Robotic-Human-Machine-Interface for Elderly Driving: Balancing Embodiment and Anthropomorphism for Improved Acceptance

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Abstract. Encouraging self-awareness among elderly drivers while driving with a passenger has the potential to reduce traffic accidents. Highly anthropomorphic Robotic-Human-Machine-Interfaces (RHMIs) have been shown to be effective in providing safe driving and review support by being perceived as fellow passengers. However, it remains unclear which specific anthropomorphic elements in the RHMI's appearance are necessary to achieve this effect. Identifying these essential elements for elderly driving could lead to a minimal design approach and reduced installation costs in car dashboards. Therefore, in this study, we investigated the effects of RHMI embodiment and anthropomorphism level on drivers' acceptability and user experience quality through a series of RHMI prototypes by conducting a crowdsource video experiment and a driving simulator experiment, respectively. The findings provide insights into the design of a low-cost, minimal, and efficient RHMI as a driving agent.

Keywords: RHMI · Elderly Drivers · Anthropomorphism · Embodiment · User Experience

1 Introduction

The global older adult population has been increasing in recent years [14], and it is crucial to provide them with a comfortable and happy lifespan by keeping them socially active and preserving their social abilities by maintaining their transportation freedom. However, due to cognitive, visual, and physical decline caused by aging, combined with overconfidence from years of driving experience, these drivers, especially the age group of 64–74 years, are prone to causing fatal accidents [1]. It has been reported that elderly drivers make a conscious effort to drive

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safely when they have a fellow passenger in the car, having a potential to result in a reduced accident rate. This phenomenon is referred to as the fellow passenger effect [20]. Previous research has indicated that the generation of the fellow passenger effect can be achieved through a small humanoid robotic-human-machine-interface (RHMI), RoBoHoN, as elderly drivers tend to perceive the robot as a companion in the vehicle [18]. Also, the short and long-term experiments with RoBoHoN, revealed that it had a positive impact on improving risky driving behaviors in elderly drivers, including reducing speeds when entering intersections [17]. These validated effects have increased the desire to incorporate this system into cars at an affordable cost to make it more accessible to society and have a wider impact. However, highly anthropomorphic features of RHMIs may rise the potential of disappointment in their interactions with their human interlocutors due to technical barriers in their development. Also, the cost of highly anthropomorphic robots is high due to the complexity involved in using advanced materials, motors, sensors, and other components. Therefore, particularly in the context of in-car environments, it is crucial to explore alternative design possibilities that are minimal, inexpensive, and seamlessly blend with the driving environment to minimize distracting elements in the peripheral visual field.

Recently, the use of minimally designed RHMIs with low anthropomorphism in their appearance as driving agents were researched. The study suggested employing three minimal robot heads as RHMIs to lessen cognitive load during driver-relevant information delivery [8]. Zihsler et al. focused on enhancing trust in autonomous cars by incorporating human-like behaviors and expressions into an RHMI [22]. Cheng et al. investigated anthropomorphism's impact on trust and driving performance, revealing that familiar users trusted less in highly anthropomorphized RHMI, unlike unfamiliar users [5]. However, in the aforementioned studies, the level of anthropomorphism in an RHMI's appearance and its impact on the user experience and acceptance among elderly drivers during driving support remains unclear. This paper adopts a user-centered approach to investigate preferred design prototypes, including sound-only, illuminated dome, a minimal robot head with eyes, head with eyes and ears, and an abstract robotic full-body. Our objective is to assess the acceptability of these designs and explore their relationship with anthropomorphism and user experience attributes through two experimental studies involving elderly drivers.

