Feedback Design to Improve Interaction of Person-following Robots for Older Adults

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***Abstract*— A sequence of user studies with older adults explored user preferences regarding feedback parameters for a socially assistive person-following robot. The preferred level of transparency and the desired content for the feedback was first explored. Then, the preferred mode and timing of feedback were assessed. Preferred parameters were then implemented and evaluated. Results revealed that older adults preferred the robot's feedback to include only basic status information. They also preferred voice feedback over tone, and at a continuous rate to keep them constantly aware of the state and actions of the robot. These results contribute towards preliminary feedback design guidelines that could improve interaction quality for person-following robots for older adults.**

Keywords—Feedback design, person-following, socially assistive robots, human-robot interaction.

1 INTRODUCTION

Socially assistive robots (SARs) are being developed to assist older adults in a wide range of activities. A major effort is focused towards instrumental activities of daily living (IADLs), tasks that are not mandatory for fundamental functioning but essential for independent living and interaction with the environment [1] (e.g., activities like housekeeping, or shopping). These activities can be made easier for older adults with the assistance of a person following robot. Person-following is an important aspect in many service robotic applications [2] whilst supporting a person in performing daily tasks (e.g., carrying groceries, physical monitoring, and companionship).

The robot can be programmed to autonomously track the older adult and follow as he or she moves. It often has a compartment to carry the belongings of the user as it moves. It helps relieve the older adults from the physical stress of carrying loads while walking and performing other IADLs. To create robots that move in socially acceptable manners it is important to consider a multitude of parameters such as the robots' speed, acceleration and deceleration properties, the lead human's walking speed, and the appropriate physical proximity, as a function of the environment (e.g., a narrow corridor vs. an open room), context (e.g., routine vs. urgent), physical state and human intent [3]–[5].

User studies are required to improve and design smoother human-robot interactions in person-following robots [6]. This is particularly critical for older adults who have peculiar needs that require attention and care in design [7], [8]. Some of these needs could be perception-related such as decline in visual, audial and haptic acuity [9]. These needs are also related to cognitive challenges that affect the rate of understanding, integrating and processing of information [10]. Physical challenges connected with stability and movement also require special consideration during design [8]. SARs designed for these older adults must therefore cater for these needs to ensure that the age-related peculiarities do not partially or completely limit the use of these SARs.

2 RELATED WORK

Successful interaction requires communication between the human and the robot which generally involves sending and receiving of information to achieve specific goals [11]. Communicative actions when presented in the most comprehensible form promotes understanding which aids a successful interaction of the user with the robot [12], [13]. The communicative actions from the robot to the user, herein referred to as feedback, is the presentation of information by the robot to the user in response to the user's actions.

Feedback can be presented in various modes including audial, visual or haptic modes [10]. It could also be in various other forms of non-verbal modes such as eye blinks, shifts in gaze (for robots with a face) or body posture for humanoid robots [14]. Results discussed in [14] revealed that implicit non-verbal communication positively impacts understandability, efficiency and robustness to errors arising from miscommunication. It was also discovered in the study [14] that transparency reduces conflict in joint task situations and when errors occur.

The content of the feedback is a crucial influencing factor for successful interaction between humans and robots [15]. This feedback content is predicated on the desired level of transparency (LOT) in such interaction [16], [17]. LOT, in this context, can be described as the degree of task-related information of a system provided to users to achieve a certain level of situational awareness (SA). It determines the content of the information provided by the robot to inform the user of its state, actions and intentions to help the user gain good SA at all times. Chen et al., [18] developed a situation awareness based transparency model (SAT) which mirrors Endsley's model of situation awareness [19]. It identifies what information could be provided to users for a specific LOT. Three levels adapted from [18] are presented in *Table 1*.

Table 1: Information provided at various LOT

LOT	Information Provided
1. Perception	Information about **the state of the robot** and/or the context that the user must be aware of. For example – the robot makes a sound or says 'yes' when it acknowledges the user giving the command 'follow me'.
2. Comprehension	Information about **how** the state of the robot or the context may affect achieving the goal For example – The robot verbally says that it is following the user from behind in a distance of 2 meters.
3. Projection	Information about **how the future state** of the robot may change based on the context For example – The robot verbally says that in a few meters it will have to slow down to an anticipated change in the walking surface.

