Task Influence on Perceptions of a Person-Following Robot and Following-Angle Preferences

Shanee Honig
shaneeh@post.bgu.ac.il
Ben-Gurion University of the Negev
Be'er Sheva, Israel

Hanan Zaichyk
zaichyk@post.bgu.ac.il
Ben-Gurion University of the Negev
Be'er Sheva, Israel

Yael Edan
yael@bgu.ac.il
Ben-Gurion University of the Negev
Be'er Sheva, Israel

Tal Oron-Gilad
orontal@bgu.ac.il
Ben-Gurion University of the Negev
Be'er Sheva, Israel

ABSTRACT

To improve the design of a person-following robot, this preliminary study evaluates the influence of user tasks on human preferences of the robot's following angle and human perceptions of the robot's behavior. 32 participants were followed by a robot at three different following angles twice, once with an auditory task and once with a visual task, for a total of six walking trials. Results indicate that the type of user task influences participant preferences and perceptions. For the auditory task, as the following angle increased, participants were more satisfied with the robot's following behavior. For the visual task, as the following angle increased, participants were less satisfied with the robot's following behavior. In addition, participants were more perceptive of the robot's following behavior

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for the auditory task compared to the visual task. Additional research is required to better understand whether human preferences and perceptions depend on task modality or task complexity.

KEYWORDS
Person-following robot; following angle; user task; robot behavior

1 INTRODUCTION

In all contexts of human-robot interaction, person-following robots should accompany people in socially acceptable ways. Robots that move in socially acceptable ways consistently receive higher ratings of user satisfaction, trust, comfort and perceived safety than their non-social counterparts [2]. Thus, it is important to design a robot's proxemic behavior according to user preferences. Yet, less research is available about human proxemic preferences when being followed by a robot and the explanatory variables they depend upon on [2].

We aim to develop an adaptive person-following algorithm capable of dynamically adjusting its spatial parameters (following speed, distance and angle) to best suit user needs and desires in different interaction scenarios. To achieve this goal, spatial preferences under various conditions must first be identified. This paper describes a preliminary attempt by a multidisciplinary team of roboticists, computer scientists, and human-factors engineers to examine one of these conditions. More specifically, the goal of this study is to evaluate how user tasks influence human preferences for the robot's following angle and human perceptions of a robot's person-following behavior.

Person-following experiments usually focus on scenarios where the only user task is to be followed by the robot [2]. For the most part, user tasks that do not involve the robot, such as using a smartphone or talking to a friend, have not been considered [2]. It is important to consider the influence of such separate tasks since they occur frequently and are likely to influence perceived and desired robot behavior. A preliminary study done in our lab [5] found evidence of this. 52 participants were followed by a robot at varying distances (0.8m or 0.3m). In some conditions they were given a visual task (to play with an iPad) while in others they were not. Participants reported feeling more satisfied with the robot's following behavior and more comfortable with the robot's speed when performing the secondary task, and their ability to distinguish between the robot's varying following distances also improved. Moreover, their selection of preferred following distance changed as a result of the manipulation: without a secondary task, 71% of participants preferred the longer following distance, whereas with a secondary task, preferences were split between the two distances (46% vs. 54%).

People's preferences for a robot's following angle is another topic that has barely been studied, yet needs to be identified in order to develop socially acceptable person-following robots [2]. A first attempt at understanding human preferences of a robot's following angle is described in our previous work [1], however, the study did not asses the role of separate user tasks on user preferences. Since following distance preferences and perceptions of the robot's behavior seem to have changed as a result of a secondary task in our preliminary study [5], it is conceivable that the secondary task will influence preferences of following angle as well. In the current study, an improved person-following

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algorithm was used to test whether the type of user task will influence people's preferences of the robot's following angle and perceptions of the robot's behavior.