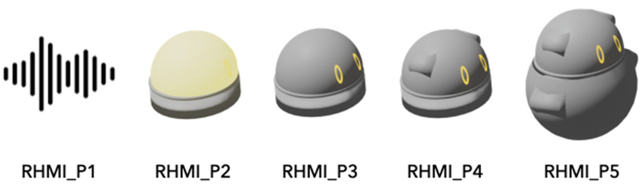

Fig. 1. RHMI prototypes (RHMI-P) that are used for the Study 1: RHMI-P1: sound-only, RHMI-P2: illuminated dome, RHMI-P3: dome with eyes, RHMI-P4: dome with eyes and ears, RHMI-P5: full body

2 Method

2.1 RHMI Design

In driving, sound-only systems can be sufficient for providing driving support, as many of today's driver assistance systems offer capabilities such as voice-based navigation and audio alerts for collision warnings [9]. On the other hand, by leveraging additional communication channels like oculesics [12] and gestures [4], the embodiment can enhance communication and create a perception of increased trustworthiness [22], sociability [21] and familiarity [18] that would help an RHMI to increase its acceptance. When developing the embodiment, it is important to meticulously design the anthropomorphism level of the RHMI to appropriately align drivers' expectations and prevent potential negative experiences in their interactions with the RHMI.

The user-centered design approach for developing robotic artifacts involves utilizing prototyping tools, available in both virtual and physical forms, each with distinct advantages. Virtual prototypes offer design flexibility, cost-effectiveness, and accessibility, but may lack real-world realism. In contrast, physical prototypes provide a more authentic evaluation experience. In this study, we initially created virtual prototypes for a video recording session involving a broad participant range (Study 1). Subsequently, we selected prototypes from Study 1, physically built them, and conducted a realistic driving simulator experiment to assess these prototypes' acceptance by a smaller group of drivers, aiming for obtaining detailed feedback (Study 2).

Our iterative process for this study involved several phases: (a) initial pencil sketches to explore different shapes, (b) development of 3D computer graphic models, (c) evaluation of the models through an online experiment, (d) refinement of the models and creation of 3D printed versions based on the online video experiment results, (e) evaluation of these 3D printed models in a driving simulator experiment, guided by feedback from the simulation experiment. At the stage (b), we designed five RHMI prototypes (RHMI-P1, RHMI-P2, RHMI-P3, RHMI-P4, RHMI-P5) as part of this process (Fig. 1).

2.2 Prototype Design Condition Creations

RHMI-P1: Sound Only. In the control condition, a voice-only support system was employed using the Nozomi voice from AI Talk 3 software, characterized by a young female voice. To align with previous research by Miyamoto et al. [10], which found that a positive and polite speech style was more acceptable for driving support, we utilized a polite, casual, and friendly speech style in Japanese for this condition.

RHMI-P2: Illuminated Dome. Illuminated color, by itself, is an important for non-verbal interaction element in robotics [3]. Also, round shapes generally preferred in various applications [6]. Therefore, the second RHMI design featured an illuminated dome measuring H62 mm × W100 mm × D100 mm, with a yellow blinking light to convey alertness [13] and readiness for providing driving support.

RHMI-P3: Dome with Eyes. Previous research has emphasized the significance of eyes in robot perception [11], particularly the design with two eyes, which is perceived as more human-like [7]. Therefore, the third RHMI design featured a two-eyed head with a baby schema, incorporating two LED eyes of the same size as RHMI-P2 (Fig. 1).

RHMI-P4: Dome with Eyes and Ears. The inclusion of ears in an RHMI design, along with eyes, is an anthropomorphic feature aimed at helping drivers perceive the RHMI's orientation. Given that the RHMI's head is positioned away from the road, it becomes crucial for drivers to accurately perceive the orientation of the RHMI. Therefore, our fourth RHMI design condition features a head with both eyes and ears (Fig. 1).

Fig. 2. A third eye view from the video footage of the RHMI-P5 condition.

RHMI-P5: Full Body. To achieve a higher level of anthropomorphism in our RHMI design, we created a full-body representation with abstractly integrated arms with the dimensions of H120 mm × W100 mm × D100 mm. The incorporation of a complete body figure is essential for fostering a sense of familiarity among users [15]. Therefore, our fifth RHMI design condition features an abstract full-body version of the RHMI.

In a study by Tanaka et al., RHMI was positioned facing away from the driver to avoid distractions during driving [18]. We adopted a similar positioning for our RHMI on the dashboard during the driving video recording. During driving support, the RHMI rotated 160° to the right and its LED eyes blinked.