Wortham and Theodorou argued in their paper [20] that a robot which is truly transparent may contravene the ideology of worthy companionship where the companion has a social value of independence, agency and autonomy to disclose information. The authors hypothesized that the user may perceive the robot more as a tool than a companion, as transparency is increased. This is contrary to the expectation desired in domestic and healthcare settings where the users are expected to interact with the robots as partners, companions and entities capable of caring for them. It was recommended in the paper [20] that transparency of the robot's communication be implemented in a wide range of domestic environments to explore the relationship between transparency, utility and trust in HRI.

The effect of transparency and communication modality on trust was examined in [21]. The level of information the robotic teammate provided to users was varied along with the feedback modality to explore the effect on the users' trust in the robot. Results reveal that users preferred a constant stream of information compared to lesser content. The modality was also not significant in the study. The experiment conducted in the study was an interaction with a simulated robot deployed on a desktop computer. This interaction differs from interaction with a mobile and embodied robot such as a person following robot which this current paper focuses on. Also, the users in [21] were undergraduate students (aged 18 – 22 years) which have different characteristics and perceptual peculiarities from the older adults. The study [21], which was focused on trust recommended that more user studies should be carried out in specific domains in order to determine influence of information level, modality and content on trust.

Discussions by Lyons [22] focused on strategies to foster transparency between the human. It was recommended that the interface through which the human interacted with the robot should provide useful information relating to the task and environment. The author cautioned that too much information or a non-intuitive display may cause confusion or frustration for the user [22]. This is in agreement with the findings in [23] where it was also noted that multi-modal communication aided performance of the users. Though Kim and Hinds [24] noted in their study that users understand the robot better if it explains the reasons behind it's behaviour. Cring and Lenfesty [25] confirmed this in an unmanned aerial system scenario with multiple operators. The hypothesis is expected to be further investigated in other scenarios to determine if this varies with the complexity and nature of the task or environment.

Timing of the feedback is also critical to maintain comprehension of the information being communicated [26]. For instance, feedback given too late causes confusion [17]. Temporal immediacy between a user's input and the robot's response influences the naturalness of the interaction [27].

In the studies involving person-following robot applications, most of the developments did not explicitly incorporate feedback from the robot regarding the robot's actions as it follows. The robot simply followed the target person as soon as the person was detected in a predetermined range as noted in [28]. The few studies that incorporated feedback [29]–[31] provided a message acknowledging user commands such as saying 'yes' or other specific expressions [30]. These were implemented as part of the robot's behaviour without explicit user studies to determine the preferred content, mode or timing of feedback from the robot.

There is generally a gap in user-centered preferences in feedback parameters for person following robots [4], particularly those used in eldercare [10]. The current study aims to evaluate older adults' preferences for the feedback parameters of a person-following robot to increase user satisfaction, acceptance and improve the quality of the interaction. This includes the preferred LOT (perception, comprehension, projection), content of the information to be presented (depending on the LOT), mode (voice or tone) and timing and frequency of the feedback (continuous or discrete). The outcome aims to provide design guidelines for improved feedback design in the development of an assistive person-following robot for older adults.

3 METHODS

3.1 Overview

Coactive design right from the initial design phase was conducted via preliminary discussions with the older people regarding what they would like the robot to do and how. A sequence of user studies with older adults was then performed (*Figure 1*) with the following research questions:

- *What level of transparency would the older adults desire and what would they prefer as feedback content at their desired LOT?*
- *Which feedback mode would the older adults prefer?*
- *What would the preferred feedback timing be?*

The design parameters gathered in the preceding studies were implemented and tested to evaluate the effectiveness of the feedback design. It provided an answer to the question of the fourth stage: *Does the feedback implementation improve the quality of interaction?*

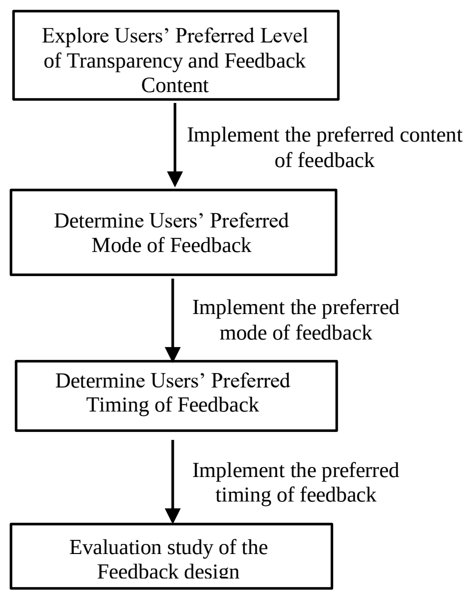

Figure 1: Experimental Design of the Current Study.

