulić, D., Croft, E., Zoghbi, S.: Measurement instruments for the anthropomorphism, animacy, likeability, perceived intelligence, and perceived safety of robots. International journal of social robotics **1**(1), 71–81 (2009)
2. Bianchini, S., Levillain, F., Menicacci, A., Quinz, E., Zibetti, E.: Towards behavioral objects: A twofold approach for a system of notation to design and implement behaviors in non-anthropomorphic robotic artifacts. In: Dance Notations and Robot Motion, pp. 1–24. Springer (2016)
3. iRobotRoomba Brand Publishing, B.N.: Every pet on a roomba you ever need to see (2013), https://www.buzzfeed.com/irobotroomba
4. Breazeal, C.: Emotion and sociable humanoid robots. International Journal of Human-Computer Studies **59**(1), 119–155 (2003)
5. Broekens, J., Heerink, M., Rosendal, H., et al.: Assistive social robots in elderly care: a review. Gerontechnology **8**(2), 94–103 (2009)
6. Crilly, N., Moultrie, J., Clarkson, P.J.: Seeing things: consumer response to the visual domain in product design. Design studies **25**(6), 547–577 (2004)
7. Cuan, C., Pakrasi, I., LaViers, A.: Time to compile: An interactive art installation. In: 16th Biennial Symposium on Arts & Technology. vol. 51, p. 19 (2018)
8. Darling, K., Nandy, P., Breazeal, C.: Empathic concern and the effect of stories in human-robot interaction. In: Robot and Human Interactive Communication (RO-MAN), 2015 24th IEEE International Symposium on. pp. 770–775. IEEE (2015)
9. Dautenhahn, K.: The art of designing socially intelligent agents: Science, fiction, and the human in the loop. Applied artificial intelligence **12**(7-8), 573–617 (1998)
10. Eyssel, F., Kuchenbrandt, D.: Social categorization of social robots: Anthropomorphism as a function of robot group membership. British Journal of Social Psychology **51**(4), 724–731 (2012)

11. Fischer-Lichte, E.: The transformative power of performance. In: The Transformative Power of Performance, pp. 19–31. Routledge (2008)
12. Forlizzi, J., DiSalvo, C.: Service robots in the domestic environment: a study of the roomba vacuum in the home. In: Proceedings of the 1st ACM SIGCHI/SIGART conference on Human-robot interaction. pp. 258–265. ACM (2006)
13. Hendriks, B., Meerbeek, B., Boess, S., Pauws, S., Sonneveld, M.: Robot vacuum cleaner personality and behavior. International Journal of Social Robotics **3**(2), 187–195 (2011)
14. Knight, H., Simmons, R.: Expressive motion with x, y and theta: Laban effort features for mobile robots. In: Robot and Human Interactive Communication, 2014 RO-MAN: The 23rd IEEE International Symposium on. pp. 267–273. IEEE (2014)
15. LaViers, A.: An information theoretic measure for robot expressivity. arXiv preprint arXiv:1707.05365 (2017)
16. Manyika, J., Chui, M., Miremadi, M., Bughin, J., George, K., Willmott, P., Dewhurst, M.: A future that works: automation, employment, and productivity. Tech. rep., San Francisco CA (2017)
17. Nagamachi, M.: Kansei engineering: a new ergonomic consumer-oriented technology for product development. International Journal of industrial ergonomics **15**(1), 3–11 (1995)
18. Pakrasi, I., LaViers, A., Chakraborty, N.: A design methodology for abstracting character archetypes onto robotic systems. In: Paper present at the 5th International Conference on Movement and Computing (MOCO), Genoa, Italy, June. pp. 28–30 (2018)
19. Rachel Zarrell, B.N.: This cat dressed as a shark riding a roomba with a shark-baby is the zen you need today (2014), https://www.buzzfeed.com/rachelzarrell
20. Simmons, R., Makatchev, M., Kirby, R., Lee, M.K., Fanaswala, I., Browning, B., Forlizzi, J., Sakr, M.: Believable robot characters. AI Magazine **32**(4), 39–52 (2011)
21. Stevens, C.J., Schubert, E., Morris, R.H., Frear, M., Chen, J., Healey, S., Schoknecht, C., Hansen, S.: Cognition and the temporal arts: Investigating audience response to dance using pdas that record continuous data during live performance. International Journal of Human-Computer Studies **67**(9), 800–813 (2009)
22. Studd, K., Cox, L.: Everybody is a Body. Dog Ear Publishing (2013)
23. Swift-Spong, K., Wen, C.K.F., Spruijt-Metz, D., Matarić, M.J.: Comparing backstories of a socially assistive robot exercise buddy for adolescent youth. In: Robot and Human Interactive Communication (RO-MAN), 2016 25th IEEE International Symposium on. pp. 1013–1018. IEEE (2016)
24. Terada, K., Shamoto, T., Ito, A., Mei, H.: Reactive movements of non-humanoid robots cause intention attribution in humans. In: Intelligent Robots and Systems, 2007. IROS 2007. IEEE/RSJ International Conference on. pp. 3715–3720. IEEE (2007)
25. Ward, A.F., Olsen, A.S., Wegner, D.M.: The harm-made mind: Observing victimization augments attribution of minds to vegetative patients, robots, and the dead. Psychological Science **24**(8), 1437–1445 (2013)
26. Ward, F.: No innocent bystanders: Performance art and audience. UPNE (2012)
27. Young, J.E., Hawkins, R., Sharlin, E., Igarashi, T.: Toward acceptable domestic robots: Applying insights from social psychology. International Journal of Social Robotics **1**(1), 95–108 (2009)
28. Young, J.E., Sung, J., Voida, A., Sharlin, E., Igarashi, T., Christensen, H.I., Grinter, R.E.: Evaluating human-robot interaction. International Journal of Social Robotics **3**(1), 53–67 (2011)