For our online experimental study, the RHMI designs were created using Blender Version 3.1.2, ensuring the highest level of realism. To seamlessly merge the 3D models with real-world recorded videos, we utilized After Effects 22.5.0. For consistency across the designs, the synthesized voice of Nozomi from AI Talk was employed for the all prototypes.

3 Study 1: Video-Based Online Experiment

The aim of this experiment was to explore the acceptance, user experience (UEX) factors, and perceived anthropomorphism levels of each RHMI prototype specifically within the elderly group. To ensure a well-rounded comprehension of the perceptions of the RHMI prototypes for the elderly age group, and to enhance the validation of responses from this group, we included participants from all age groups in this online survey.

3.1 Experimental Scenario

We utilized pre-recorded driving video footage that included four driving-related conversational script in Japanese: 1) starting the driving (*"Untenshien wo kaishishimasu."*), 2) warning about approaching a stop sign (*"Ichiji teishi desu ne"*), 3) reminding the speed limit (*"Koko wa nan kiro seigen kana."*), and 4) ending the driving (*"Otsukaresama deshita."*). The driving scenarios used in the experiment were originally recorded with an omnidirectional camera. We selected specific segments from the recording, ensuring that each driving support scenario was included once. As a result, we obtained 35-second videos (Fig. 2).

3.2 Experimental Protocol

The study employed a within-subject design with counterbalancing to address order effects. Participants were recruited through Crowdworks[1], a Japanese crowdsourcing service, and the experiment was conducted using Google Forms[2]. Following a brief procedure briefing, participants completed a demographic questionnaire. They then viewed five experimental videos for each RHMI design and filled out three sets of questionnaires: a 7-point Likert scale Acceptance questionnaire (AQ1: Likability, AQ2: Reliability, AQ3: Ease of noticing environmental changes, AQ4: Willingness to use, AQ5: Sense of security, AQ6: Perceived annoyance, adapted from [18]), a 7-point Likert scale User Experience (UEX) questionnaire covering Attractiveness, Perspicuity, Efficiency, Dependability, Stimulation, and Novelty factors [16], and a 5-point Likert scale GodSpeed questionnaire including Anthropomorphism, Animacy, Likability, Perceived Intelligence, and Perceived Safety [2]. The online survey took approximately 20 min to complete, and participants received a 400 yen incentive. This experiment had the approval of the Institutional Review Board of the Institutes of Innovation for Future Society, Nagoya University, and Toyota Motor Corporation.

[1] https://crowdworks.jp/.
[2] https://www.google.com/forms/about/.

4 Results: Study 1

In total 317 subjects (female: 154, male: 163, $M = 42.30$ years, $SD = 12.83$) participated in this experiment. All the participants had a valid car driving license. We categorized the participant sample size based on age intervals: Young (20s–30s) with 106 participants, Middle (40s–50s) with 159 participants, and Older (60s+) with 52 participants.

We performed a two-way mixed ANOVA to analyze the impacts of RHMI and age interval on Acceptance, UEX, and Godspeed questionnaire items. The age interval was considered a between-subjects factor, while the RHMI type was considered a within-subjects factor. However, the assumption of sphericity was violated for the effect of RHMI type ($\varepsilon > .9$) across all questionnaire items. Consequently, the Huynh-Feldt correction was applied to account for this violation. The adjusted degrees of freedom were employed to determine the significance of the RHMI effect. When significance was detected, post hoc analysis was conducted using Bonferroni-adjusted pairwise comparisons. Table 1 and Table 2 display the main and interaction effects of the related questionnaire items, pairs indicating significance, mean differences, and Bonferroni-adjusted p-values.