3.2 Apparatus

A Pioneer LX mobile robot (50 cm width, 70 cm length and 45 cm height) equipped with an integrated on-board computer, 1.8 GHz Dual Core processor, and 2GB DDR3 RAM was used. The person tracking and following commands were executed in ROS [32] and were sent to the Pioneer LX's onboard computer using a TPLINK router with wireless speed up to 300 Mbps. A built-in SICK S300 scanning laser rangefinder, mounted approximately 20 cm above the ground, was used to detect nearby obstacles and stop the robot if it detected an object 50 cm from its core. Distant obstacles were tracked using an external Kinect camera with a pan mechanism that was added to the robot and mounted 1.5m from the ground, as shown in Figure *2*.

3.3 Person Tracking and Following Algorithms

To identify and track the coordinates of the person to be followed, OpenPTrack is used with some adjustments to ensure it can detect a human 1.4m to 2m tall, with a confidence level threshold of 1.1. The algorithm works without a map. It selects the first person detected and moves the robot to the defined position behind the person. It uses the angle of the pan of the robot ($RAngle$) and angle of the person being detected ($PAngle$), measured from the centre of the robot, to constantly estimate the position of the person. The position (coordinates X,Y) of the person is calculated as follows:

$$X = distance\left(cos(Pangle + RAngle)\right) \quad (1)$$

$$Y = distance\left(sin(Pangle + RAngle)\right) \quad (2)$$

Figure 2: A participant communicating with the robot.

The linear velocity ($lVel$) of the robot is updated dynamically based on the distance between the robot and the target while the angular velocity ($aVel$) is updated dynamically based on the angular displacement of the target. These are calculated as follows:

$$(lVel) = (lVel)(distance - target) \quad (3)$$

$$(aVel) = (PAngle)(aVel) \quad (4)$$

3.4 Parameters for Person Tracking and Following Algorithms

Parameters were set according to recommendations for social following robots [3], [5]. [21], [26], [34]. The maximum following speed was set to 1.0m/s for safety reasons as emphasized in [5], [35], [36]. Other parameters such as acceleration coefficient, following distance and following angle were set to 0.5, 0.3m and 30˚, respectively.

3.5 Procedure

In each stage of the study, participants completed a preliminary questionnaire before the experiment. This included demographic information, the Technology Adoption Propensity (TAP) index [37] and the Negative Attitude toward Robots Scale (NARS) [38]. They were then introduced to the robot and performed the task. The task was to walk down a straight 40m path while the robot communicated with them by voice in English. The study took place in a 2.5 m wide corridor in a university laboratory building. After each trial, participants were given a post-trial questionnaire [39] which used 3-point Likert scales with 3 representing "Agree" and 1 representing "Disagree". The 3-point scale was selected since previous trials with older adults showed that that the 5 and 7 point scales caused them confusion. At the end of all trials, a final questionnaire was provided to enable the participants to express their experience with the robot. Procedures were approved by the university's ethical committee.

3.6 Analyses

Subjective measures: Preference among options given, understanding, comfortability, engagement, persuasiveness and satisfaction were assessed through questionnaires and short interviews at the end of each experimental trial.

Objective measures: 1. Understanding (the number of clarifications participants asked for from the experimenter during the interaction regarding the information the robot was giving) 2. Effort (measured by recording participant heartrate before and after each trial). 3. Engagement (the number of times participants looked back at the robot during the trial, the number of times participants initiated communication with the robot while gazing at the robot, the time it took participants to respond to the robot's instructions and the duration of gazes the participants made to the robot), 4. Persuasiveness (participant's reaction time when the robot gave instructions such as 'I will follow you, as you move. You can start moving now').

Data Analyses: The tests were designed as two-tailed with a significance level of 0.05. The model for the analyses was the General Linear Mixed Model (GLMM) with user ID included as a random effect to account for individual differences.

4 Level of Transparency and Content of Feedback

The preferable level of transparency was explored along with the appropriate information content. The aim was to provide the users sufficient SA without overwhelming them with information.

4.1 Experimental design

Independent Variable: The level of transparency was the independent variable. Three levels of information were presented to the participant (**what** the robot is doing, **why** the robot was doing what it was doing, and what the robot was **planning to do next**).