2 METHODS

2.1 General

Thirty two participants experienced three target following angles (0°, 60°, 90°; See Figure 1) twice, once with an auditory task (paced walking according to the sound of a metronome) and once with a visual task (playing a game on a smartphone), for a total of six walking trials. To establish personal relevance, participants placed their cellphone on the robot for each walk. The order of the tasks and the following angles differed between participants. The study took place in an open lobby, on tile flooring. Participants were Industrial Engineering students who received course credit for participating.

Figure 1: The robot's following angles: 0° **(left),** 60° **(center),** 90° **(right)**

2.2 Hardware

The experiment used a Pioneer LX robot equipped with a SICK S300 scanning laser range finder that was used to detect people and obstacles in the environment. An Asus laptop (intel core i7-4710HQ processor) was used to execute the person tracking and following commands in ROS. The commands were then sent to the robot's onboard computer (1.8 GHz Dual Core processor and 2GB DDR3 RAM) using a TP-LINK router with wireless speed up to 300 Mbps. The setup included an idle Microsoft Kinect V2 mounted on a pan mechanism and connected by a rod to the robot.

2.3 Person-Following Algorithm

The person-following algorithm calculated the robot's target position (X_t, Y_t) using the person's location relative to the robot ($X_{relative}$, $Y_{relative}$), the desired angle of following (θ) and the desired following distance (*distance*):

$$X_t = X_{relative} + sin(\theta) \times distance \quad (1)$$

$$Y_t = Y_{relative} - cos(\theta) \times distance \quad (2)$$

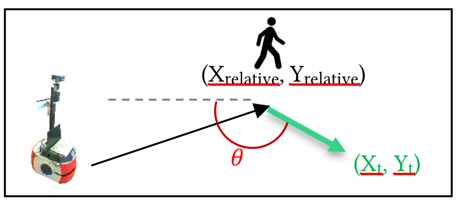

Figure 2: Parameters used for Person-Following at Different Angles

A person-tracking algorithm that identifies the pattern of a person's leg, similar to the one described in [4], was used to identify people in the environment. Once the person was located, the algorithm calculates the robot's target location and navigates its way to the target position by considering its distance to the target *targetDistance*, the change needed in the angle of the robot to achieve the target angle *targetAngle*, the robot's maximum speed *MaxSpeed*, and the robot's feedback gain when walking straight K_{linear} and when turning K_{angle} (Figure 2):

$$targetDistance = \sqrt{(X_t^2) + (Y_t^2)} \quad (3)$$

Post-trial Questionnaire

1. The robot was stressful
2. I adapted my walking behavior in direct response to the robot's walking behavior
3. The robot's adapted its walking behavior in direct response to my walking behavior
4. The robot was considerate of my personal space
5. I felt comfortable with the speed of the robot
6. I felt comfortable with the robot's following distance
7. The robot moved too slowly
8. I walked naturally
9. The robot walked naturally
10. I was satisfied with the way in which the robot followed me
11. I adapted my walking speed to suit the speed of the robot
12. The robot's walking behavior suited my expectations
13. My impressions of the robot are: (1) friendly, (2) intruding, (3) considerate, (4) safe, (5) frightening, (6) stressful, (7) noisy, (8) something else?

Post-session Questionnaire

1. Did you feel a difference between trials? (Y/N)
2. In which session did you feel most comfortable? (choice of session #)
3. In your opinion, what was the difference between trials?

Figure 3: Questions administered to assess participant perceptions and preferences

$$targetAngle = \tan \frac{y_t}{x_t} \tag{4}$$

$$V_{linear} = \min(MaxSpeed, K_{linear} \times targetDistance) \tag{5}$$

$$V_{angular} = K_{angle} \times targetAngle \tag{6}$$

Preliminary experiments were performed to evaluate the algorithm and identify the best parameters (Robot maximum speed, Robot linear feedback gain, Robot following distance, User walking speed) for each of three following angles (30°, 60°, 90°). Parameter combinations that enable the robot to consistently maintain different following angles when walking on a straight path were identified. The robot's maximum angular and linear feedback coefficients were set to 1.2 scalar, the maximum speed of the robot was set to 0.8 m/s, and the robot's minimum following distance was set to 1.2 m.