4.1 Acceptance

According to the results, there was a significant main effect of RHMI on AQ2 ($F(3.910, 1227.759) = 3.400$, $p = .009$, $\eta^2 = .011$), AQ3 ($F(3.742, 1175.029) = 10.329$, $p = .000$, $\eta^2 = .032$), AQ4 ($F(3.671, 1152.747) = 6.514$, $p = .000$, $\eta^2 = .020$) and AQ5 ($F(3.876, 1217.026) = 8.662$, $p = .000$, $\eta^2 = .027$). The post hoc analysis revealed a notable trend where RHMI-P5 received significantly higher ratings than the other conditions for these items (Table 1).

The findings also indicated an interaction effect between RHMI and Age interval on AQ1 ($F(7.543, 1184.189) = 10.095$, p $= .014$, $\eta^2 = .015$) and AQ6 ($F(7.543, 1184.189) = 10.095$, $p = .014$, $\eta^2 = .015$). Post hoc analysis showed that, within the older age group, participants found RHMI-P5 to be more favorable than RHMI-P4 and RHMI-P3 in terms of design preference. Additionally, the elderly group rated RHMI-P1 as significantly less annoying compared to RHMI-P2 and RHMI-P4 (Table 2, Fig. 3).

4.2 User Experience Quality

Results showed a significant main effect of RHMI on Attractiveness ($F(3.717, 1167.110) = 19.433$, $p = .000$, $\eta^2 = .058$) and Novelty ($F(3.445, 1081.763) = 22.812$, $p = .000$, $\eta^2 = .068$) factors. In the post hoc analysis, RHMI-P5 received significantly higher ratings than all other conditions. Also, RHMI-P4 was rated higher than RHMI-P1 and RHMI-P2 for these two factors (Table 1).

An interaction effect of RHMI x Age interval was observed for the Stimulation factor ($F(7.510, 1179.144) = 2.427$, $p = .015$, $\eta^2 = .015$). Post hoc analysis revealed that RHMI-P5 was rated significantly higher than other conditions, especially in the young and middle age groups. Additionally, RHMI-P4 received

Table 1. Results of the Main Effect in Two-way Mixed Measures ANOVA: S.C. (Significant Comparisons) and M.D. (Mean Differences), RP: RHMI-P

Main Effect: RHMI Type							
Items	S. C.	M. D.	p-value	Items	S. C.	M. D.	p-value
AQ2	RP5-RP1	0.249	.024		RP5-RP4	0.204	.010
	RP5-RP2	0.227	.036		RP4-RP1	0.44	.000
AQ3	RP5-RP1	0.565	.000		RP4-RP2	0.251	.021
	RP5-RP3	0.37	.000		RP3-RP1	0.379	.000
	RP5-RP4	0.255	.022	Anthropomorphism.	RP5-RP1	0.226	.001
	RP4-RP1	0.31	.008		RP5-RP2	0.388	.000
	RP2-RP1	0.377	.004		RP5-RP3	0.155	.004
AQ4	RP5-RP1	0.299	.028		RP5-RP4	0.156	.014
	RP5-RP2	0.452	.000		RP4-RP2	0.232	.000
	RP5-RP3	0.271	.004		RP3-RP2	0.233	.000
	RP5-RP4	0.252	.014		RP2-RP1	-0.162	.008
AQ5	RP5-RP1	0.441	.000	Animacy	RP5-RP1	0.342	.000
	RP5-RP2	0.424	.000		RP5-RP2	0.432	.000
	RP5-RP3	0.368	.000		RP5-RP3	0.225	.000
	RP5-RP4	0.3	.001		RP5-RP4	0.179	.000
Attractiveness	RP5-RP1	0.471	.000		RP4-RP1	0.162	.014
	RP5-RP2	0.53	.000		RP4-RP2	0.252	.000
	RP5-RP3	0.313	.000		RP3-RP2	0.206	.000
	RP5-RP4	0.225	.003	Likability	RP5-RP3	0.157	.001
	RP4-RP1	0.245	.004		RP5-RP2	0.329	.000
	RP4-RP2	0.305	.000		RP5-RP1	0.258	.000
	RP3-RP2	0.217	.012		RP4-RP1	0.145	.035
Novelty	RP5-RP1	0.645	.000		RP4-RP2	0.216	.000
	RP5-RP2	0.456	.000		RP3-RP2	0.172	.001
	RP5-RP3	0.266	.000	Perc. Safety	RP5-RP2	0.121	.007