Dependent Variable: Preference regarding the amount of information participants wanted the robot to present to them was collected through questionnaires and short interviews that contained specific items related to the participants' understanding of the robot's feedback. Questions regarding level of comfort and mental workload while interacting at various levels of transparency were asked.

Participants: Thirteen older adult participants (8 Females, 5 Males) aged 65-85 were recruited via social networks and colleagues. They were all healthy participants with no physical disability, vision or hearing impairment. A short interview was held with them before the experiment commenced to ascertain their comfortability with the experiments and understanding of the procedure. It also served to ensure that they were cognitively fit for the interaction. Each participant experienced all three levels of information presentation from the robot. They completed the study separately at different timeslots, so there was no contact between participants.

4.2 Results

Analysis on LOT preferences revealed significant differences among users (*$p<0.001$*). Most of the participants (85%) preferred the robot to say what it was doing at the moment (LOT level 1). 38% of the participants wanted the robot to additionally present the reason for its actions (LOT level 2), while only 23% of the participants wanted information on future actions of the robot (LOT level 3).

Participants did not express discomfort or excess workload while interacting with the robot at higher LOTs. They gave their preferences for specific feedback content from the robot. Several participants wanted it to say more than basic task related information such as 'following', 'stopping'. Some wished it would introduce itself and greet them. Most of the participants (85%) also desired for the robot to communicate in their native language (Hebrew). The results provided the rationale for the use of the first LOT (robot's current action) with specific expressions such as 'starting', 'following', 'stopping' in the next experimental stage. Greetings according to the suggested content (such as 'Hello', 'Bye') during the interaction with the robot were also added to the communication to make it friendlier. This modification was implemented for subsequent studies by enabling the users to choose the preferred language of feedback (English or Hebrew).

5 MODE OF FEEDBACK

The aim of this experiment was to identify the most suitable mode of feedback considering that the robot is specifically a person-following robot which would be behind the user most of the time. This requires the feedback to be audible to the user particularly when following. Two audial feedback modes were explored: a female voice and a tone in a form of beeps (beep, beep…). The beeping indicated the following action of the robot. The beeping starts once the robot begins to follow. The robot ceased to beep when it stops following. The voice content was the same: 'following', 'stopping', and greetings. The sound of the voice and tone feedback was maintained at approximately 60dB, well above background noise level. The volume was made adjustable to the preference of the participant, such that it could be increased or decreased to make it comfortable and audible to the participant in accordance with audial feedback design guidelines [40].

The feedback modes were implemented according to design guidelines for general multimodal human-robot interaction [41]. The standards for developers to address the needs of older persons [9], [10] was also consulted in order to satisfy design recommendations for presentation of auditory information. Actual human speech was used instead of synthesized speech based on earlier studies which revealed that it aided higher intelligibility [42]. A native speaker's recording was used in order to avoid accent-related understanding difficulties [43]. The content of the feedback was based on the results obtained in the previous stage.

5.1 Experimental Design

Independent Variable: The mode of feedback manipulated as voice mode and tone mode.

Dependent Variables: Subjective and objective measures as described in section 3.6.

Participants: Twelve additional older adults' participants (9 Females, 3 Males) aged 62-73, were recruited. They were physically and cognitively fit for the experiments as described in section 4.1. Each participant received feedback from the robot in both tone and voice modes.

5.2 Results

Analysis revealed that 10 of the participants (77%) preferred the voice feedback mode (*$M=0.77, SD=0.43$*) to the tone mode (*$M=0.08, SD=0.272$*) and 8% were fine with either of the modes (*$M=0.15$*, *$SD=0.368$*). This effect of feedback mode on their preference was significant (*$M=0.92$*, *$SD=0.484$*, $p<0.001$). Feedback mode had no significant effect on comfortability, engagement and persuasiveness. Eight of the 12 participants reported that they were comfortable in both trials. Three of the participants were indifferent. The heart rate was also not significantly affected by the feedback mode. A one-way ANOVA using mode of feedback as the fixed factor and user ID as a random effect revealed that the mode of feedback had significant effect on the users' **understanding** (*$M=2.0$, $SD=0.938$*, *$p<0.001$*). Voice feedback was therefore used for the subsequent experimental stages.

6 TIMING OF FEEDBACK

The temporal dimension of the feedback preference of the older adults was studied. The transparency level, content and mode of feedback used were based on the outcome of the previous stages.

