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EFFECT OF THE SIZE FACTOR ON PSYCHOLOGICAL THREAT OF A MOBILE ROBOT MOVING TOWARD HUMAN

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Abstract: Although human symbiosis service robots have been developed in various sizes, there have been few quantitative investigations on the psychological effect that the size of a robot has on the user. We focused on the height of a robot (robot size), its relationship to the degree of fear or anxiety experienced by a human interacting with the robot, and the appropriate human-robot distance. We prepared three mobile robots measuring 0.6, 1.2 and 1.8 m tall. In our experiment, one of these robots would approach a male subject from a distance of 3 m at up to 0.4 m/s, and the subject would use a switch to stop the robot when he felt anxious. We measured the human-robot distance at the point when the subject stopped the robot. Then we asked the subject to fill out a questionnaire to evaluate the difference in degree of anxiety for robots of different sizes. Experiments with 19 subjects showed a tendency towards a longer human-robot distance for a larger robot. The questionnaire results revealed that the subjects felt maximum anxiety for the 1.8-m-tall robot although some subjects experienced anxiety in the case of the 0.6-m-tall robot, too. The results for both human-robot distance and the questionnaires will be useful in designing service robots.

Keywords: Service robot, Robot size, Psychological threat, Human-robot distance

1. INTRODUCTION

The development of robots in the fields of nursing care and welfare is expected to help resolve problems arising from the aging of society, such as the decrease in the population of workers [1]. For example, Hiroi *et al.* developed a nursing-care service robot called IRIS [2]. This robot understands a patient's orders through spoken dialogue and performs several tasks, such as bringing a bottle of water, opening or closing curtains, etc. in real environments.

These kinds of robots need to be made safe for humans, and several studies have been published on this subject. Prassler *et al.* developed a robot equipped with sensors in order to avoid collisions with humans [3]. Jeong *et al.* proposed a collision sensor with a shock-absorbing function [4]. Using a different approach, Matsumaru *et al.* proposed a method for announcing a robot's movements in advance, using devices such as a laser pointer or an LCD projector to warn users of the robot's next action [5, 6].

In addition to maintaining physical safety, we must also consider the psychological effects of robots operating in the midst of humans. Ikeura *et al.* measured the psychological threat of an approaching robot by conducting a subjective evaluation as well as by measuring the subjects' galvanic skin response [7]. Note that a small robot moving on a desk was used in their experiment. Nakajima *et al.* investigated the relationship between a moving robot's velocity and the human-robot distance at which subjects felt no psychological threat [8]. They used the mobile

robot HelpMate, which is employed as a courier in hospitals. Their results are meaningful, but psychological perceptions such as anxiety or feeling threatened are affected not only by the velocity but also by the size of the robot. Walter *et al.* carried out similar experiments using the mobile robot PeopleBot, and measured the effects of personal factors such as gender on the subjects' impressions of the robot [9]. Because Nakajima and Walter used ready-made robots in their experiments, they did not investigate the effect of the size of the robots on these impressions.

In this study, we focused on the size of a moving robot and measured the effect of robot size upon the psychological threat perceived by subjects. In general, the size of a robot is determined by its width, height and depth. In a situation where a robot is approaching in front of the subject, width and height must be considered. Here, we consider only the height of a robot because the width cannot vary greatly due to stability (a thin shape makes the robot unstable) and environmental (a very wide robot cannot pass through a doorway) restrictions. In addition, we can arbitrarily design the height of a robot compared with the width. However, as mentioned above, previous studies did not investigate the psychological effect from robots with different height. We define the height of a robot as the "robot size." The height of robots used in conventional experiments is around 1200 mm [8, 9]. In this study, we investigated the psychological effects of varying the size of a robot. In addition to the robot height, there can also be some psychological effects from its velocity, shape, material and color. In our work, however,

we assume that the tendency of the psychological effect of the robot height is not greatly affected by other factors.

We define “subjective acceptable distance” as the minimal distance at which a subject does not feel any psychological threat. We measured the subjective acceptable distance using robots of various sizes in order to investigate the relationship between robot size and subjective acceptable distance. Next, we determined whether or not changing the robot size affects the psychological threat perceived by a subject.

2. EXPERIMENTAL DESIGN

On designing the experiment, we first considered the appearance of the robot, and then its velocity, which is a significant factor of a perceived psychological threat. Finally, we considered the posture of the subjects. We then produced the mobile robot for the experiment.