Table 2. Results of the Interaction Effect in ANOVA: S.C. (Significant Comparisons) and M.D. (Mean Differences), RP: RHMI-P, Y: Young, M: Middle, O: Older

Interaction Effect: RHMI Type x Age Interval							
Items	S. C.	M. D.	p-value	Items	S. C.	M. D.	p-value
AQ1	RP5-RP1 (Y)	0.566	.002		RP4-RP1 (M)	0.393	.000
	RP5-RP2 (Y)	0.67	.000		RP4-RP2 (M)	0.275	.009
	RP5-RP3 (Y)	0.358	.021		RP3-RP1 (M)	0.33	.001
	RP4-RP2 (Y)	0.434	.022		RP5-RP3 (O)	0.433	.002
	RP5-RP1 (M)	0.365	.028		RP5-RP1 (Y)	0.627	.000
	RP5-RP2 (M)	0.34	.032		RP5-RP2 (Y)	0.585	.000
	RP5-RP4 (O)	0.577	.006		RP5-RP3 (Y)	0.233	.037
	RP5-RP3 (O)	0.596	.008		RP5-RP4 (Y)	0.323	.008
AQ6	RP4-RP1 (O)	0.981	.000		RP4-RP1 (Y)	0.304	.027
	RP2-RP1 (O)	0.923	.002		RP3-RP1 (Y)	0.394	.001
Stimulation	RP5-RP1 (M)	0.624	.000		RP3-RP2 (Y)	0.351	.003
	RP5-RP2 (M)	0.506	.000	Perc. Intelligence	RP5-RP1 (M)	0.231	.000
	RP5-RP3 (M)	0.294	.000		RP5-RP2 (M)	0.182	.005
	RP5-RP4 (M)	0.231	.031		RP4-RP1 (M)	0.179	.006

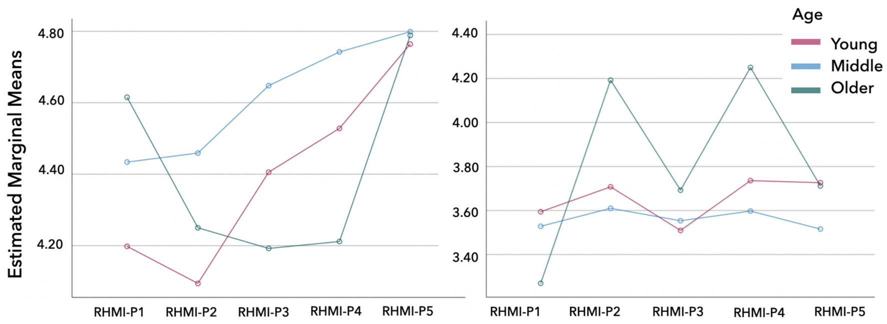

Fig. 3. Graph representations of interaction effect results of AQ1 *(left)* and AQ6 *(right)*.

higher ratings compared to RHMI-P1 and RHMI-P2, and RHMI-P3 was preferred over RHMI-P1 and RHMI-P2. Among the older age group, the sole significant distinction was that RHMI-P5 outperformed RHMI-P3 (Table 2).

4.3 Godspeed Questionnaire

Results showed a significant main effect of RHMI on Anthropomorphism ($F(3.553,\ 1115.652) = 14.883$, $p = .000$, $\eta^2 = .045$), Animacy ($F(3.397,\ 1066.686) = 22.993$, $p = .000$, $\eta^2 = .068$), Likability ($F(3.778, 1186.168) = 15.053$, $p = .000$, $\eta^2 = .046$) and Perceived Safety ($F(3.891, 1221.645) = 3.443$, $p = .009$, $\eta^2 = .011$). The post hoc analysis revealed that RHMI-P5 received significantly higher ratings than all other conditions, while RHMI-P4 outperformed RHMI-P1 and RHMI-P2, and RHMI-P3 showed higher ratings compared to RHMI-P2. Also, RHMI-P1 rated significantly higher than RHMI-P2 (Table 1).