6.1 Experimental Design

Independent Variable: the timing of feedback included 3 timing options: continuous (5 and 10 seconds intervals) and discrete. As an example, in the continuous timing mode (5 seconds interval), the verbal feedback was given continuously, every 5 seconds (e.g., "Following", "Following", …every 5 seconds). In the discrete timing mode, the feedback was given only at the beginning and at the end of the interaction with the robot. In this mode, the robot would simply inform the participants when it begins the following and inform the participants when it is stopping.

Dependent Variable: the same variables described in section 3.6.

Participants: The same 12 participants recruited in 5.1 followed up with this experiment. Each participant received verbal feedback from the robot in the discrete and continuous timing options. They answered brief questions in questionnaire and interview format after the trials regarding which feedback timing they prefer and why.

6.2 Results

Analyses showed that 80% (10) of the participants preferred the continuous feedback (*$M=0.85$, $SD=0.366$*) over the discrete feedback with (*$M=0.15, SD=0.366$*). The effect of the feedback timing on the users' preference was significant (*$M=1.46, SD=0.756, p<0.001$*). The effect of feedback timing as a fixed variable on understanding was also statistically significant (*$M=1.87, SD=0.923, p<0.001$*). Among those who selected the continuous feedback as their preferred timing mode, 84.6% preferred an interval of 5 seconds (*M=0.69, SD=0.468*) over 10 seconds (*M=0.15, SD=0.366*). The reason given was better awareness of what the robot was doing behind them at every point in time. This provided a rationale for the use of continuous feedback at the rate of 5 seconds in the following experiment.

7 DOES THE FEEDBACK IMPLEMENTATION IMPROVE THE QUALITY OF INTERACTION?

The feedback design parameters obtained in the previous studies and their effects on the quality of interaction relative to no feedback were evaluated.

7.1 Experimental Design

Independent Variable: There were two groups: one group interacted with the robot without feedback, the other group interacted with the implemented feedback.

Dependent Variable: Quality of interaction was measured both objectively and subjectively in terms of engagement, understanding, trust and comfortability.

Objective Measures: Engagement and comfortability was measured as explained in section 3.6. The number of clarifications that was made by the participant during the interaction was counted as a measure of the understanding they had regarding the information the robot was giving them.

Subjective Measures: Questionnaires and short interviews regarding their comfort level, understanding of the robot's information, trust and satisfaction as explained in section 3.6

Participants: 20 additional older adult participants (13 Females, 7 Males) aged 65-85. They were healthy participants who had been confirmed as physically and cognitively fit for the experiments as described in section 4.1. Ten of the participants received feedback from the robot while the other 10 received no feedback from the robot.

Feedback Design: Feedback was designed using the preferred parameters identified in the preceding stages (*).*

Table *2*).

Table 2: Parameters for Feedback Design

Parameter	*Preference*	*Description*
Level of Transparency	Level 1 LOT	Information on what the robot is currently doing.
Content of Feedback	Action of the robot, Friendly content.	Specific information such as 'Starting', 'Following', 'Stopping'. Greetings from the robot.
Mode of Feedback	Voice Feedback	Audible female voice with speech rate less than 140 wpm with adequate pauses at grammatical boundaries.
Timing of Feedback	Continuous Feedback (5 seconds interval)	Notification of the state of the robot every 5 seconds (like, 'following, following..')

7.2 Results

Attitude Towards Technology

Most of the participants were acquainted with the use of innovative technologies (*M = 3.39, SD = 0.72*). The TAP index [20] revealed that more than half of the participants were affirmative that technology could provide more control and flexibility in life (*M = 2.48, SD = 1.59*). Several of them also showed confidence in learning new technologies (*M = 2.95, SD = 1.18*), and trusted technology (*M = 3.04, SD = 1.58*). The NARS index [21] revealed that several of the participants were comfortable with the idea of robots having emotions (*M= 3.79, SD = 1.053*).

Quality of Interaction

The comparison between the group with feedback (*M = 0.51, SD = 0.51*) and the group without feedback (*M = 0.49, SD = 0.51*) revealed that the feedback design significantly improved the overall quality of interaction (*M=21.58, SD = 14.80, p<0.001*).