2.4 Procedure

The robot was introduced to participants as their personal assistant who could be used to carry personal belongings. Participants were instructed regarding the task they had to perform while being followed by the robot: either walking to the pace of a metronome, set to produce a sound every 30 seconds, or walking at their natural walking pace while playing a game ("aa") on a smartphone provided by the experimenters. They were then asked to place their cellphone in a basket on the robot and walk the 24m long path (12m in each direction) while being followed by the robot and completing the instructed task. At each trial, the robot followed them at a different angle (0°, 60°, 90°). At the end of each run, participants retrieved their cellphone and filled out a questionnaire (Figure 3; used 5-point Likert scales with 5 representing "Strongly agree" and 1 representing "Strongly disagree"). After three runs in which participants experienced all three following angles for a certain task, participants were given a post-session questionnaire and instructed regarding the second task they had yet to experience. The framework of analysis for the objective measures and questionnaires was the General Linear Model. All statistical tests were designed as two tailed, and used a significance level of 0.05.

3 RESULTS AND DISCUSSION

Objective indicators of the quality of following are summarized in Table 1. While we aimed to evaluate a robot following at 0°, 60°, and 90°, the robot followed at 0°, 47°–58° and 61°–77°. The robot's average following distance depended on the type of task and following angle ($p=0.00$). There weren't many instances of loss, however, the likelihood of loss increased as the following angle increased ($p=0.01$).

The type of task significantly affected how the robot was perceived. Participants rated the robot as more stressful ($p=0.02$), frightening ($p=0.023$) and intruding ($p=0.024$), and less friendly ($p=0.01$) when completing the auditory task than the visual task. In addition, they rated the robot's walking behavior as less natural when completing the auditory task ($p=0.00$) and the robot's speed was perceived to

Table 1: Objective measures for walk quality

Intended Angle / Task		N	Distance Mean	Distance Std. Dev [b]	Actual Angle Mean	Actual Angle Std. Dev [c]	Losses	Interventions loss	Interventions safety	Engagement
0	Mean	64	1.35	0.19	0.31	0.69	0	0	0	1.8
	SD [a]		0.22	0.13	0.71	2.06	0	0	0	1.8
60	Mean	64	1.32	0.21	52.27	9.99	0.18	0.30	0.03	1.8
	SD		0.17	0.12	5.61	3.82	0.53	0.57	0.17	1.6
90	Mean	64	1.33	0.21	68.54	10.01	0.14	0.22	0.03	2.22
	SD		0.12	0.06	7.44	2.27	0.43	0.53	0.17	1.75
Auditory	Mean	96	1.27	0.17	42.41	8.05	0.07	0.11	0.02	2.23
	SD		0.07	0.07	30.96	3.32	0.30	0.37	0.14	1.9
Visual	Mean	96	1.4	0.24	38.34	8.40	0.14	0.23	0.02	1.66
	SD		0.22	0.13	28.33	4.20	0.48	0.54	0.14	1.47

[a] The standard deviation for each variable of all trials in the 0° angle condition.

[b] The standard deviation of all distance measurements that the robot recorded from the participant.

[c] The standard deviation of all following angle measurements that the robot recorded during trials

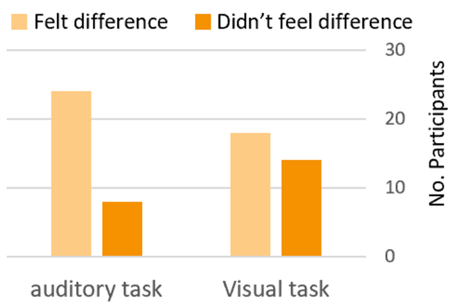

Figure 4: Number of participants that felt a difference between trials

be slower (p=0.00) and less comfortable (p=0.05). There were also differences in people's ability to perceive the robot's behavior as a function of task: in the auditory task, 75% of participants said they felt a difference between the three trials, whereas only 56% did in the visual task (Figure 4). In line with this finding, in the auditory task more participants (58%) correctly identified the difference between trials to be a change in following angle than in the visual task (17%) (Figure 5).