2.1 Robot Appearance

The appearance of a robot varies greatly according to its purpose. The major features included in the appearance are shape, color and size. For example, the shape of a robot can be human-like or animal-like, and there are even more artificial shapes such as in factory robots. Robots with the former shape look friendlier than those with the latter shape. Although it is difficult to make a general statement on the relationship between robot shape and how friendly it looks, the robots developed in companies and research institutes employ friendly appearances. Next, considering color, robots can be white, black or even yellow. Moreover, a robot does not necessarily have to be a uniform color. Therefore, it is also difficult to make a general statement on the psychological effect of the color of a robot. In this experiment, we decided to design the robot with as few features as possible, and so used the simplest possible shape (a rectangular parallelepiped) and color (white).

Next, we considered the size of the robot, based on actual robots designed for use in care support or communication fields. Many robots measure around 1200 mm, including the robots used by Nakajima and Walter. Several examples are described below.

Kanda *et al.* developed Robovie [10], a wheeled robot with a human-like appearance. They explained that the height of Robovie (1200 mm) was selected so as to be less than that of an adult human and thus not threatening to users. Honda Motor Co., Ltd. developed a biped humanoid named ASIMO [11], also around 1200 mm tall, suitable for conducting work in an office. The above-mentioned robot HelpMate is also about 1200 mm tall. A hospital delivery robot, HOSPI [12], developed by Matsushita

Electric, is almost the same size as the HelpMate. Kouno *et al.* developed a robot for conveying food trays [13], and it is also about 1200 mm in height. They explained that they had designed the robot to be suitable for achieving the intended task, but did not mention users’ feelings of a psychological threat from the robot.

Next, we survey robots that have been developed with sizes greater or less than 1200 mm. Takahashi *et al.* developed the robot AMOS for assisting in nursing care [14]. AMOS has two driving wheels and a manipulator with 4 DOF. Its height is 700 mm. Bishoff developed the humanoid robot HERMES, whose height is 1850 mm so that it could work in a human environment [15].

The body-to-limb proportion of biped humanoid robots cannot differ greatly from that of humans because they must be able to walk. To design such a robot for a specific purpose, the designer must ensure that the robot can achieve the task while maintaining its balance. Conversely, non-humanoid robots, such as AMOS, can be made any size. A robot smaller than AMOS would have trouble delivering documents or food, while a 2000-mm-tall robot would not be able to pass through an ordinary doorway. Considering these existing robots, we decided to test three robot sizes, 600, 1200 and 1800 mm, which cover the standard robot size (1200 mm) and those that are 600 mm taller and shorter than the standard size.

2.2 Robot Velocity

Nakajima *et al.* reported that the subjective acceptable distance was proportional to the moving velocity of the robot [8]. They investigated the subjective acceptable distance for five velocities: 200, 400, 600, 800 and 1000 mm/s. In their study, they explained that it was not desirable for a robot to move towards a human faster than 800 mm/s because it would appear very threatening. However, some subjects experienced no anxiety when a robot approached at a velocity as low as 200 mm/s. Taking these results into account, we chose a velocity of 400 mm/s for the robots in our experiment so that the anxiety or threat perceived by a subject would be affected by the size of the robot alone.

2.3 Subject Posture

The robots in this study are meant to deliver documents in an office or assist in nursing care at a hospital. Considering these functions, possible users may be standing by a robot, as well as seated in a chair, a bed or a wheelchair. Nakajima *et al.* claimed that the subjective acceptable distance measured from the subject’s eye level was greater when a subject was seated than that when standing. However, the effect of a subject’s posture on the subjective acceptable distance of different robot sizes is unclear. Therefore, we

investigated the effect of a subject's posture on the subjective acceptable distance for various sizes of robots. To this end, we considered two postures, standing and seated, as in the experiment conducted by Nakajima *et al.*

3. EXPERIMENTAL SETUP

We carried out an experiment using a mobile robot designed according to the discussion in the previous section