Engagement

The results showed that the feedback design significantly reduced the reaction time (*M=2.2, SD=1.84, p=0.024*) and increased the time the participant was focused on the robot while the robot was presenting some information about the interaction before following (*M=3.15, SD=4.38, p<0.001*). This suggests improved engagement. The responses from the questionnaire did not show significant differences in the response of the participants related to engagement. However, during the interviews, several participants expressed excitement at the robot's communicative ability. Some of the comments made were, "I was thrilled to hear the robot communicate with me in Hebrew. It helped me relate better with it", "the way it spoke every time, telling me what it's doing made it interesting to interact with". These comments suggest some form of engagement with the robot.

Understanding

The understanding of the participants improved with the feedback design as expressed by the number of clarifications that participants needed to make which impeded the flow of the interaction was also significantly reduced by the feedback implementation (*M=0.36, SD=0.49, p=0.041*). Also, the responses of the participants in the questionnaires regarding understanding showed that the group with feedback had a better understanding of the robot (*M=3.05, SD=0.82, p=0.047*).

Trust and Comfortability

The results show that the participants waited more for the robot when the feedback was implemented (*M=2.85, SD=3.81, p<0.001*). This suggests some level of trust that the robot would not collide with them or cause any harm to them. It could also be a reflection of comfortability while walking with the robot. There was no significant difference in the groups regarding naturalness with the robot *(M=3.0, SD=0.93, p=0.081)* based on the questionnaires. But a significant difference was found in the ease and comfortability of communicating with the robot (*M=3.03, SD=0.92, p=0.005*).

8 DISCUSSION

This is a first study to explore feedback parameters in a series of user studies focusing on older adults. It is a sequential user-centered study, where we learned in the first stage that ***users prefer LOT 1***. Hence, ***they do not need the robotic***

system to be fully transparent, rather they ***want it to be current and immediate***. They are satisfied with the robot ***communicating just its status information and current actions***. Older adults seem to trust that the robot will know how to handle itself if more information is available or if the state of matters will change. In that sense, this population may be unique in their LOT demands, but we cannot assure this conclusion since there were not enough studies on older adults in this context.

In the second stage, we learned that the ***users prefer the robot to communicate with them in voice mode***. The voice, as compared to tone-mode, tends to give the robot a form of personality which enables the users to better envision it as an assistant or partner than just a mere machine. This, also, tends to keep them more engaged with the robot which is one of the variables that indicates the potential of an improvement in the quality of interaction. In the third stage, ***continuous feedback, at short intervals, was preferred*** by the participants. It seemed to provide them with better SA regarding the state of the interaction compared to just discrete feedback used in previous studies.

In the final stage, while evaluating the effectiveness of the feedback design, we observed that the users were more comfortable with the robot's behaviour when it communicated with them using the implemented feedback compared to situations where the robot followed without such feedback. This feedback was designed to match the perceptual demands of the target users. The outcome supports the proposition in literature that such ***user-centered feedback design can increase the quality of interaction***.

One of the limitations of this study is that the feedback design was evaluated on a single task scenario. The feedback was not evaluated in multiple task situations with varying environmental variables such as noise and space type. These are crucial factors that should be considered in future work to improve the robustness of the feedback design. The outcome of this study provides some guidance and recommendations that could be useful while conducting more extensive studies on feedback design guidelines in person following robots that will accommodate user needs in eldercare.

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REFERENCES

[1] D. Tang, B. Yusuf, J. Botzheim, N. Kubota, and C. S. Chan, "A novel multimodal communication framework using robot partner for aging population," *Expert Syst. Appl.*, vol. 42, no. 9, pp. 4540–4555, 2015.

[2] H. Sidenbladh, D. Kragic, and H. I. Christensen, "A person following behaviour for a mobile robot," *Proceedings 1999 IEEE International Conference on Robotics and Automation (Cat. No.99CH36288C)*, vol. 1, no. May. pp. 670–675, 1999.

[3] H. S. Shanee, K. Dror, O. G. Tal, and E. Yael, "The influence of following angle on performance metrics of a human-following robot," *25th IEEE Int. Symp. Robot Hum. Interact. Commun. RO-MAN 2016*, pp. 593–598, 2016.

[4] S. S. Honig, T. Oron-Gilad, H. Zaichyk, V. Sarne-Fleischmann, S. Olatunji, and Y. Edan, "Towards Socially Aware Person-Following Robots," *IEEE Trans. Cogn. Dev. Syst.*, pp. 1–1, 2018.