Perceptions of the robot were also affected by its following angle – participants rated the robot's following as less natural as the following angle increased (p=0.00), and the robot itself as more stressful (p=0.02), more frightening (p=0.023), more intruding (p=0.024) and less friendly (p=0.01). An interaction effect between following angle and type of task was found in terms of how stressful the robot was perceived to be (p=0.044) and how satisfied participants were with the robot's following behavior (p=0.035): in the auditory task, as the following angle increased, the robot was perceived as less stressful and the participants became more satisfied with the robot's following behavior. In contrast, in the visual task, as the following angle increased, the robot was perceived as more stressful and participants became less satisfied with the robot's following behavior.

Participant selection of favorite trial was influenced by run order: out of 42 trials which participants stated were differentiable, 62% selected the third run as their favorite, 26% selected the second run, and 12% selected the first run. Participant's choices of favorite trials were consistent with their responses in the post-trial questionnaires. For both tasks, when evaluating only trials in which participants correctly identified a change in the robot's following angle, larger following angles were favored over the smaller ones (Figure 6). Since the questionnaire was administered at the end of the three runs,

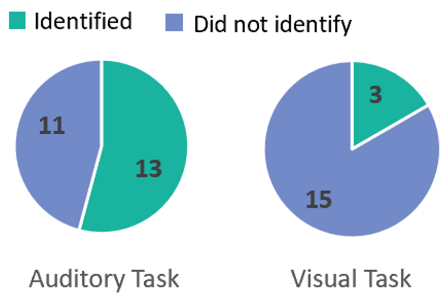

Figure 5: Number of participants that identified the difference between trials as a change in following angles

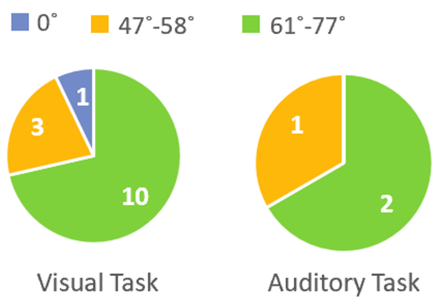

Figure 6: Selection of favorite trial when the difference between trials was identified as a change in following angle

participant's selection may have been based on what was most readily available to them in memory. Alternatively, perhaps gaining familiarity may have a more significant impact on user preferences in human-robot interaction than following angle. In line with this theory, [3] found familiarity with the robot to be more influential on preferred approach distances than the angle of approach.

This investigation has several limitations which will be addressed in future iterations. The primary limitation is that the two tasks differed from one another both in terms of task modality and task complexity, preventing us from identifying the sources of the task-related differences observed. The auditory task, unlike the visual task, allowed participants to visually engage with the robot without harming their performance in the task, which could have led to the higher engagements in this condition. Alternatively, if the visual task was more cognitively demanding, the participants would be left with less attentional resources to comprehend the robot's behavior, and would be less likely to notice things about the robot or its behavior that they do not like. Future studies will use comparable tasks, treating modality and complexity as separate independent variables. Another limitation is that the study did not use pre-validated questionnaires or in-person interviews, which may impact the applicability and breadth of the results. Future work will improve the quality of measurements.

4 CONCLUSION

Experiments studying the human-robot interaction of a person-following robot typically do not evaluate interactions where the user performs a separate task, irrespective of the robot, while walking. This preliminary study has shown that such tasks can influence user preferences of the robot's following angle and user perceptions of the robot's behavior. Consequently, separate user tasks must be taken into consideration when evaluating and designing spatial human-robot interactions.

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