3.1 Robots and Experimental Arrangement

Figure 1 shows the base of the robots used in the experiment. The base included two driving wheels and two castors, and was 450 mm wide, 390 mm deep and 250 mm high, with a weight of 15.0 kg. Assuming that the effect of the depth of the robot is sufficiently smaller than that of the height, we designed the depth to allow for stable operation of the robot. We changed the height of the robot by changing its frame on the base, which was made of L-shaped aluminum. We covered the frame with white paper so that the subjects could not see the frame: we covered the whole of the front side and upper side, and the front half of both sides. The reason why we used paper is due to its safety and ease in performing the experiment. If we had made the robot using material other than paper, the subjective acceptable distance might have changed because of the difference in the feel of the material. However, on performing the experiment, we assumed that the psychological effect from the difference in material is sufficiently smaller than that from the robot size. The shape of the robot was a rectangular parallelepiped that measured 450 mm wide and 390 mm deep. The height of the robot could be selected from 600, 1200 or 1800 mm, as shown in Fig. 2. The robot moved back and forth using trapezoidal velocity control at an acceleration of 200 mm/s² and a maximum velocity of 400 mm/s. Each subject held a button control switch that was connected to the robot, as shown in Fig. 3. The robot began moving toward the subject at the first push of the button and it stopped immediately at the second push. We prepared a cable between the robot and the switch long enough that the cable would not disturb the robot's movement. For safety, we also designed the circuit so that the robot would stop moving if the circuit failed. On carrying out the experiment, we confirmed the safety of the subjects, and also confirmed that all sides of the robot that were visible to a subject were covered with paper.

3.2 Experimental Paradigm

We conducted an experiment to investigate the relationship between robot size and subjective acceptable distance.

The subjects were 19 male undergraduate students ranging in age from 19 to 22. The subjects had never seen the robots before. The experiment was carried out in a 5×6-m room. We shut all of the curtains to block out the daylight, and turned on all of the lights in the room. A robot was set at a distance of 3 m in front of each of the subjects, each of whom practiced using the switch several times before the experiment began. We then gave the subjects the following instructions:

"The robot will start moving towards you from 3 m away at a velocity of 400 mm/s when you push the button. When you start to feel threatened, push the button again. The robot will stop immediately. When the robot stops, if the distance to the robot is shorter or longer than you intended, please tell me. If the robot does not stop, please avoid it by moving out of its way. You will evaluate three robots of different sizes from two postures, a seated posture and a standing posture. Please look at the robot during the experiment. After the experiment, you will be asked to complete a questionnaire."

We did not take special action for fixing a subject's gaze. We recorded the experiment using a video camera so that all equipment including the robot and the subject shown in Fig. 3 could be recorded.

The order of robot sizes and postures were randomized from subject to subject. When a subject accidentally stopped the robot earlier or later than intended, the experiment was repeated. On measuring the subjective acceptable distance, Nakajima *et al.* [8] performed measurement several times for each subject. Regarding the measurement results, they remarked that the fluctuation of measured distances was sufficiently small compared with fluctuation from other factors. Considering this result, we measured the distance only once for one experimental condition for one subject, except in the case of measurement failure.

As a result, there were no claims from the subjects that the measured distances were too short or too long. There were no operation errors, and no collisions between the robot and the subjects. Furthermore, none of the robots went out of control during the experiment. These results mean that measurement was performed exactly once for one condition for one subject.

Figure 4 defines the distances between the robot and the subject. Let L1 be the distance between the front of the stopped robot and the eyes of the seated subject. Next, let L2 be the distance between the front of the robot and the toes of the standing subject. Moreover, we measured the height of the eyes of the subjects from the floor for both seated and standing posture using a tape measure. Then, we chose subjects that have almost the same height of eyes.

After the experiment, we asked each subject to complete

the following questionnaire:

- Q1: Let subjects rank the six conditions (all possible combinations of three sizes and two postures) from most to least threatening. In this question, we only need the order of perceiving a psychological threat among the six conditions used in the experiment. For example, if a subject felt the robot to be most threatening under the 1800-mm, standing condition, let the subject assign the number 6 to that condition. Similarly, if a subject felt the robot to be least threatening under the 600-mm, seated condition, let the subject assign the number 1 to the condition.
- Q2: If a subject reacted differently to the same robot under the standing condition compared to the seated condition, let the subject describe the difference.
- Q3: Let a subject describe any other comments.

4. EXPERIMENTAL RESULTS AND DISCUSSION

4.1 Subjective Acceptable Distance and Posture

Figure 5 shows the average subjective acceptable distance for each of the six conditions. An error bar in the figure shows the standard deviation for the condition. From this figure, we can see an increase in L2 along with robot size. However, the L1s for 1200 and 1800 mm do not appear to differ. To validate this data, we conducted ANOVA using a randomized block design for both L1 and L2 to determine whether the subjective acceptable distance was affected by robot size. The results showed significant differences in both L1 and L2 ($p < 0.001$). Next, we conducted Dunnett's test to find out if the subjective acceptable distance at 600 or 1800 mm differed from that at 1200 mm. The results showed significant differences for the L2s of 600 and 1800 mm ($p < 0.05$), and an L1 of 600 mm ($p < 0.01$). However, there was no significant difference between the L1s of 1200 and 1800 mm. These results suggest that the subjective acceptable distance was long for larger robots and short for smaller robots when the subjects were standing. However, the subjective acceptable distance does not increase when the robot size is greater than 1200 mm and the subject is seated.