The results also showed an interaction effect of RHMI x Age interval on Perceived Intelligence ($F(7.581, 1190.295) = 2.971$, $p = .003$, $\eta^2 = .019$) factor. Subsequent post hoc analysis indicated that the middle age group rated RHMI-P5 significantly higher than RHMI-P1 and RHMI-P2, as well as RHMI-P4 higher than RHMI-P1 (Table 2).

4.4 Correlations

We evaluated the internal consistency of the Acceptability questionnaire items excluding AQ6, using the evaluation data from the elderly age group. The Cronbach's alpha coefficient exceeded 0.905 across all five RHMI-P conditions (95% CI: $min = 0.889$, $max = 0.936$). Thus, Spearman's rank correlation analysis was conducted between the Acceptability and the Godspeed. We found strong significant correlations between Acceptability and Likability ($r = 0.741$, $p = .000$) and Perceived Intelligence ($r = 0.695$, $p = .000$). On the other hand, we found moderate correlation between Acceptability and Anthropomorphism ($r = 0.535$, $p = .000$), Animacy ($r = 0.515$, $p = .000$) and Perceived Safety ($r = 0.589$, $p = .000$).

5 Study 2: Driving Simulator Experiment

Considering the evaluation by the elderly age group, a significant difference was observed only in AQ1, where RHMI-P5 received higher ratings than RHMI-P4 and RHMI-P3 (Table 2, 3). Furthermore, considering the consistent trend of RHMI-P5 receiving the highest ratings and RHMI-P4 ranking second-highest in Study 1 (Table 1), RHMI-P4 and RHMI-P5 were chosen for further evaluation as physical embodied agents in Study 2. Additionally, due to the significantly better evaluation for RHMI-P1 over RHMI-P4 and RHMI-P2 in AQ6, we included the sound-only driving support condition in Study 2.

Research demonstrated that RoBoHoN (Fig. 4, *right*) positively impacted the acceptability of receiving driving support by the elderly as a highly anthropomorphized RHMI [18]. To assess our RHMI prototypes across varying levels of anthropomorphism, from low (sound-only) to high, we included RoBoHoN as a highly anthropomorphized RHMI condition in this study. Consequently, in Study 2, our aim was to investigate how elderly drivers would assess these two prototypes in comparison to sound-only driving support and RoBoHoN, within a realistic driving simulator setup.

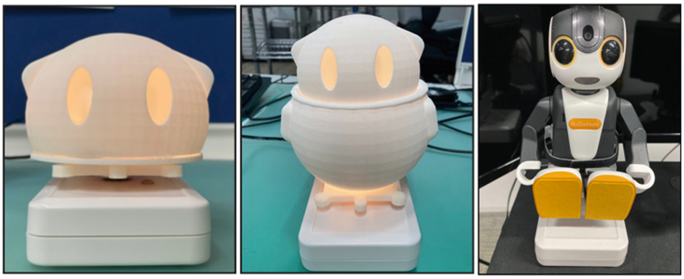

Fig. 4. RHMIs used in Study 2: RHMI-P4 (*left*), RHMI-P5 (*middle*), RoBoHoN (*right*).

5.1 Integration of RHMIs in the Driving Simulator

RHMI-P4 (Fig. 4, *left*) and RHMI-P5 (Fig. 4, *middle*) were remodeled in Tinkercad[3] and were subsequently 3D printed. The illumination of the eyes was achieved using an Arduino-nano microcontroller[4] and a Neo pixel 16 LED ring. RHMI-P4 had dimensions of H62 mm × W100 mm × D100 mm, while RHMI-P5 (Fig. 4, *middle*) had dimensions of H120 mm × W100 mm × D100 mm. RoBoHoN (195 mm tall humanoid robot from SHARP Co.), RHMI-P4, and RHMI-P5 were positioned on individual turntables, which could be connected to a computer through Bluetooth. The turn-table was positioned slightly to the left of

[3] https://www.tinkercad.com/.
[4] https://www.arduino.cc/.

the driver, as the driver seat was on the right side. The direction of RHMIs was set to face away from the driver. When providing driving support, the RHMIs would turn 160° to the right, as established in Study 1.