[5] S. Olatunji *et al.*, "User Preferences for socially acceptable person-following robots," in *Assistance and Service Robotics in a Human Environment: From Personal Mobility Aids to Rehabilitation-Oriented Robotics. A Workshop in conjunction with the 2018 IEEE/RSJ International Conference on Intelligent Robots and Systems*, 2018.

[6] O. Zafrani and G. Nimrod, "Towards a Holistic Approach to Studying Human–Robot Interaction in Later Life," *Gerontologist*, vol. 59, no. 1, pp. e26–e36, Jan. 2019.

[7] C. Owsley and G. McGwin, "Association between visual attention and mobility in older adults," *J. Am. Geriatr. Soc.*, vol. 52, no. 11, pp. 1901–1906, 2004.

[8] I. Leite, C. Martinho, and A. Paiva, "Social Robots for Long-Term Interaction: A Survey," *Int. J. Soc. Robot.*, vol. 5, no. 2, 2013.

[9] Cen/Cenelec, "Guidelines for standards developers to address the needs of older persons and persons with disabilities," *Ed. 1, January 2002*, vol. CEN/CENELE, no. January, p. 31, 2002.

[10] T. L. Mitzner, C. A. Smarr, W. A. Rogers, and A. D. Fisk, "Adult's perceptual abilities.pdf," in *The Cambridge Handbook of Applied Perception Research*, 2015, pp. 1051–1079.

[11] C. E. Shannon, "Communication Theory of Secrecy Systems*," *Bell Syst. Tech. J.*, vol. 28, no. 4, pp. 656–715, Oct. 1949.

[12] D. Doran, S. Schulz, and T. R. Besold, "What Does Explainable AI Really Mean? A New Conceptualization of Perspectives," 2017.

[13] N. Balfe, S. Sharples, and J. R. Wilson, "Understanding Is Key: An Analysis of Factors Pertaining to Trust in a Real-World Automation System," *Hum. Factors*, no. 1983, 2018.

[14] C. Breazeal, C. D. Kidd, A. L. Thomaz, G. Hoffman, and M. Berlin, "Effects of Nonverbal Communication on Efficiency and Robustness in Human-Robot Teamwork," in *IEEE/RSJ International Conference on Intelligent Robots and Systems*, 2005.

[15] N. Mirnig and T. Manfred, "Comprehension, coherence and consistency: Essentials of robot feedback," in *Robots that Talk and Listen: Technology and Social Impact - Google Books*, J. Markowitz, Ed. 2015.

[16] J. Y. C. Chen, S. G. Lakhmani, K. Stowers, A. R. Selkowitz, J. L. Wright, and M. Barnes, "Situation awareness-based agent transparency and human-autonomy teaming effectiveness," *Theor. Issues Ergon. Sci.*, vol. 19, no. 3, pp. 259–282, 2018.

[17] N. Mirnig, A. Weiss, and M. Tscheligi, "A communication structure for human-robot itinerary requests," *Human-Robot Interact. (HRI), 2011 6th ACM/IEEE Int. Conf.*, pp. 205–206, 2011.

[18] J. Y. C. Chen, K. Procci, M. Boyce, J. Wright, A. Garcia, and M. J. Barnes, "Situation Awareness – Based Agent Transparency," no. April, pp. 1–29, 2014.

[19] M. R. Endsley, "Toward a theory of situation awareness in dynamic systems," *Hum. Factors*, vol. 37, no. 1, pp. 32–65, Mar. 1995.

[20] R. H. Wortham, A. Theodorou, R. H. Wortham, and A. Theodorou, "Robot transparency , trust and utility Robot transparency , trust and utility," vol. 91, no. May, 2017.

[21] T. Sanders, Wixon Tarita, Schafer Kristen, J. Y. C. Chen, and P. A. Hancock, "The Influence of Modality and Transparency on Trust in Human-Robot Interaction," in *IEEE International Inter-Disciplinary Conference on Cognitive Methods in Situational Awareness and Decision Support (CogSIMA)*, 2014, pp. 156–159.

[22] J. B. Lyons, "Being Transparent about Transparency : A Model for Human-Robot Interaction," *Trust Auton. Syst. Pap. from 2013 AAAI Spring Symp.*, pp. 48–53, 2013.

[23] V. Finomore *et al.*, "Effects of the Multi-Modal Communication tool on Communication and Change Detection for Command & Control Operators," pp. 1461–1465, 2012.

[24] T. Kim and P. Hinds, "Who Should I Blame ? Effects of Autonomy and Transparency on Attributions in Human-Robot Interaction," pp. 80–85, 2006.