We measured the distance between the subjects' eyes and the floor. The average distance was 1186 mm (standard deviation 38.7 mm) for a seated posture and 1601 mm (standard deviation 60.0 mm) for a standing posture. The height of the eyes of the seated subjects is comparable with the robot size of 1200 mm. The following hypothesis may explain this result.

We measured the height of the eyes when the subjects were seated, and calculated the average height. As a result,

the average height of eyes was 1186 mm (standard deviation 38.705). This value is comparable with the robot size of 1200 mm. When the height of an object is lower than the

Figure 1: Overview of the base of the mobile robot

Figure 2: External view of the mobile robot

Figure 3: Arrangement of the robot and subject

Figure 4: Definition of distances between robot and subject

observer's eyes, the observer uses the height of the object in the visual field as a cue for perception of distance [16]. However, if the object's height is higher than the height of the observer's eyes, this cue is lost. As the effect of cues for perceiving distance is additive [17], losing one of the cues may affect the observer's perception of distance. This fact means that the effect of robot size on subjective acceptable distance changes depending on whether or not the robot size is higher than a subject's eyes.

We also tested subjective acceptable distance of two groups for the 1200-mm robot, where the subjects in one group had eye height lower than 1200 mm, and that of another group with higher eye height. We could not confirm any statistically significant difference in distance between the two groups. As the average eye height of the higher group was only 25 mm greater than 1200 mm (standard deviation 17), the difference between the robot size and subject's eye height of the higher group might be too small to obtain a significant difference in distance.

4.2 Effect of Posture on Subjective Acceptable Distance

When a subject is seated, the subject's eye height is lower compared with the height when the subject is standing. Therefore, the relative robot size is larger when a subject is seated than when he/she is standing. Here, we make a hypothesis that the subjective acceptable distance when a subject is seated is longer than that when the subject is standing. In Nakajima *et al.*, the subjective acceptable distance reported by seated subjects was larger than that reported by standing subjects [8]. We validated the difference in subjective acceptable distance between different postures using a *t*-test. Our results showed significant differences between L1 and L2 for all robot sizes ($p < 0.001$ for 600 and 1200 mm, $p < 0.01$ for 1800 mm), consistent with Nakajima's results.

4.3 Questionnaire Results

The results of the questionnaire are summarized in Fig. 6. The horizontal axis is robot size, and the vertical axis is

Figure 5: Relationship between robot size and subjective acceptable distance

the sum of the ranks from Q1. The labels A to F correspond to the robot size and posture of the subject. The labels A, B and C correspond to the robot sizes 600, 1200 and 1800 mm, respectively, when the subject is seated. The labels D, E and F correspond to the same sizes when the subject is standing, respectively.

We found significant differences among these values using Friedman's test ($p < 0.001$). Then, we investigated whether or not the values differed for each pair, using the Steel-Dwass test. The results are shown in Table 1. Based on the results of these tests, we have made the following observations:

- (1) A subject feels most threatened in the presence of an 1800-mm robot, regardless of the subject's posture.
- (2) No difference is observed in psychological threat when the robot size is 600 mm, regardless of the subject's posture. When the robot size is 1200 or 1800 mm, the subject's perception of a psychological threat differs for different postures.
- (3) When seated, the subject perceives a greater psychological threat in the presence of taller robots.

Observation (1) roughly corresponds to the subjective acceptable distances shown in Fig. 5. However, when the subjects were seated, there was no difference in subjective acceptable distance between the 1200- and 1800-mm robots, while a significant difference was observed in perceived psychological threat. These results suggest that the relationship between subjective acceptable distance and perceived psychological threat is not simple.

Next, let us consider observation (2). From the subjective acceptable distance of the two postures, we found that the distance was greater when a subject was seated. However, the level of anxiety was the same for the two postures when the robot size was 600 mm. To investigate this result further, we focused on the question asking the subjects to describe the difference in feelings when standing and seated.

There were 9 subjects out of 19 who perceived a psychological threat when the robot size was small (600 mm). The subjects' comments are as shown below.