Fig. 5. Driving simulator environment used in the Study 2.

5.2 Experimental Scenario

In this experiment, we used a simulated urban road. The driving support was as follows 1) starting the driving, 2) warning for approaching to an intersection, 3) reminding the speed limit, 4) warning for another intersection, 5) warning for a group of pedestrian on the side of the road, 6) ending the driving, respectively. The speed limit in the simulator was set as 40 km/h. The driving scenario took 5 min to complete. The driving simulator software utilized in this study was UC-win/road[5]. The driving simulator comprised five monitors, a driving seat, a steering wheel, and accelerator and brake pedals. The RHMI prototypes were operated through a GUI controller developed with Python. A UDP connection was established between the driving simulator software and the RHMI controller to enable the RHMIs to initiate driving support behavior and speech automatically (Fig. 5). When the self-vehicle approached a designated checkpoint within a 150-meter range (i.e. intersections, pedestrian zones) the RHMI was automatically activated by the controller.

5.3 Experimental Protocol

In this study, a within-subject design was employed. Participants first received a briefing on the experiment's procedure. Afterward, they filled out a demographic

[5] https://www.forum8.com/.

questionnaire, then engaged in a three-minute practice session on the driving simulator. Following this, they completed the experimental session. After each session, they filled out two sets of questionnaires: the Acceptance [19] and God-Speed [2]. The entire experimental process took approximately 1.5 h to complete.

6 Results: Study 2

A total of 10 subjects participated in this experiment (5 females). The participants had a mean age of 73.9 years ($SD = 5.08$). All participants held a valid car driving license and reported using their car at least once a week for more than 10 min. We conducted a one-way repeated ANOVA analysis to examine the statistical difference among the conditions on the questionnaires.

The results showed no statistically significant results on AQ1 ($F = 1.752$, $p = .173$), AQ2 ($F = 0.672$, $p = .574$), AQ3 ($F = 1.528$, $p = .223$), AQ4 ($F = 1.408$, $p = .256$), AQ5 ($F = 0.905$, $p = .447$) or AQ6 ($F = 0.0975$, $p = .96$). The results also yielded no statistically significant result on Anthropomorphism ($F = 0.942$, $p = .43$), Animacy ($F = 0.543$, $p = .655$), Likability ($F = 1.992$, $p = .132$), Perceived Intelligence ($F = 1.724$, $p = .179$) or Perceived Safety ($F = 0.433$, $p = .73$).

6.1 Correlations

We assessed the internal consistency of the Acceptability questionnaire items. The Cronbach's alpha coefficient exceeded 0.90 across all four RHMI-P conditions (95% CI: $min = 0.87$, $max = 0.962$). Thus, we conducted Spearman's rank correlation analysis between the Acceptability questionnaire items and the Godspeed factors. We found significant, strong correlations between Acceptability and Anthropomorphism ($r = 0.649$, $p = .000$), Animacy ($r = 0.609$, $p = .000$) Likability ($r = 0.773$, $p = .000$) while moderate correlations with Perceived Intelligence ($r = 0.477$, $p = .001$) and Safety ($r = 0.416$, $p = .007$).

6.2 Participants Comments and Feedback

While four participants found the voice-only system sufficient and easier to understand, two participants mentioned concerns about the potential distraction caused by a physical robot presence. However, six participants expressed a desire for an RHMI as a driving support system, with one participant specifically valuing the sense of support provided by a robot during driving assistance.

Two participants anticipated greater responsiveness and more dialogue from RoBoHon. Although one participant acknowledged the tension generated by its human-like shape, they appreciated it as an effective warning for the driver. In contrast, two participants preferred the size of Robohon and considered it superior to other robot forms, while three participants found it distracting. Overall, five participants expressed their dislike for RoBoHon, citing potential distraction and the tension arising from its human-like appearance.