[25] E. A. Cring and A. G. Lenfestey, "Architecting human operator trust in automation to improve system effectiveness in multiple unmanned aerial vehicle (UAV) control," Air Force Institute of Technology, Air University, 2009.

[26] G. Doisy, J. Meyer, and Y. Edan, "The Impact of Human - Robot Interface Design on the Use of a Learning Robot System," pp. 1–10, 2014.

[27] K. Fischer, K. Lohan, J. Saunders, C. Nehaniv, B. Wrede, and K. Rohlfing, "The impact of the contingency of robot feedback on HRI," *Proc. 2013 Int. Conf. Collab. Technol. Syst. CTS 2013*, no. 214668, pp. 210–217, 2013.

[28] H. S. Shanee, O. Tal, Z. Hanan, F. Vardit, O. Samuel, and E. Yael, "Towards Socially Aware Person-Following Robots."

[29] H. Zender, P. Jensfelt, and G.-J. M. Kruijff, "Human- and Situation-Aware People Following," in *RO-MAN 2007 - The 16th IEEE International Symposium on Robot and Human Interactive Communication*, 2007, pp. 1131–1136.

[30] R. Gockley, J. Forlizzi, and R. Simmons, "Natural person-following behavior for social robots," in *Proceeding of the ACM/IEEE international conference on Human-robot interaction - HRI '07*, 2007, p. 17.

[31] H.-M. Gross *et al.*, "ROREAS: robot coach for walking and orientation training in clinical post-stroke rehabilitation—prototype implementation and evaluation in field trials," *Auton. Robots*, vol. 41, no. 3, pp. 679–698, Mar. 2017.

[32] K. E. Schaefer, *Programming Robots with ROS A Practical Introduction to the Robot Operating System*, vol. 53. 2015.

[33] Z. Hanan, H. S. Shanee, E. Yael, and O. Tal, "From 0 to 90 : Developing a Robot that can Follow People at Various Angles in Unmapped Environments."

[34] C. Piezzo and K. Suzuki, "Feasibility study of a socially assistive humanoid robot for Guiding elderly individuals during walking," *Futur. Internet*, vol. 9, no. 3, 2017.

[35] M. Chiba *et al.*, "Development of a Human Following Robot and its Experimental Evaluation," in *11th Int. Conf. on Intelligent Autonomous Systems, Ottawa, Canada*, 2010, pp. 89–98.

[36] C. Bassani, A. Scalmato, F. Mastrogiovanni, and A. Sgorbissa, "Towards an integrated and human-friendly path following and obstacle avoidance behaviour for robots," *25th IEEE Int. Symp. Robot Hum. Interact. Commun. RO-MAN 2016*, pp. 599–605, 2016.

[37] M. Ratchford and M. Barnhart, "Development and validation of the technology adoption propensity (TAP) index," *J. Bus. Res.*, vol. 65, no. 8, pp. 1209–1215, 2012.

[38] D. S. Syrdal, K. Dautenhahn, K. Koay, and M. L. Walters, "The negative attitudes towards robots scale and reactions to robot behaviour in a live human-robot interaction study," *23rd Conv. Soc. Study Artif. Intell. Simul. Behav. AISB*, pp. 109–115, 2009.

[39] Noa Markfeld, "Feedback design for older adults in robot-assisted table setting task," Ben-Gurion University of the Negev, Beer Sheva, Israel, 2019.

[40] A. D. Fisk, W. A. Rogers, N. Charness, S. J. Czaja, and J. Sharit, *Designing for Older Adults*, vol. 133, no. 4. 2009.

[41] N. Mirnig *et al.*, "Feedback guidelines for multimodal human-robot interaction: How should a robot give feedback when asking for directions?," *Proc. - IEEE Int. Work. Robot Hum. Interact. Commun.*, no. September 2012, pp. 533–538, 2012.

[42] M. K. Pichora-Fuller, C. E. Johnson, and K. E. J. Roodenburg, "The discrepancy between hearing impairment and handicap in the elderly: Balancing transaction and interaction in conversation," *J. Appl. Commun. Res.*, vol. 26, no. 1, pp. 99–119, 1998.

[43] A. N. Burda, "Age and Understanding Speakers With Spanish or Taiwanese Accents," *Percept. Mot. Skills*, vol. 97, no. 5, p. 11, 2007.