- I was anxious when the robot went underneath me out of my sight
- I felt scared when I was standing because the robot moved out of sight as it approached (anxious)
- I could hardly catch it in my sight as it got nearer
- I felt uncomfortable when the small robot was moving out of sight

- I felt anxious when it moved out of sight
- I was somehow uncomfortable because it was below my line of sight
- The robot looked like it was approaching my feet
- I felt more threatened than when I was seated because my eyes looked downward.
- I was not scared but I was uncomfortable looking at it with my head down

As shown above, most descriptions were concerned with the subject's sight. From observing the recorded video of the experiment, the small robot did not appear to go completely out of the subjects' sight; we think this was a kind of expression by the subjects.

Next, we divided the subjects into two groups, one group involving those who answered that they perceived a psychological threat because of the robot's small size (600 mm), and the other involving the remaining subjects. Table 2 shows the average rank of perceived psychological threat for these two groups, accounted for seated and standing postures.

According to Table 2, the average rank of the two postures appear to be reversed for the subjects who felt threatened because of the small size of the robot and the other subjects. The former group involves 9 subjects and the latter 10. The average rank of all subjects is 2.26 when seated and 2.21 when standing. This reversal of rank between the two subject groups might be one reason why no significant difference can be observed between conditions A and D.

Let us consider observation (3). In Section 4.1, no significant difference was observed in subjective acceptable distance between the 1200- and 1800-mm robots when the subjects were seated. This result does not correspond to observation (3). To clarify this difference, we focus on the eye height of the subjects. Perceived psychological threat increases when the robot size is equal to or larger than the subject's eye height, corresponding to conditions B, C and F. In this case, 13 out of 19 subjects commented that a psychological threat arose from the robot having higher size than the subject's eyes or the subject's height. Among those conditions, C had the biggest difference in height, which might be a reason why condition C had a higher perceived psychological threat and we observed a significant difference between conditions B and C.

From the subjective acceptable distance and questionnaire results, it is clear that the subjects felt most threatened in the presence of the 1800-mm robot. Note that subjects also feel threatened around larger robots, even when the subjective acceptable distance is not long. From these facts, we can say that robots larger than 1800 mm are not

suitable for working around humans. Robots smaller than 600 mm would be acceptable from the viewpoint of acceptable distance, but we must also note that many subjects in our study claimed to have felt threatened around small robots.

5. CONCLUSIONS

To investigate subjective acceptable distance and anxiety concerning robots of various sizes, we carried out experiments using nineteen subjects and three robots. We measured subjective acceptable distance by asking subjects to stop an approaching robot using a switch when the distance between the subject and the robot reached a point where the subject felt uncomfortable. As a result, the subjective acceptable distance became smaller when the robot size was smaller than 1200 mm, whereas the subjective acceptable distance tended to become larger for larger robot size. However, the acceptable distance was not higher for 1800-mm robots when the subjects were seated. We hypothesized that this result was caused by the relationship between robot size and the height of the subject's

Figure 6: Comparison of perceived psychological threat between seated posture and standing posture

Table 1: Results of Steel-Dwass test

Cond.	B	C	D	E	F
A	p<0.05	p<0.001	NS	NS	p<0.001
B		p<0.001	p<0.05	p<0.05	p<0.01
C			p<0.001	p<0.001	p<0.05
D				NS	p<0.001
E					p<0.001

Table 2: Effect of anxiety about small robot (600 mm) on the difference in perceived threat for different postures

	Seated	Standing
Anxious	2.00	2.78
Not Anxious	2.58	1.70
Total	2.26	2.21

eyes. If this hypothesis is true, we should pay attention to the likely postures of users in their environments when designing and selecting the sizes of robots.

Next, we analyzed the answers to the questionnaire and found that robots over 1800 mm tall are not desirable for work in a real environment because of their tendency to make users feel threatened.

As we found few studies concerning the relationship between robot size and user impressions of robots, our work provides important information about the design of robots for use around humans.

Our results using box-shaped robots can be applied to designing delivery robots in an environment around humans [12, 13]. Small robot size is desirable in terms of subjective acceptable distance. However, delivery robots must be able to carry larger loads. Those delivery robots work in an environment where most humans are standing. From the results of the questionnaire, we observed no difference in perceived psychological threat between the 1200- and 600-mm-tall robot when the subjects were standing. Therefore, if we want to choose larger robot size from the conditions examined in our experiment, 1200 mm would be permissible. Conversely, the smallest robot is desirable when humans in the environment are seated.

In the future, we will further investigate the factors affecting people's perception of robots, which involve human factors such as subject age or gender [9, 18], knowledge of robots [19], and robot appearance (shape, material, color, etc.) [20], as well as a robot's behavior (moving pattern, etc.) [7, 8].

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