Four participants expressed their preference against the RHMI-P4 design due to its artificial appearance, lack of cuteness, and perceived awkwardness. However, three participants found the head-only design (RHMI-P4) small, less conspicuous and thus more suitable for driving situations. They also believed RHMI-P4 to be less human-like, therefore less distracting compared to Robohon.

Four participants deemed the RHMI-P5 design unnecessary due to concerns about its size, preference for simpler forms, and the perceived tension associated with a full-body design. In contrast, one participant noted that having only a head created a sense of being in an intermediate state between a machine and a living being, which was more acceptable. Two participants also found the appearance and size of RHMI-P5 awkward, suggesting that it could be slightly smaller. In terms of prior preference among the four RHMIs, two participants favored the Sound-only condition, four preferred Robohon, three preferred RHMI-P4, and none preferred RHMI-P5.

7 Discussion

Based on the two studies, the results can be summarized as follows:

- The importance of the embodiment in improved acceptability of an RHMI.
- The significance of a full-body prototype design, while maintaining a compact and efficient structure.
- The strong correlation between acceptability and likability of the RHMI rather than its anthropomorphism or animacy.

In Study 1, involving 317 participants in an online survey, significant differences in questionnaire items were observed based on RHMI type. RHMI-P5 received higher ratings for reliability (AQ2), situational awareness (AQ3), desirability for use (AQ4), and the sense of security (AQ5) compared to other prototypes. It was also perceived as more attractive, novel, anthropomorphic, animated, likable, and safer (Table 1). The interaction effect for the elderly age group favored RHMI-P5 in terms of favorability (AQ1) and found it more stimulating than RHMI-P3. RHMI-P1 was rated significantly less annoying than RHMI-P4 and RHMI-P2 (AQ6) (Table 2). On the other hand, RHMI-P4 showed strengths in situational awareness, attractiveness, novelty, animation, and likability, as well as perceived anthropomorphism. Also, the ear-like anthropomorphic elements were considered helpful for interpreting the RHMI's actions when viewed from behind [19]. Consequently, for Study 2, RHMI-P1, RHMI-P4, and RHMI-P5 were included in Study 2, conducted in a realistic driving simulator environment.

Study 2 demonstrated that some participants favored the sound-only system (RHMI-P1), considering it sufficient and less distracting. Others expressed worries about potential distractions from a physical robot presence. However, a significant portion of participants desired an RHMI as a driving support system, valuing the sense of support provided by a robot during driving assistance. In fact, seven out of ten participants preferred to have an embodied RHMI (RoBoHoN: 4, RHMI-P4: 3) as their driving support system. It's important to note that individual preferences were evident, and some participants had concerns about the size, tension, and potential distractions related to the full-body design of RHMI-P5. However, due to the limited number of participants in this study, generalization of these findings was not possible.

In both Study 1 and 2, the strong positive correlation between Acceptability and Likability highlights the importance of aligning the visual elements and their functions when designing an RHMI for driving support. This suggests that when striving for a minimal and compact design, with safety in mind, it's crucial to either omit non-functional anthropomorphic parts and/or assign meaningful functions to the retained body parts.

8 Conclusion

This research, consisting of two studies, delved into the design and evaluation of RHMIs for driving support, with a particular emphasis on acceptability among the elderly age group. Both studies revealed that the elderly group preferred embodied RHMIs and were more likely to accept the RHMI as a driving agent when they found it likable, rather than whether it was highly anthropomorphic or not. Anthropomorphic body elements should only be included when they serve an interaction purpose with the driver within safety constraints or facilitate interactions. These findings also emphasize the importance of a balanced RHMI design approach that accommodates individual preferences, as there is no one-size-fits-all RHMI design. RHMI designs for driving support should also consider user experience qualities to enhance the acceptability of the driving support. Future research aims to extend these findings by increasing the participant number, isolating better the distinction of anthropomorphic elements across various RHMIs, and exploring individual preferences in RHMI design and user experience in greater depth.

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